I. Identification of a Diagnostic Formula and Procedure

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ABSTRACT

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A benchtop baking method has been developed to predict the contribution of gluten functionality to overall flour performance for chemically leavened crackers. To identify a diagnostic cracker formula, the effects of leavening system (sodium bicarbonate, monocalcium phosphate, and ammonium bicarbonate), sugar concentration (%S), and total solvent (TS) on cracker-baking performance were explored. From preliminary experiments to establish a production procedure, 10 min of dough-mixing time, a cord-weave baking mesh, and a 500°F oven temperature were selected. For the leavening system, increasing ammonium bicarbonate (ABC) level at constant sodium bicarbonate (soda) and monocalcium phosphate (MCP) levels resulted in increased cracker height. For the diagnostic formula, 1.25 g of soda, 1.25 g of MCP, and 1.25 g of ABC were selected, based on 100 g of flour. As the sugar concentration in the cracker formula, at constant total solvent (38 TS), decreased to <20%, the resulting cracker dough became softer, and the baked cracker exhibited an increased blistering tendency because of a too-high formula water level. In contrast, a cracker dough formulated with ≥40% sugar concentration was too crumbly to handle and sheet. As the total solvent in the cracker formula increased at constant sugar concentration (>23.7% S), the resulting dough became softer. A dough with 34 TS was too crumbly to handle, while doughs with 42 and 46 TS were too soft to handle and resulted in blistering. Therefore, 38 TS and 23.7% S were identified for the diagnostic formula. Crackers baked with a hard wheat flour, a soft wheat flour, and blends validated the utility of the developed method.

Traditionally, the baking performance of soft wheat flours was evaluated by well-established benchtop cookie-baking methods as in Approved Methods 10-52.01 and 10-53.01 (AACC International 2010). In contrast, 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). Despite such hurdles, there remains a demand in academia and industry for a benchtop baking method to predict the contribution of gluten functionality and performance to overall flour performance for crackers.

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,b,c; Pizzinatto and Hoseney 1980; Doescher and Hoseney 1985; Rogers and Hoseney 1987; Pérez et al. 2003). The typical processes for preparing saltine and savory crackers usually require ≈24 hr due to a prolonged fermentation time. In comparison, chemically leavened crackers ordinarily do not require a fermentation step, and processing is relatively easy and simple to manage. Development of a benchtop method for chemically leavened crackers would enable use of such a method as a predictive tool for evaluating gluten functionality in flour for crackers.

For commercial cracker production, soft wheat flours with greater gluten strength are typically preferred. Gluten development in cracker dough during mixing and sheeting is a critical factor linked to cracker quality. Gluten development is facilitated in a cracker dough, compared to a cookie dough, because the sugar concentration (%S, expressed as weight of sucrose/weight of total solvent) in a typical cracker formula is usually much lower (%S < 30%) than that in a typical cookie formula. Slade and Levine (1994) reported the effect of sucrose concentration on gluten development during dough mixing using a mixograph: the mixing time to peak dough development increased as sugar concentration increased. They explained that the increasing development time is a reflection of decreasing molecular mobility of the gluten in the antiplasticizing sugar-water solution, which retards the rate of gluten swelling and network development with increasing sugar concentration. The effect of total solvent (TS, expressed as the sum of the weights of sucrose and formula water) on gluten development during dough mixing is complex (Slade and Levine 1994). Excessive total solvent decreases the initial bulk viscosity of the dough and the resulting low shear is insufficient to produce rapid gluten alignment. Consequently, the addition of increasing total solvent to a constant weight of flour increases the mixing time required to attain peak dough development. In contrast, insufficient total solvent restricts the swelling volume for gluten network formation, and excessive torque is required for mixing.

The total solvent in a typical cracker formula is relatively low, so the dough can be mixed in a short time, but a powerful mixer is required for dough development.

The leavening system is also critical to cracker quality. In general, the pH range for chemically leavened crackers is ≈6.5–7.5, which typically can be achieved with combinations of soda and leavening acids (Faridi and Faubion 1995). Commonly used leavening agents for crackers are sodium bicarbonate, monocalcium phosphate (MCP), and ammonium bicarbonate (ABC). ABC is the preferred leavening agent, often used for fine-tuning cracker height in commercial bakery production. It can be used in such low-moisture baked goods because it is completely volatilized during baking, thus leaving behind no residual ammonia, which would be unacceptable in such baked goods.

