Influence of Flour Chlorination and Ingredient Formulation on the Quality Attributes of Pancakes

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ABSTRACT

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Soft wheat flour is commonly chlorinated in North America for the production of cakes and pancakes. The oxidative properties of chlorine gas cause chemical modifications to flour components that enhance processing and end-use functionality of the intended food products. The objectives of this study were 1) to compare how untreated and chlorine-treated commercial soft wheat flour perform in a standard pancake formulation and 2) to compare how the individual ingredients in a standard pancake formulation influence quality attributes of pancakes made with untreated as well as chlorine-treated commercial soft wheat flour. Two portions of the same soft wheat flour, one chlorinated and the other unchlorinated, were used to study the effects of flour chlorination on batter viscosity, geometry, and texture quality attributes of pancakes. Commercial pancake formula ingredients were evaluated at different concentrations for their individual influence on quality attributes of pancakes. Differences in means (ANOVA) were used to evaluate the influence of the sources of pancake quality variation. The results indicate that flour chlorination had a significant influence on pancake batter viscosity, geometry, and texture, with chlorinated flour producing a more viscous batter, a larger and thicker pancake that was softer, more cohesive and resilient. The evaluation of a wide range of formula ingredient concentrations indicated that none could wholly substitute for chlorination. Individual ingredients did dramatically influence pancake batter viscosity, geometry, and texture, especially soy flour, dextrose, and leavening agents. However, sucrose and shortening had nonsignificant influences on the end-use quality of both chlorinated and unchlorinated pancakes.

Various chemical and thermic treatments have been devised to alter and thereby improve the functionality of wheat (*Triticum aestivum* L.) flour. One such treatment is chlorination. The treatment of freshly milled wheat flour with chlorine gas was first introduced in 1912 (Harrel 1952) and was shown to improve flour color and cake baking quality (Montzheimer 1931; Smith 1932). Flour chlorination decreases flour pH due to the production of hydrochloric acid. Generally, flour is chlorinated to pH 4.5–5.2, as dictated by the requirements of the intended product (Sollars 1958; Hoseney et al 1988). Lower pH indicates a greater degree of chemical modification.

The oxidative properties of chlorine gas chemically modify various wheat flour components (Sollars 1958; Gough et al 1978; Greenwell and Brock 1996). Gough et al (1978) deduced that flour chlorination is nonselective and affects all types of flour lipids. Kissell et al (1979) showed that chlorination increased free lipid and diglyceride contents while decreasing the relative amount of less polar lipids. Conforti et al (1993) and Daniels (1960) found that essential fatty acids such as linoleic acid were decreased by flour chlorination. Flour chlorination increased the amount of water-extractable proteins while decreasing the amount of acetic acid extractable proteins (Kissell et al 1971; Tsen and Kulp 1971). Within the class of gluten-forming proteins, Duviau et al (1996) established that flour chlorination caused gliadin proteins to become more water extractable, whereas glutenin proteins were not affected. Prolonged chlorination of flour alters the configuration of water soluble arabinoxylan by cleaving arabinose side chains from the xylan polymer, resulting in an increase in water insoluble arabinoxylans (Cole 1970).

The properties of starch granules are changed considerably by chlorination (Sollars 1958; Hoseney et al 1988), although no measurable change in starch molecular composition due to chlorination was observed using differential scanning calorimetry (Allen et al 1982). Seguchi (1987) reported an increase in starch granule hydrophobicity and later attributed the increase in hydrophobicity to changes to starch granule surface proteins (Seguchi 1990).

The treatment of freshly milled cake flour with chlorine gas results in cakes with increased volume and finer crumb texture compared with cakes made from unchlorinated flour (Montzheimer 1931). Cakes produced from unchlorinated flour tend to collapse while cooling, resulting in an unacceptable product, whereas cakes made with chlorinated flour maintain their structure and do not collapse (Ohtsubo et al 1978; Greenwell and Brock 1996). It is believed that the structural support found in cakes produced from chlorinated flour is caused by ruptured gas cells and starch gelatinization toward the end of baking (Ohtsubo et al 1978). The rupture of gas cells and starch gelatinization provide a continuous supportive matrix preventing the collapse of the cake during initial cooling. Ohtsubo et al (1978) and Greenwell and Brock (1996) suggested that the atmospheric air pressure and pressure within the cakes were able to equilibrate during cooling due to ruptured gas cells, which provided a permeable structure allowing movement of air in and out of the cake. Without the rupture of gas cells, the internal pressure decreased during cooling, causing the cake to collapse due to the greater pressure exerted by the atmosphere.

