Effects of Damaged Starch, Chlorine Gas, Flour Particle Size, and Dough Holding Time and Temperature on Cookie Dough Handling Properties and Cookie Size

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ABSTRACT

Five physical-textural attributes (stiffness, consistency, flow, adhesion, and cohesion) of sugar-snap cookie dough were evaluated as they were affected by variations in dough energy input (rerolled one to five times), dough age (1–3 hr holding time after mixing), dough temperature (22 and 31°C), flour chlorination (pH 6.0 and 4.8), flour particle size (24–68 μm), flour damaged starch content (1.9–8.8%), and flour moisture content (8.2–15.4%). Flour chlorination, flour moisture content, and damaged starch had the greatest effects on cookie size. Flour moisture content and dough holding time had the greatest effects on dough handling properties. Decreased flour moisture, increased starch damage, longer holding time, warmer dough temperature, increased dough handling, and flour chlorination caused doughs to handle as if they were more plastic; these doughs were more stiff and cohesive, had greater consistency, had less flow and adhesion, and made smaller cookies. Combinations of treatments compounded changes in dough handling properties.

To achieve the desired machining properties for high speed production equipment it is desirable to formulate and mix commercial cookie doughs to meet narrow physical-textural tolerances. Dough physical-textural properties of primary importance are adhesion, cohesion, flow, viscosity, consistency, and hardness. Those properties can be grouped into three categories: water relations, flour quality, and dough structure. Water relations include formula water level, water mobility as affected by ingredients, dough temperature, and time after mixing. Flour quality is a function of heritable cultivar quality as well as flour particle size, damaged starch level, flour moisture content, chlorination, etc. Dough structure includes the amount of gluten developed during mixing and machine handling. To a great extent, all of those properties are related.

To comply with narrow tolerances for handling properties, doughs are formulated using critical amounts of liquid and are mixed in water-jacketed mixers, often to a specific temperature between 22 and 32°C (Matz and Matz 1978). Doughs are sometimes held in troughs for several hours before machining and baking. During that holding time, water is continuously mobile and is exchanged among dough ingredients depending on their relative vapor pressures, hydration rates, concentrations, fat content, and temperature.

Unwanted variations in dough handling properties occur when flour quality changes or dough holding time or temperature is changed. Undesirable handling properties are sometimes compensated for by adjusting the dough water content, which can create other processing problems. Additional water must be baked out to achieve proper product weight. This may slow production, darken product color, and increase energy costs.

Compensating for handling problems is further complicated when two dissimilar doughs are extruded together, as in some dual textured cookies. Such doughs are often made with flour treated with chlorine gas to control cookie size and texture. Chlorination profoundly affects the water relations of doughs and batters. Flour particle size (surface area) and the amount of damaged starch generated during milling also affect water relationships in cookie doughs. Cookie dough handling properties are also affected by the degree of gluten development created during mixing and machining (energy input), by flour moisture content (which also affects cookie size), and by the amount of water added to produce a dough of constant consistency.

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The objectives of this study were to determine the relative effects of chlorine gas, flour moisture content, work input, starch damage, and flour particle size on several rheological components of dough handling properties of sugar-snap cookie doughs held at 22 and 31°C for 0, 1, 2, and 3 hr. This information should help establish which of these factors and their combinations are most likely to cause dough handling problems for commercial producers and which factors are most important for quality testing of soft wheat cultivars.

MATERIALS AND METHODS

Flours

Three flours from three soft wheat blends were evaluated. Flour A was a commercial mill-mix medium-patent flour. Flour B was a commercial mill-mix long-patent flour. Flour C was an Allis-Chalmers laboratory-milled straight-grade flour from a blend of 20 soft red winter wheat cultivars. Protein contents of the three flours were 8.4, 8.7, and 8.0%, respectively.