For development of a benchtop method for chemically leavened crackers, identification of a diagnostic formula is the most important requirement for a reliable, validatable method. In the present study, the effects of leavening system, total solvent, and sugar concentration on cracker-baking performance were explored to identify a diagnostic formula. In addition, the developed formula was employed to evaluate cracker-baking performance, using both hard wheat and soft wheat flours and their blends.
a Miag mill to produce straight-grade flours. Branson flour (7.5% protein content) was used for developing the cracker formula and procedure, whereas USG 3665 and NuPlains flours (9.1 and 11.6% protein contents, respectively) were used for testing the developed cracker method.

The leavening agents, sodium bicarbonate (USP 1 grade) and monocalcium phosphate (HT MCP, monohydrate, fines), were obtained from Church & Dwight (Old Port, OH) and ICL Performance Products (St. Louis, MO), respectively. Ammonium bicarbonate was purchased from Fisher Scientific. Fine-granulated sucrose (FG sugar, Domino Foods, New York, NY) and a commercial shortening (Crisco, Smuckers, Orville, OH) were used for cracker baking. Other chemicals were reagent-grade.

**Solvent Retention Capacity (SRC)**

Flour samples were analyzed by SRC testing. SRC tests with four solvents were in duplicate according to Approved Method 56-11.01 (AACC International 2010). Flour samples (5 g) were suspended in 25 g of deionized water, 5% (w/w) lactic acid (LA), 5% (w/w) sodium carbonate (SC), and 50% (w/w) sucrose (Suc), and hydrated for 20 min, shaking at 5-min intervals. The hydrated flour slurries were centrifuged at 1,000 × g for 15 min, and the supernatants were drained. Each pellet was weighed and the SRC (%) for each sample was calculated according to AACC Approved Method 56-11.01. The ratio of SRC LA to the sum of SRC SC and SRC Suc was calculated for each flour sample (Kweon et al 2009a,b).

**Cracker-Making Procedure**

The basic ingredients and formula are listed in Table I and the cracker-making procedure is described in Fig. 1. The pin mixer used (National Manufacturing Co., Lincoln, NE) had two pins in the bowl and four pins in the mixer head; rotating speed was 102 rpm. The fine-granulated sucrose was predissolved in the water to reduce the variability in sugar dissolution during dough mixing. This sugar solution was added to a 100-g pin-mixer bowl, then ABC was added and mixed for ≈1 min to dissolve (i.e., until large lumps were gone). Shortening was added and mixed for 1 min. Dry ingredients including flour, salt, soda, and MCP were added and mixed for 10 min. The mixed dough was sheeted with a dough sheeter (model SFB 528, Univex, Salem, NH). Sheeting rolls were 19 5/8” wide (Fig. 2A) for five passes without folding or rotation of the sheet between passes to minimize operating variations. The roll-gap settings were 5, 3, 2, 1, and the second smallest gap on the sheeter spacing number, which corresponded to 5.59, 3.78, 2.72, 1.78, and 0.54 mm gap spacings, respectively. After sheeting, the dough was rested for 1 min, then cut twice with a custom-made hand-cutter (2.25 × 1.65 in., 7 docker pins) (Weidenmiller, Itasca, IL) (Fig. 2C) to prepare eight cracker pieces. Before the start of dough sheeting, a cord-weave baking mesh (13L × 10W, 0.26 in. thickness, Hi Carbon Steel, spec. C-100-3F (Audubon, Feasterville, PA) (Fig. 2B) was placed on top of a cookie-baking sheet and preheated in an oven at 500°F for 5 min. The cut dough pieces were placed on another cookie-baking sheet to measure dough weight of all eight cracker dough pieces together. The dough pieces were then transferred to the preheated baking mesh and baked at 500°F for 5–6 min (depending on dough weight). Immediately after baking, the crackers were transferred from the baking mesh to a cookie-baking sheet and weighed to calculate the cracker weight loss during baking. After the baked crackers cooled to room temperature, the stack height of eight crackers was measured with a height gauge and the width and length (perpendicular diameters) of eight crackers were measured. The average cracker height, width, and length were calculated. For evaluating cracker-baking performance, the ratio of cracker height to dough weight (CH/DW) was calculated because dough weight affects weight loss during baking and cracker height and thus should be accounted for in the context of cracker geometry. Also, the ratio of cracker width to length (W/L) was calculated to characterize the extent of snap-back.