Another soft wheat flour product that has been evaluated for the effects of flour chlorination is Japanese pan-cake (Seguchi and Matsuki 1977). Chlorinated prime starch increased the springiness and decreased the gumminess of Japanese pan-cakes, as determined by sensory evaluation (Seguchi and Matsuki 1977). The Japanese pan-cakes described by Seguchi and Matsuki (1977) were prepared by baking a batter in a shallow iron pan (diameter 25 cm and depth 2.5 cm) for 13 min. This Japanese-style pancake is different than the typical North American pancake, which is flat (1–2 cm), round (10–20 cm), has an intermediate moisture content (25–30%), and is made from a chemically leavened batter in which chlorinated wheat flour is the predominate dry ingredient (Morris and Rose 1996). North American pancakes are made by pouring an aliquot of batter onto a hot oiled surface and frying on each side (1–2 min). There are no barriers to lateral flow, in contrast to the pan used in Japanese pan-cakes.

Dry pancake mixtures are widely used by restaurants, food services, and individual consumers. Most pancake mixtures contain chlorinated soft wheat flour, various saccharides, salt, shortening,

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emulsifiers, and chemical leavening agents. The pancake quality attributes contributed by the various ingredients are not well understood. Saccharides, besides providing sweetness, may contribute to surface color browning (Pomeranz et al 1962) and delay starch gelatinization onset (Allen et al 1982). Sodium chloride strengthens and enhances the elasticity of gluten in dough (Pyler 1988), possibly by causing conformational changes in the gluten proteins, leading to increased water solubility of the gluten proteins (Fu et al 1996). Shortening influences the volume and crumb structure of cakes made from unchlorinated flour (Johnson and Hoseney 1979), while cakes made with chlorinated flour are not affected by shortening levels (Kissell and Marshall 1962). Wong and Kitts (2003) stated that emulsifiers will increase the water-holding capacity of the foam, as defined by Approved Method 56-30 (AACC International 2000); foam stability and capacity were as defined by Ahmendna et al (1999). Wong and Kitts (2003) further stated that soy protein has a greater water-holding and lipid-absorption capacity than does buttermilk or dried egg yolk. Chemical leavening agents influence batter viscosity and batter expansion (Heidolph 1996).

The influence of flour chlorination and various ingredients on the quality attributes of pancakes has not been reported. Therefore, the objectives of this study were 1) to compare how chlorinated and unchlorinated commercial soft wheat flours perform in a standard pancake formulation and 2) to compare the influence of individual formula ingredients on various quality attributes of pancakes made with chlorinated as well as unchlorinated commercial soft wheat flour.

MATERIALS AND METHODS

Soft White Wheat Flour and Ingredients

A commercial soft white wheat pancake flour with and without commercial chlorination was provided by The Archer Daniels Midland (ADM) Milling Company, Cheney, WA. The chlorinated flour is marketed for production of commercial pancake dry mixes. To provide a direct comparison as to the effect of chlorination, a portion of the untreated "parent" flour was obtained before chlorination, a second portion was obtained after the normal chlorination treatment. The untreated flour sample had a protein content of 8.7%, an ash content of 0.46%, and pH 6.28. The portion treated with chlorine gas had pH 5.28 (target range 5.05–5.30).

Sucrose was obtained from L&H Sugar Company, Crockett, CA. Dextrose and sodium bicarbonate were obtained from J.T. Baker Chemical Company, Phillipsburg, NJ. Sodium chloride was obtained from Fisher Scientific, Fair Lawn, NJ. Defatted soy flour (lipoxygenase-active) was obtained from ADM. Dried egg yolk was obtained from Sonstegard Food Company, Sioux Falls, SD. Dried cultured buttermilk was obtained from Dana Food Inc., Hillsboro, WI. All-purpose shortening with no mono- or diglycerides added was provided by Cargill Inc., Minneapolis, MN. Sodium acid pyrophosphate 40 (SAPP 40) and monocalcium phosphate monohydrate (MCP) were provided by ICL Performance Products LP, St. Louis, MO.