Flours B and C were subsampled into control, pin-milled (Alpine Kolloplex 160-Z, 9,000 rpm), 1-hr ball-milled, and 2-hr ball-milled portions. Half of each subsample was then treated with chlorine gas to pH 4.8. Flour particle size (mean volume diameter) was determined with a Leeds and Northrup Microtrac, model 7991-0.

Cookie Doughs and Holding Time and Temperature

Sugar-snap cookie doughs were produced according to AACC method 10-52 at a controlled room temperature (21.5–22.5°C), and relative humidity (32–48%) using the same dough liquid level for each flour. Doughs were evaluated immediately (no hold time) or sealed in plastic bags and held 1, 2, or 3 hr at room temperature (22°C) or at 31°C in a temperature-controlled fermentation cabinet.

Rheological Measurements

After holding for the appropriate times, doughs were rolled to 6 mm thickness on baking sheets that had thickness gauges attached. After cutting with a cookie cutter, doughs were evaluated with an Instron model 1000 with a 50-kg transducer, range at 20 kg, speed at 50 mm/min, and a 35-mm diameter plunger. Doughs at 31°C were quickly cooled to 22°C for Instron measurement by rolling them out on a cookie sheet (which had been cooled to 4°C) while monitoring dough temperature with a thermistor. Cooling required about 30 sec. Doughs were then transferred to the Instron for measurement.

Dough physical-textural properties were evaluated by the "two-bite" texture profile analysis method of Peleg (1976) and Bourne (1978) (Fig. 1). Doughs were compressed to 3 mm and held until dough resistance decayed to 1 kg force, creating the first force-time peak. The crosshead was reversed, and the first adhesion peak was Obtained as the dough adhered to platen and plunger before releasing. This process was repeated a second time to obtain a second resistance and adhesion peak. Dough stiffness (kg) was the maximum resistance to the first compression (height of peak 1). Dough flow (kg/min) was the linear slope of the decay of peak 1 to a resistance of 1 kg. Dough consistency (kg·min) was the combined area of the two resistance peaks. Dough adhesion (kg·min) was the combined area of the two adhesion peaks. Dough cohesion was the ratio of the area of the two resistance peaks.

Dough Evaluation Procedure

Three studies were conducted: 1) flour moisture level, 2) dough work input, and 3) dough holding time and temperature. For the first study, flour A was air-dried and humidified to five moisture levels (8.2, 10.0, 1.9, 13.7, and 15.4%). Moisture content was determined by oven drying at 40°C for 30 min. Doughs were at 22°C (no holding time) and at 31°C (3-hr holding time). For the second study, doughs made from flour C were rolled and evaluated by the Instron one to five times in succession. Dough balls were rolled to thickness (6 mm), transferred to, and measured by the Instron, reformed into a ball, rerolled, measured, etc. The third study evaluated flours B and C after holding at 22 and 31°C for 0, 1, 2, and 3 hr. All flour and dough treatments were replicated (on another day) and evaluated by analysis of variance. Least significant difference values at the 0.05 level of significance were calculated from replication error mean squares. Student's t values of multiple regression independent variables were used to compare the relative influence of flour and dough treatments.

RESULTS AND DISCUSSION

The relative effects of the various flour and dough treatments (flour pH, damaged starch content, particle size, and dough holding time and temperature) on cookie spread and dough handling properties (stiffness, consistency, flow, adhesion, and cohesion) were statistically analyzed by difference among means and by comparing the Student's t values of the independent variables in multiple regression equations. The dotted lines in Figure 2 show the relationship between flour particle size and damaged starch content of ball-milled flours B and C. Mean particle size of the roller-milled control flours (49 and 69 μm) was reduced by 1-hr ball-milling (31 and 32 μm) and by 2-hr ball-milling (25 and 24 μm). The unfilled data points (33 and 30 μm) were from the roller-milled control flours given two passes through a pin mill. Pin-milling reduced particle size similar to 1 hr of ball-milling but increased damaged starch levels only slightly. That allowed comparison of the relative contribution of starch damage and particle size to predicting dependent variables in a multiple regression equation, e.g., cookie diameter or dough handling properties. The relative size of the Student's t values for damaged starch and particle size indicated which of those two variables contributed more toward explaining the variation in the predicted parameter. That statistical technique is useful when a strong association exists, such as that between the flour particle sizes and damaged starch contents of the 1- and 2-hr ball-milled flours.