**Evaluation of Leavening System**

For selection of a leavening system, cracker baking was conducted in a random order using a full-factorial experimental design,
including center point. The three factors were soda, MCP, and ABC, and the two levels were low (0 g) and high (1.25 g) for each factor. The center point was 0.63 g for each factor. All bakes were done in duplicate. In a supplemental experiment, the effect of various ABC levels, at constant levels of soda and MCP, on cracker geometry was also evaluated.

Baked crackers were ground with a chopper/blender and 8 g of ground cracker was mixed with 80 mL of distilled water using a magnetic stirrer for preparing a 10% slurry. Cracker pH was measured on this cracker slurry using a calibrated pH meter (Fisher Scientific, Pittsburgh, PA).

**Evaluation of %S and TS**

Based on preliminary experiments, provisional ranges for %S and TS were determined. In one set of experiments, predissolved sugar solutions were prepared at 0–52.6% sucrose concentrations with TS held constant at 38. In another set of experiments, %S was held constant at 23.7%, and TS was varied from 34 to 46. The experimental formulas are shown in Table II, and cracker baking was conducted following the cracker-making procedure described previously. All bakes were done in duplicate.

**Cracker Baking with Hard and Soft Wheat Flours**

The formula and procedure were evaluated using a hard wheat flour, a soft wheat flour, and blends of those two flours. For this purpose, NuPlains flour was blended with USG 3665 flour at ratios of 1:3, 1:1, and 3:1 (w/w), respectively. All bakes were done in duplicate.

**RESULTS AND DISCUSSION**

**SRC Profiles for Flour Samples**

SRC results for the flour samples are shown in Table III. The SRC values for Branson flour indicated that it is a good quality cracker flour with sufficient gluten strength. Kweon et al (2009a,b) reported that the ratio of SRC LA/(SC+Suc) is a discerning parameter for evaluating a flour’s gluten functionality and performance. The ratio of SRC LA/(SC+Suc) for Branson flour was 0.644.

The SRC values for USG 3665 flour in all solvents except LA were similar to those for Branson flour. The SRC value in LA (84%) and the ratio of SRC LA/(SC+Suc) (0.537) for USG 3665 were much lower than those for Branson flour, indicating much lower gluten strength for USG 3665. The SRC values for NuPlains flour in all four solvents were very much higher than those for Branson and USG 3665 flours. As expected for such a hard wheat flour, NuPlains flour exhibited higher water absorption, greater gluten strength, higher damaged starch, and higher arabinoxylans than for the two soft wheat flours. The ratio of SRC LA/(SC+Suc) for NuPlains flour was 0.789, which indicated much higher gluten strength than for Branson or USG 3665 flours. However, compared with more typical hard wheats, which generate more damaged starch during milling and contain more aleurone and bran components, NuPlains showed flour SRC values in water, SC, and Suc that were unusually low. This result suggests that NuPlains is a hard wheat with softer kernel texture. For the composite flours blended at various ratios of USG 3665 and NuPlains (with increasing proportion of NuPlains flour), the SRC values in all solvents, as well as the ratio of SRC LA/(SC+Suc), increased proportionally, as expected.

**Leavening System**

Results for crackers baked with various leavening systems are shown in Table IV. Top views of crackers formulated with no or just a single leavening agent are shown in Fig. 3A. Without any leavening agent (exp. #2), the baked crackers were irregularly curved rather than flat, and top and bottom blisters were observed. When soda was used alone (exp. #1), the baked crackers were yellowish in color, due to alkaline pH ≈ 8.1, and only small blisters were observed in a few crackers. With MCP alone (exp. #4), all the baked crackers had small blisters and the cracker pH ≈ 5.5.