The research was designed to examine the influence of chlorination and individual ingredients in a standard pancake formulation on various quality attributes of pancakes. Each ingredient was varied over a range of concentrations while holding all other ingredients constant. In general concept, ingredient levels were varied around the standard formula level which was set to 'X', and then varying the ingredients in a series of 1/3X, 2/3X, X, 1 and 1/3X; 1/2X, X, 2X; etc. Several of the ingredient concentrations included a zero level to test the effect of completely removing that particular ingredient. The chemical leavening agents were varied as a group such that the relative concentration of the three chemicals was held constant as a fixed ratio. The ingredients that were varied were sucrose, dextrose, sodium chloride, defatted soy flour, dried egg yolk, dried buttermilk, all purpose shortening, and chemical leavening agents (sodium bicarbonate, SAPP 40 and MCP). Table I shows the concentration levels of each ingredient, based on a consensus commercial pancake formula.

Dry Pancake Mix Preparation

The ingredients sucrose, dextrose, salt, soy flour, dried egg yolk, dried buttermilk, sodium bicarbonate, SAPP 40, and MCP (Table I) were combined and mixed (model N50 mixer, Hobart Canada, North York, ON, Canada) with a wire whisk at low speed for 5 min, stopping at 2.5 min to scrape down the sides of the mixing bowl. Flour was then incorporated and mixed for an additional 5 min at low speed, stopping at 2.5 min to scrape down the sides of the bowl. The shortening was then added to the mixture by extruding the appropriate preweighed amount of shortening through a 35-cm^3 syringe (2 mm diameter output) distributed over the top of the dry mix. The entire mixture was mixed for an additional 5 min in the Hobart mixer with a wire whisk stopping at 2.5 min to scrape down the sides of the bowl.

Pancake Procedure

Deionized water (293 g, equal to 167.4% flour "bakers percentage") (Table I) was added to a 2.8-L stainless steel mixing bowl. The water temperature was maintained at 20°C with a refrigerated circulating water bath before use (ambient room temperature ≈25°C). The indicated amount of dry pancake mixture (Table I) was added to the water and mixed by hand for 40 sec with a wire whisk 25-cm long. The resulting batter was then rested for 1 min, at which time the temperature was recorded.

TABLE I
Standard Pancake Ingredient Formulation and Experimental Pancake Ingredient Amounts

Ingredient[a]	Standard Formula[b]		Experimental Ingredient Amounts[c]					Block
	(g)	(bakers %)	(bakers %)					
Sucrose	18.67	10.67	3.33	6.67	10.67	13.33	–	1
Dextrose	5.83	3.33	0.00	1.67	3.33	6.67	–	2
Salt (NaCl)	1.17	0.67	0.00	0.67	1.33	2.67	–	3
Soy flour	11.08	6.33	3.33	5.00	6.33	13.33	–	4
Egg yolk	2.33	1.33	0.00	0.67	1.33	2.67	–	5
Buttermilk	2.33	1.33	0.00	0.67	1.33	2.67	–	6
Shortening	5.83	3.33	0.00	1.67	3.33	6.67	–	7
Sodium bicarbonate	3.50	2.00	1.50	2.00	2.50	3.00	4.00	8
SAPP 40	4.90	2.80	2.10	2.80	3.50	4.20	5.60	8
MCP	2.28	1.30	0.98	1.30	1.63	1.95	2.60	8
Flour	175.00	100.00	100.00	100.00	100.00	100.00	100.00	–
Water	293.00	167.40	167.40	167.40	167.40	167.40	167.40	–

[a] SAPP 40, sodium acid pyrophosphate 40, MCP monocalcium phosphate monohydrate.
[b] standard formulation is expressed as a bakers % (relative to 100 units of flour) and as actual grams used.
[c] Experimental ingredient amounts varied singly as shown; while holding all other ingredients constant.