Flour Moisture Versus Dough Handling Properties

The moisture content of flour A was adjusted from 8.2 to 15.4%. Sugar-snap cookie doughs from those flours were evaluated after mixing (22°C) and after holding for three hours at 31°C. As flour moisture content increased, cookie diameter and dough flow and adhesion increased; however, dough stiffness, consistency, and cohesion decreased (Table I, Δ moisture). Those changes were usually greater in the 31°C, 3-hr doughs. When doughs were held at 31°C for 3 hr, cookie diameter and dough flow and adhesion decreased, whereas dough stiffness, consistency, and cohesion increased (Δ temperature). These changes were usually greater in doughs made with low-moisture flour. Analysis of variance showed that at the ranges studied, cookie diameter was affected more by flour moisture content than by holding the dough at elevated temperature. Dough handling properties were affected by both flour moisture and dough holding at elevated temperature.

Because all doughs in this study were made with the same amount of water, the only differences in the total water contents of the doughs were due to variation in flour moisture content. Thus, changes in dough handling properties reflect the relative contribution of "flour water" to dough plasticity and to changing the relative vapor pressures of the ingredients. As shown in Table I, holding doughs at elevated temperature accentuated the "drying" influence (reduction in plasticity) of low-moisture flour on sugar-snap cookie doughs. The magnitude and direction of the changes in cookie size and dough handling properties relative to the effect of water are useful in explaining some of the results of treatments discussed below.

Work Input Versus Dough Handling Properties

Each dough from flour C was rolled out, cut, and measured by the Instron 1 to 5 consecutive times. That additive work input which increased development of gluten proteins increased dough stiffness, consistency, and cohesion and decreased dough flow and

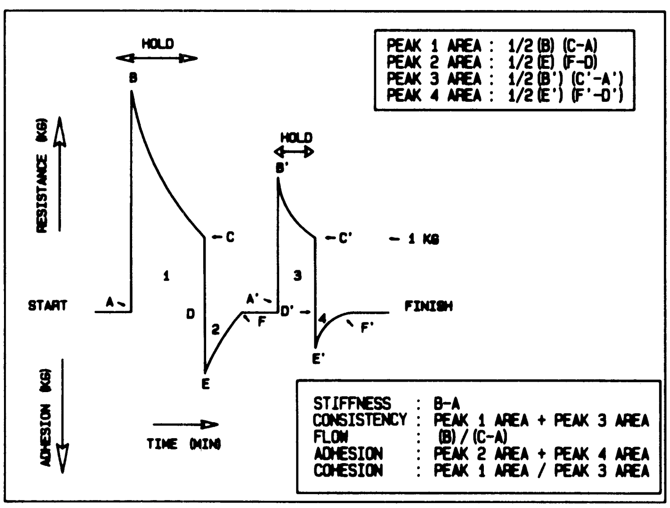

Fig. 1. The Instron "two-bite" texture profile analysis method used to evaluate sugar-snap cookie dough stiffness, consistency, flow, adhesion, and cohesion.