It was also observed that the color of the crackers was not uniform due to local brown spots from burnt blisters. When ABC was used alone (exp. #6), the cracker dough was softer and the sheeted dough was thinner, which resulted in smaller dough piece weight. The baked crackers had unattractive blisters and cracker pH ≈ 6.7, indicating that the ABC had completely volatilized during baking.
Crackers are generally formulated with low levels of sugar and water. The effect of varying %S, at constant TS (38 TS), on cracker geometry is illustrated in Fig. 4. As %S increased, the width of crackers increased (<20%S) and did not increase further, but the length of crackers increased slightly (<20%S) then decreased (≤20%S) and finally increased again at (>30%S) (Fig 4A). In Fig. 4B, cracker width-to-length ratio (W/L) increased with increasing %S (≤30%) and then decreased at >30%S. In the 20–30%S range, the increase in W/L was more dramatic. The W/L for crackers could represent the extent of snap-back of the sheeted dough, caused mainly by the extension of glutenins, although an additional effect due to dough firmness was also observed in our benchtop method. The present results agreed with those reported previously by Slade and Levine (1994) concerning dough development at different sugar concentrations. With increasing %S at >30%, gluten development was delayed and the sheeted dough was not elastic and exhibited decreased snap-back. As %S decreased to <20%, the dough became softer and the cracker height-to-dough weight ratio (CH/DW) increased significantly, but the baked crackers had excessive blisters because of the too-high level of formula water (Fig 4B). In contrast, the cracker dough formulated with >30%S was too crumbly to easily handle and sheet. With respect to dough handling and cracker blistering, 23.7%S (range 23.5–23.9) and 38 TS represented the optimum formula for our cracker-baking method.

The effect of varying TS, at constant %S (23.7 ± 0.2%S), on cracker geometry is shown in Fig. 5. As TS increased, the width of the crackers decreased slightly but the length increased (Fig 5A); as W/L decreased, the CH/DW increased significantly (Fig 5B). The dough with 34 TS was too crumbly to handle, while the doughs with 42 or 46 TS were too soft to handle and blistered during baking. Consequently, 38 TS and 23.7%S were identified again as part of the optimal diagnostic cracker formula.

Cracker Baking with Hard Wheat, Soft Wheat, and Blended Flours

Cracker-baking results for hard wheat, soft wheat, and blended flours are shown in Table VI. As mentioned earlier, the USG 3665 soft wheat flour had relatively low gluten strength, as indicated by its low ratio of SRC LA/(SC+Suc). Although the crackers made with 100% USG 3665 flour showed higher CH/DW, the presence of many blisters contributed to this anomalous value. The USG 3665 dough was apparently too soft to support uniform ovenspring during baking. In contrast, the crackers made with 100% NuPlains hard wheat flour showed lower CH/DW, apparently because the gluten strength of this flour was too great to allow easy expansion of this highly elastic dough during baking. Also, the dough weight was too high, and moisture bake-out was inhibited, which resulted in lower weight loss during baking. Although the NuPlains flour

### TABLE IV

Geometry of Crackers Baked with Two Levels of Sodium Bicarbonate (soda), Monocalcium Phosphate (MCP), and Ammonium Bicarbonate (ABC)