Pancake batter was poured into the reservoir of a Bostwick Consistometer (CSC Scientific Co., Fairfax, VA) and excess batter was scraped off the top of the reservoir with a rubber spatula. The consistometer gate was released, and after 30 sec the distance (in cm) that the batter traveled was recorded as "Bostwick" batter viscosity.

Three minutes after the incorporation of water into the dry pancake mixture, a number 20 commercial ice-cream style scoop with mechanical sweep (Polar Wave, Sheboygen, WI) was used to pour equal amounts (41 g for each pancake) of batter onto a Krampouz (Pluguffan, model CECIF4, France) commercial griddle with a surface temperature of 190°C. Four pancakes were produced from each batch of batter and fried together. The batter aliquots for the four pancakes was dispensed onto the griddle in 10-sec increments from a height of ≈8 cm. After 75 sec of cooking on the first side, the pancakes were flipped and cooked for an additional 75 sec on the second side. After cooking, the pancakes were placed on an aluminum baking sheet, first cooked side up, and cooled for 20 min. One of the four pancakes was randomly set aside to observe the gas cell structure within the pancake by peeling off the top layer of the pancake, thereby exposing the gas cell structure. The diameter of the remaining three pancakes was measured with a digital caliper (Fisher Scientific, model number 06-664-16) at three points on the pancake, 0°, 120°, and 240°, and averaged. After the 20-min cooling period, three pancakes were subjected to texture profile analysis.

Texture Profile Analysis (TPA) of Pancakes

A texture analyzer (TA-XT2i, Stable Micro Systems, Scarsdale, NY) was used to perform the TPA on the pancakes. The texture analyzer was equipped with a 50-kg load cell and a round 75-mm diameter compression platen probe. The TPA computer software was Texture Exponent 32 (Stable Micro Systems). A stack of three pancakes was orientated first baked-side up on the texture analyzer platform. The pancake stack was compressed to 50% of its original height at a constant rate of 1 mm/sec. After the initial compression, the probe retracted off the pancakes and remained stationary for 5 sec followed by a second compression to 50% of the original height.

A number of texture parameters were derived from the TPA curve. Figure 1 and Table II show how the different parameters were either directly obtained or calculated from the TPA curve. The calculated parameters were derived using the equations from Bourne (1978). The pancakes' height was also measured by the texture analyzer by determining the distance the probe traveled for 50% compression and multiplying by two-thirds.

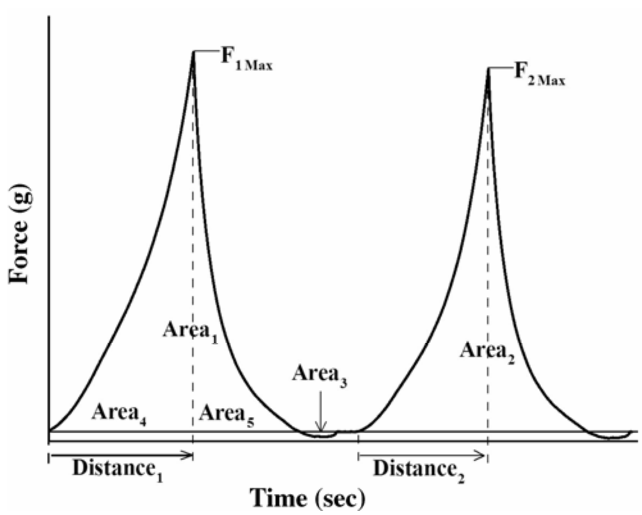

Fig. 1. Texture profile analysis graph showing the origin of the various height and texture measurements described in Table II.

Statistical Analysis

For a given ingredient, all pancakes for all levels of that ingredient were produced on the same day. Pancakes for which the combination of leavening agents was varied were produced on a single day. Each combination of flour (unchlorinated vs. chlorinated) and ingredient was replicated twice (the experimental unit was one batter that produced four pancakes, one pancake was used for observation of cell structure, the other three were used for TPA analysis). TPA was conducted as described above on the two replicate sets of three pancakes each. TPA parameter measurements and calculations are shown in Table II. The statistical analysis was conducted in two parts. The first part utilized pancakes prepared using the standard formula (Table I), and considering chlorinated vs. unchlorinated flours as the primary comparison. All of the ingredients were held constant, based on the standard pancake formulation, only the two flours were varied. A randomized complete block with 'day' as the blocking factor was the experimental design applied to this data set. Differences between flour means were examined using an LSD at the $P = 0.05$ level of significance.