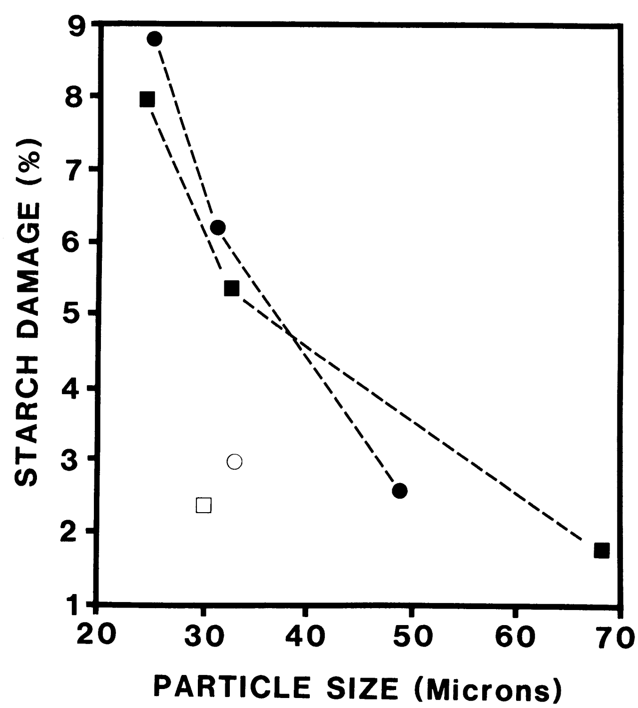

Fig. 2. The relationship between starch damage and flour particle size for flours B (circles) and C (squares). Open data points are pin-milled flours.

adhesion of chlorinated and unchlorinated flours (Table II, Δ rolls). However, there was a greater response to increase in work input in the mean values for stiffness, consistency, and cohesion in chlorinated doughs. Dough flow and adhesion decreased more in nonchlorinated doughs. Flour chlorination had a greater effect on dough stiffness, consistency, and cohesion when doughs received five additional rollings (Δ pH). Flour chlorination affected dough flow more in doughs receiving only one rolling.

Thus flow was very susceptible to available water or water mobility. When work input increased the level of gluten development, causing the dough to stiffen, water mobility probably decreased as well. Gluten development and reduced water mobility are likely highly linked. Because flour chlorination reduces water mobility in cookie dough, the influence of additional work input on dough flow was less in doughs produced with chlorinated flour.

The relative magnitude of the Student's t values for predicting each rheological parameter from the independent parameters of work input, chlorination, damaged starch, and flour particle size (Table III) indicate that work input and then flour chlorination were the two most important treatments associated with explaining the variability of each handling parameter. Except for

TABLE I
Means and Analysis of Variance for Cookie Diameter and Dough Handling Properties Associated with Variation of Flour Moisture Content from 8.2 to 15.4% and Change of Dough Temperature from 22 to 31° C

Dependent Variable	Mean 22° C[a]	Mean 31° C[b]	Analysis of Variance: Source	F Ratio	Level of Probability	Δ Moisture[c] 22° C[a]	Δ Moisture[c] 31° C[b]	Δ Temperature[c] 22–31° C 8.2% mc	Δ Temperature[c] 22–31° C 15.4% mc
Cookie diameter, cm	17.7	17.4	Flour moisture	32.1	0.000	+1.5	+2.1	−0.7	−0.1
			Dough holding time and temperature	5.5	0.042				
			Interaction	1.1	0.390				
Dough stiffness, kg	7.3	14.1	Flour moisture	1,176.3	0.000	−11.3	−25.9	+16.6	+2.0
			Dough holding time and temperature	1,192.0	0.000				
			Interaction	183.4	0.000				
Dough consistency, kg·min	4.0	15.8	Flour moisture	78.6	0.000	−19.1	−73.9	+54.9	+0.1
			Dough holding time and temperature	32.2	0.000				
			Interaction	27.1	0.000				
Dough flow, kg/min	180	72	Flour moisture	305.2	0.000	+532	+110	−1	−422
			Dough holding time and temperature	300.2	0.000				
			Interaction	164.6	0.000				
Dough adhesion, kg·min	0.015	0.004	Flour moisture	857.8	0.000	+0.024	+0.008	−0.002	−0.017
			Dough holding time and temperature	3,065.7	0.000				
			Interaction	300.4	0.000				
Dough cohesion	81	406	Flour moisture	2.3	0.131	−370	−1,913	+1,559	+16
			Dough holding time and temperature	1.2	0.302				
			Interaction	1.1	0.425				

[a] No holding time at 22° C.
[b] Held 3 hr at 31° C.
[c] Δ Values represent mean changes from low to high flour moisture or low to high temperature. Plus or minus indicates direction of change.