<table>
<thead>
<tr>
<th>Exp</th>
<th>Soda (g)</th>
<th>MCP (g)</th>
<th>ABC (g)</th>
<th>Dough Wt/ Piece (g)</th>
<th>Cracker pH</th>
<th>Length (cm)</th>
<th>Width (cm)</th>
<th>Height (cm)</th>
<th>Dough Wt</th>
<th>Blisters*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.25</td>
<td>0</td>
<td>0</td>
<td>3.5</td>
<td>8.1</td>
<td>5.3</td>
<td>4.1</td>
<td>0.34</td>
<td>0.097</td>
<td>+</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3.3</td>
<td>5.9</td>
<td>5.2</td>
<td>4.2</td>
<td>0.36</td>
<td>0.109</td>
<td>++++</td>
</tr>
<tr>
<td>3</td>
<td>1.25</td>
<td>1.25</td>
<td>0</td>
<td>3.9</td>
<td>6.9</td>
<td>5.2</td>
<td>4.1</td>
<td>0.44</td>
<td>0.116</td>
<td>++</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>1.25</td>
<td>0</td>
<td>3.8</td>
<td>5.5</td>
<td>5.2</td>
<td>4.3</td>
<td>0.45</td>
<td>0.125</td>
<td>++</td>
</tr>
<tr>
<td>5</td>
<td>1.25</td>
<td>0</td>
<td>1.25</td>
<td>3.6</td>
<td>7.9</td>
<td>5.2</td>
<td>4.1</td>
<td>0.44</td>
<td>0.116</td>
<td>++</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>1.25</td>
<td>2.8</td>
<td>6.7</td>
<td>5.2</td>
<td>4.1</td>
<td>0.45</td>
<td>0.125</td>
<td>++</td>
</tr>
<tr>
<td>7</td>
<td>1.25</td>
<td>1.25</td>
<td>1.25</td>
<td>3.8</td>
<td>7.2</td>
<td>5.2</td>
<td>4.2</td>
<td>0.45</td>
<td>0.118</td>
<td>++</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>1.25</td>
<td>0</td>
<td>3.5</td>
<td>6.4</td>
<td>5.3</td>
<td>4.2</td>
<td>0.39</td>
<td>0.111</td>
<td>+</td>
</tr>
<tr>
<td>9</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>3.2</td>
<td>7.1</td>
<td>5.3</td>
<td>4.2</td>
<td>0.39</td>
<td>0.122</td>
<td>++++</td>
</tr>
</tbody>
</table>

* Blister designations: – no blisters; + small blisters in 1–2 crackers; ++ small blisters in 3–4 crackers; +++ small blisters in 5–8 crackers; ++++ large blisters in all 8 crackers.
a hard wheat flour, the contributions from damaged starch and arabinoxylans to its water-holding capacity are not overly large, as evidenced by its SRC profile. Consequently, the dough made with 100% NuPlains flour was not crumbly. As the proportion of NuPlains flour in a flour blend was increased, the dough weight increased, and the weight loss during baking decreased, but the blistering tendency decreased significantly. The flour blend with 25% NuPlains and 75% USG 3665 showed the greatest CH/DW, without generating blisters.

In cracker production in commercial bakeries, it is common practice to add a minor amount of hard wheat flour to boost the gluten strength of a soft wheat biscuit flour. However, hard wheat typically generates increased damaged starch during milling and contributes higher levels of arabinoxylans, due in part to shattered bran particles; such increased contributions from damaged starch and arabinoxylans are generally not favorable to cracker flour functionality (Slade and Levine 1994). Thus, it is advisable to minimize any necessary addition of hard wheat flour and monitor the increases in damaged starch and arabinoxylans, whenever hard wheat is blended with soft wheat for cracker flour.

CONCLUSIONS

To develop a benchtop baking method for chemically leavened crackers, the effects of leavening system (soda, MCP, or ABC), sugar concentration, and total solvent were explored to identify a diagnostic cracker formula. Based on preliminary experiments, 10 min of dough mixing, a cord-weave baking mesh, and a 500°F oven temperature were selected as parts of the production procedure. For the diagnostic formula, 1.25 g of soda, 1.25 g of MCP, and 1.25 g of ABC were selected as the leavening system. As %S was reduced to <20% at constant 38 TS, the dough became softer, and the baked crackers exhibited excessive blisters due to excessive formula water. In contrast, at >40%S, the dough was too crumbly to handle and sheet. As TS was increased at constant 23.7%S, the dough became softer, resulting in an increased blistering tendency for 42 and 46 TS. In contrast, the dough at 34 TS was too crumbly to handle. For ease of dough handling and minimization of blistering, 38 TS and 23.7%S were identified as the preferred formula. Evaluation of hard and soft wheat flours (and blends) with the cracker method developed in this work clearly demonstrated the differences in the cracker-baking performance of such flours. This conclusion will be further validated in future reports.

LITERATURE CITED


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