The second part of the statistical analysis examined the effect of each ingredient. The analysis was conducted as eight separate analyses, one for each of the varied ingredients (leavening agents were varied as a group) (Table I). The analyses were conducted as two-way ANOVA with flour treatment and ingredient level as fixed sources of variation, to compare the impact of flour treatment and ingredient formulation on the quality attributes of pancakes. All statistical analyses were conducted with the general linear model software, (v.9.0; SAS Institute, Cary, NC). Type III Sums of Squares were used throughout.

Titration of Standard Pancake Formulation

Three pairs of titration curves were produced: 1) pancake flours alone, chlorinated and unchlorinated; 2) pancake flours, chlorinated and unchlorinated, plus the standard pancake formula ingredients

TABLE II
Description of Texture Profile Analysis (TPA) Parameters with Calculations

Parameter	Descriptive Definition
Hardness	Force required to compress pancakes to 50% of original height ($F1_{max}$) (g)
Height$_1$	Average height of one pancake (distance to reach $F1_{max} \times 2/3$) (cm)
Height$_2$	Average height of one pancake after first compression (distance to reach second $F2_{max} \times 2/3$) (cm)
Area$_1$	Work of first compression (area under first curve to reach $F1_{max}$) (g/mm)
Area$_2$	Work of second compression (area under second curve to reach $F2_{max}$) (g/mm)
Adhesiveness	Area$_3$; work of adherence of pancakes to the compression plate and stage (area under the retraction curve) (g/mm)
Area$_4$	Work to reach $F1_{max}$ (area under first curve to reach $F1_{max}$) (g/mm)
Area$_5$	Work after $F1_{max}$ (area under first curve after $F1_{max}$) (g/mm)
Cohesiveness	Area$_2$/Area$_1$
Springiness	Height$_2$/Height$_1$
Resilience	Area$_5$/Area$_4$
Gumminess	Hardness × Cohesiveness; i.e ($F1_{max}$) × (Area$_2$ / Area$_1$)
Chewiness	Gumminess × Springiness ; i.e ($F1_{max}$) × (Area$_2$ / Area$_1$) × (Height$_2$ / Height$_1$)

(no shortening), but without leavening agents; and 3) pancake flours, chlorinated and unchlorinated, plus the standard pancake formula ingredients (no shortening), with the leavening agents. Sample (10 g, dwb) was added to 100 mL of ddH_2O and hydrated for 1 hr. After 1 hr 100-µL aliquots of 1N HCl were added in 30-sec increments. The pH of the suspension was measured with an Orion Aplus bench top pH meter (model #920A+), equipped with a Ross Ultra pH electrode (model # 8102BNU).

RESULTS

Chlorination produced distinct differences in the structure and formation of gas cells within standard formula pancakes (Fig. 2). Pancakes made from chlorinated flour had a highly heterogenous cell structure that provided a continuous matrix of interconnected cells (Fig. 2A). Pancakes made from untreated flour generally had a more homogeneous cell structure comprised of large, independent gas cells with minimal interconnection (Fig. 2B). The exact mechanism responsible for the distinct differences was not determined. The way in which the visual differences in gas cell structure related to the quality attributes of pancakes was evaluated by comparing differences in batter viscosity and the geometry and texture quality attributes of standard formula pancakes made with chlorinated and unchlorinated flours.

A randomized complete block design ANOVA comparing flour chlorination and including day of the experiment as a blocking factor was conducted. Flour chlorination significantly affected all of the batter and pancake quality traits with the exception of pancake adhesiveness (the negative force during retraction of the TPA probe, Fig. 1 and Table II) (Table III). Pancake chewiness and gumminess had a correlation of $r = 0.99$ to hardness; consequently only hardness results are presented here. Analysis of day as the blocking factor indicated that for the majority of the batter and pancake quality traits, day was a minor albeit significant source of variation (F-values from 1.15–4.30; data not shown). This result has relevance to the conduct of the research where ingredient concentration was varied systematically; pancakes for each ingredient were produced on a single day. The largest F-values for pancake quality, in rank order, were resilience, height and hardness (Table III), indicating that variation between chlorinated and unchlorinated flours were greatest for these quality traits. Based on this ANOVA, the specific flour means were compared.