TABLE II
Mean Dough Handling Parameters and Analysis of Variance Associated with Mechanical Work Input (1–5 rolls) on Sugar-Snap Cookie Dough and Chlorinated and Unchlorinated Flour (pH)

Dough Rheological Property	Mean pH 6.2	Mean pH 4.8	Analysis of Variance: Source	F Ratio	Level of Probability	Δ 1–5 Rolls[a] pH 6.2	Δ 1–5 Rolls[a] pH 4.8	Δ pH 6.2–4.8[a] 1 Roll	Δ pH 6.2–4.8[a] 5 Rolls
Stiffness, kg·min	7.6	9.0	Work input	15.7	0.000	+3.3	+3.8	+1.0	+1.5
			Chlorination	21.2	0.000				
			Interaction	0.2	0.939				
Consistency, kg·min	3.3	5.5	Work input	9.4	0.000	+3.8	+6.5	+0.8	+3.5
			Chlorination	12.0	0.000				
			Interaction	0.6	0.690				
Flow, kg/min	11.9	9.5	Work input	2.7	0.038	−6.7	−3.3	−4.6	−1.2
			Chlorination	5.4	0.023				
			Interaction	0.4	0.799				
Adhesion, kg·min	0.10	0.006	Work input	16.2	0.000	−0.014	−0.002	−0.012	0.000
			Chlorination	29.9	0.000				
			Interaction	7.6	0.000				
Cohesion	89	248	Work input	9.1	0.000	+234	+588	+33	+389
			Chlorination	10.9	0.002				
			Interaction	1.6	0.195				

[a] Δ Values represent mean changes from one to five rerolls or the change when doughs were made from chlorinated flour. Plus or minus indicates direction of change.

dough flow, damaged starch content contributed more than flour particle size to predicting handling parameters.

Dough Holding Time and Temperature Versus Dough Handling Properties

Means and changes in cookie diameter and dough handling properties of chlorinated and nonchlorinated flours B and C when held from 0 to 3 hr at 22 and 31°C are shown in Table IV. At the two lower levels of damaged starch, cookie size was usually reduced when doughs were held up to 3 hr, reflecting the greater plasticity of doughs made from flours containing less damaged starch. At the two higher levels of damaged starch, cookie size usually increased after holding for 3 hr, probably reflecting the increased mobility of water, and thus increased plasticity with time of those doughs. For both flours at both pH values and temperatures, the changes in dough handling properties due to holding time increased as damaged starch increased, reflecting the greater effect of holding time on less plastic doughs containing already low water mobility.

The magnitude of the Student's *t* values in Table V shows relative effect of damaged starch and flour particle size on cookie size and dough handling properties from flours B and C. At both temperatures, dough holding time from 0 to 3 hr produced smaller

TABLE III
Student's *t* Values Associated with the Independent Variables in a Multiple Regression for Predicting Sugar-Snap Cookie Dough Handling Properties

Predicted Dough Rheological Property	Independent Variables			
	Dough Work Input	Flour Chlorination	Flour Damaged Starch	Flour Particle Size
Stiffness	10.6	−6.2	3.4	−2.4
Consistency	6.9	−4.1	2.5	−1.8
Flow	−3.5	2.5	−0.5	2.1
Adhesion	−6.4	4.8	−3.0	−0.9
Cohesion	5.9	−3.5	2.8	−0.7

TABLE IV
Change in Cookie Size and Dough Handling Properties of Flours B and C at Varied Dough Temperatures, pH Levels, and Levels of Damaged Starch

	22°C								31°C							
	Flour pH 6.2				Flour pH 4.8				Flour pH 6.2				Flour pH 4.8			
Factor	2.8[a]	3.0	6.3	8.8	2.8	3.0	6.3	8.8	2.8	3.0	6.3	8.8	2.8	3.0	6.3	8.8
Flour B																
Cookie diameter, cm																
Δ 0–3 hr	−0.31	−0.29	0.54	0.67	−1.06	−0.74	−0.44	0.37	−0.33	0.37	0.70	0.58	−1.14	−0.95	−0.54	0.48
Mean[b,c]	17.77	17.46	17.02	16.47	16.55	16.08	15.68	14.92	17.74	17.57	17.30	16.34	16.57	15.96	15.61	14.93
Stiffness, kg																
Δ 0–3 hr	3.6	3.5	4.6	7.4	4.5	5.3	10.0	7.8	3.9	3.8	4.9	7.9	4.6	5.0	7.0	3.7
Mean[b,c]	7.1	7.7	8.5	9.8	7.1	7.5	9.4	6.0	7.3	7.9	8.6	10.3	7.5	8.1	9.5	11.2
Consistency, kg·min																
Δ 0–3 hr	3.1	2.5	6.2	13.9	3.0	5.1	7.6	17.1	3.6	4.4	8.0	20.5	4.3	5.9	11.5	27.5
Mean[b,c]	2.0	2.0	3.3	5.8	1.9	2.3	4.3	8.5	2.3	3.1	4.4	10.3	2.7	3.6	6.6	13.7
Flow, kg/min																
Δ 0–3 hr	−17	−14	−33	−35	−40	−37	−39	−51	−18	−19	−34	−37	−43	−39	−41	−52
Mean[b,c]	16	18	19	17	24	21	18	17	15	14	17	14	21	18	16	15
Adhesion, kg·min																
Δ 0–3 hr	−0.012	−0.013	−0.015	−0.013	−0.011	−0.011	−0.015	−0.014	0.012	−0.013	−0.015	−0.013	−0.012	−0.012	−0.015	−0.016
Mean[b,c]	0.008	0.009	0.010	0.009	0.008	0.009	0.009	0.009	0.008	0.008	0.009	0.008	0.008	0.007	0.008	0.009
Cohesion																
Δ 0–3 hr	104	120	404	1,339	64	123	668	881	149	371	260	1,596	157	364	578	1,413
Mean[b,c]	31	49	126	428	22	54	218	441	53	128	157	533	81	124	333	735
Flour C																
Cookie diameter, cm																
Δ 0–3 hr	−0.61	−0.36	0.28	0.35	−0.72	−0.67	−0.46	−0.36	−0.65	−0.45	0.42	0.54	−0.84	−0.77	−0.66	−0.48
Mean[b,c]	17.85	17.42	17.01	16.26	16.83	16.24	16.01	15.29	17.87	17.30	17.14	16.36	16.64	16.15	15.86	15.21
Stiffness, kg																
Δ 0–3 hr	1.8	3.2	3.0	6.6	3.1	4.5	5.3	7.8	1.7	4.5	4.5	6.6	4.0	5.2	6.6	9.6
Mean[b,c]	6.3	7.2	7.0	8.5	6.9	7.7	8.3	10.0	6.1	7.7	7.6	9.2	7.2	8.3	9.0	11.5
Consistency, kg·min																
Δ 0–3 hr	1.2	2.4	2.9	8.5	2.0	4.1	4.7	14.7	1.0	4.1	4.8	14.9	3.7	5.9	10.4	31.4
Mean[b,c]	1.4	1.9	2.1	4.0	1.7	2.3	3.0	7.1	1.3	2.8	2.9	7.6	2.1	3.6	5.4	15.3
Flow, kg/min																
Δ 0–3 hr	−6	−14	−35	−46	−15	−37	−33	−33	−7	−17	−38	−49	−19	−39	−37	−35
Mean[b,c]	16	17	22	20	18	19	20	15	16	14	18	17	17	16	17	12
Adhesion, kg·min																
Δ 0–3 hr	−0.010	−0.015	−0.019	−0.016	−0.013	−0.015	−0.017	−0.017	−0.014	−0.016	−0.020	−0.017	−0.014	−0.016	−0.018	−0.018
Mean[b,c]	0.010	0.009	0.011	0.010	0.010	0.010	0.010	0.011	0.009	0.009	0.010	0.009	0.009	0.009	0.009	0.009
Cohesion																
Δ 0–3 hr	−12	124	91	697	62	193	259	1,197	−12	249	196	1,059	162	380	816	4,971
Mean[b,c]	15	58	18	191	23	60	93	382	13	107	96	474	64	161	285	1,624

[a] Values in this row are percentages of damaged starch in the flour.

[b] $LSD_{0.05}$ values for means are cookie diameter, 0.15; stiffness, 0.9; consistency, 2.0; flow, 2; adhesion, 0.001; and cohesion, 3. For calculation of LSDs for consistency, flow, and cohesion, data were log transformed as variances were proportional to the means.

[c] Mean of 0-, 1-, 2-, and 3-hr holding time.

TABLE V
Mean Effects of Holding Sugar-Snap Cookie Doughs 0, 1, 2, and 3 hr at Two Dough Temperatures and pH Levels and Student's *t* Statistics Associated with Predicting Cookie Size and Dough Handling Properties from Holding Times, Levels of Damaged Starch (DS), and Flour Particle Size (PS) for Flours B and C

	22°C				31°C			
	Mean[a]		Student's *t* Values		Mean[a]		Student's *t* Values	
Factor	pH 6.2	pH 4.8	pH 6.2	pH 4.8	pH 6.2	pH 4.8	pH 6.2	pH 4.8
Flour B								
Cookie diameter, cm	17.18	15.85			17.24	15.77		
DS			−7.6	−4.5			−6.1	−3.6
PS			3.1	3.4			0.6	−3.5
Stiffness, kg	8.3	8.6			8.5	9.1		
DS			1.5	1.8			1.5	1.7
PS			−0.5	−0.2			−0.4	−0.4
Consistency, kg·min	3.3	4.3			5.1	6.7		
DS			2.1	2.5			2.2	2.6
PS			0.2	−0.0			−0.2	−0.1
Flow, kg/min	17.6	20.0			15.1	17.3		
DS			−0.3	−0.4			0.2	−0.1
PS			−0.4	0.3			0.2	0.4
Adhesion, kg·min	0.009	0.009			0.008	0.008		
DS			0.2	0.1			0.2	0.4
PS			−0.1	−0.2			0.1	0.1
Cohesion	159	184			218	318		
DS			2.2	2.6			1.8	3.0
PS			0.1	−0.1			0.2	−0.1
Flour C								
Cookie diameter, cm	17.13	16.10			17.17	15.97		
DS			−12.2	−7.1			−6.5	−5.7
PS			3.6	4.2			3.7	2.6
Stiffness, kg	7.3	8.2			7.6	9.0		
DS			1.3	2.0			1.3	2.1
PS			−0.9	0.6			−1.5	−0.6
Consistency, kg·min	2.3	3.5			3.7	6.6		
DS			1.9	2.7			2.6	3.2
PS			−0.3	0.0			−0.5	0.0
Flow, kg/min	19.1	16.5			16.5	15.5		
DS			0.6	−0.7			0.5	0.5
PS			−0.2	−0.4			0.2	−0.1
Adhesion, kg·min	0.010	0.010			0.009	0.009		
DS			0.4	0.3			0.2	0.2
PS			0.4	0.1			0.0	0.2
Cohesion	70	139			173	533		
DS			−1.7	2.4			2.7	2.8
PS			−0.3	0.0			−0.4	0.2

[a] $LSD_{0.05}$ values for means are cookie diameter, 0.15; stiffness, 0.9; consistency, 2.0; flow, 2.0; adhesion, 0.001; and cohesion, 3. For calculation of LSDs for consistency, flow, and cohesion, data were log transformed as variances were proportional to the means.

TABLE VI
Student's *t* Statistics for Predicting Cookie Size and Dough Handling Properties from Dough Holding Time and Temperature, Flour pH, Damaged Starch Level, and Particle Size for Flours B and C

Factor	Dough Holding Temperature	Dough Holding Time	Flour pH	Flour Damaged Starch	Flour Particle Size
Cookie diameter	−1.0	−4.4	40.3	−19.1	7.5
Dough stiffness	3.3	24.4	−5.6	10.1	−2.9
Dough consistency	5.6	13.8	−4.3	9.9	−0.2
Dough flow	−2.3	−17.4	−0.6	−0.8	0.3
Dough adhesion	−2.2	−27.4	0.1	1.5	0.9
Dough cohesion	3.6	6.3	−2.9	6.2	−0.1

cookies from doughs made from chlorinated flour. Damaged starch content contributed more to explaining the reduction in cookie size than did flour particle size. Mean values for dough stiffness, consistency, and cohesion were greater in doughs held at 31°C, especially in doughs made with chlorinated flours.

The flow of doughs from flour B increased and the flow of doughs of flour C decreased with chlorination. Perhaps since the stiffness of doughs from flour B was increased less by flour chlorination (those doughs had lower initial water mobility), the chlorination of flour B had relatively less effect on reducing dough plasticity. Most of the above changes in handling properties were accentuated more by increased damaged starch levels than by reduction in flour particle size. As in the flour moisture study, chlorinated flours and high levels of damaged starch lowered dough plasticity. A similar influence was caused by holding doughs up to 3 hr and by elevating dough temperatures during holding.

A comparison of Student's *t* values for predicting cookie size and dough handling properties from dough holding time and temperature, flour pH, particle size, and damaged starch content is shown in Table VI. Flour chlorination (pH) and damaged starch content had the greatest effects on cookie diameter. Dough stiffness, consistency, and cohesion were more influenced by dough holding time and damaged starch. Dough flow and adhesion were mostly influenced by dough holding time. Holding time had greater influence than holding temperature on all dough handling properties. Damaged starch had a greater influence than flour particle size on all dough handling properties.

CONCLUSIONS

As commercial high-speed cookie dough machining requires consistent and predictable physical-textural attributes of dough, flour quality factors that affect cookie dough handling properties must be understood by both the baker and the wheat quality evaluator. Dough handling properties are likely to change (create processing problems) with fluctuation in any of the variables studied, and likely flour protein as well, which was not studied. The relative influences of the treatments studied are, in part, functions of the product formula and of the ranges of the variables studied. Thus no absolute comparisons of the treatments can be made; but as the ranges of each variable studied are likely to be, if not commonly, dealt with in commercial production of cookies, some practical generalizations are allowed.

In order of importance, sugar-snap cookie size was mostly affected by the studied ranges of flour chlorination, flour moisture content, and damaged starch content. Dough stiffness was mostly affected by the studied ranges of flour moisture content, dough holding time, and damaged starch content. Dough consistency, flow, and adhesion were mostly affected by the studied ranges of flour moisture content and dough holding time. Dough cohesion was mostly affected by the studied ranges of damaged starch content and flour chlorination.

More importantly from a practical point of view, any combination of those factors caused greater changes than did the individual factors. For example, in the production of the new dual-textured commercial cookie doughs (the flours for which are often treated with chlorine), flour damaged starch content should be kept as low as possible, and dough processing time and temperature should be kept as constant as possible.

Additionally, because flour B appeared to respond to chlorination by having somewhat greater water mobility in its doughs, it may be possible to choose cultivars (or milling methods) that will become more plastic and less "dry" upon chlorination and subsequently cause fewer dough handling problems. Finally, the data suggest to the wheat quality evaluator that soft wheat cultivars that have relatively hard kernel texture and, therefore, yield relatively high levels of damaged starch upon milling, are likely to cause more dough handling problems in high-speed cookie bakeries than will wheats with softer kernel texture.

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