Comparison of the means for pancake batter viscosity, geometry, and texture (Table IV) showed that chlorination produced significantly more viscous batter, and pancakes with greater diameter and height which were much softer (less hard), slightly more cohesive and less springy but with much greater resilience. As indicated in the ANOVA, no significant difference was observed for pancake adhesiveness. Interestingly, the difference in pancake cohesiveness was significant ($P < 0.001$) even though the mean values were 0.795 and 0.787 (chlorinated and unchlorinated flours, respectively). These results indicate that in this study, like hardness and resilience, cohesiveness was a highly repeatable measurement with good precision.

Chlorinated pancakes were on average >0.27 cm in diameter and 0.12 cm thicker (greater height) (typical standard deviation of mean diameter among the three pancakes of a replicate batter was on the order of 0.05–0.10 cm) than unchlorinated flour. Because the difference in height represented an 11% increase, this difference in dimension would appear to have some practical significance. Hardness of pancakes made from chlorinated flour, however, was dramatically reduced, by ≈30%. Chlorine treatment reduced springiness, although the pancakes from both flours had springiness values of ≈1, indicating nearly complete recoil after 50% compression. In addition to hardness, the other large effect of chlorination was observed with resilience, where resilience was improved (increased) by 20%. These results indicated that in addition to the visual differences observed in internal cell structure of standard formula pancakes made from chlorinated and unchlor-

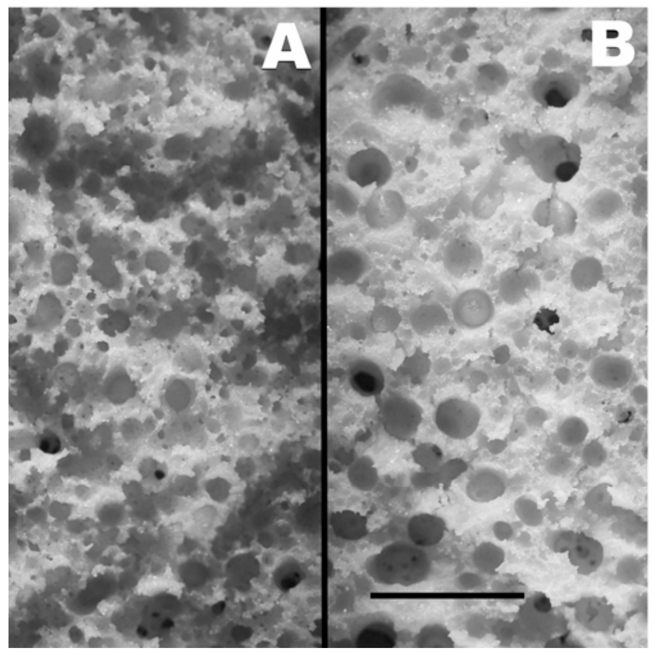

Fig. 2. Photographs of pancake crumb structure and gas cell formation from (**A**) pancakes made from chlorinated flour and (**B**) pancakes made from untreated flour. Both pancakes were produced with the standard pancake formulation (Table I). Bar = 1 cm.

TABLE III
F-Values from Analysis of Variance of Pancake Quality Attributes Using a Standard Pancake Formula on Chlorinated vs. Unchlorinated Soft Wheat Flours[a]

Flour Source	df	Viscosity	Diameter	Height	Hardness	Adhesiveness	Cohesiveness	Springiness	Resilience
Whole model	8	4.08**	3.81**	35.11***	30.36***	1.43ns	4.74**	6.40***	97.60***
Chlorination	1	5.61*	16.81***	255.8***	221.6***	3.42ns	24.39***	21.11***	753.3***

[a] *, **, and ***: significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. F-values were derived from type III sums of squares.

TABLE IV
Mean Quality Attributes of Pancakes Made with Chlorinated and Unchlorinated Soft Wheat Flours

Flour	Viscosity(cm)	Diameter(cm)	Height(cm)	Hardness(g)	Adhesiveness (g/cm)	Cohesiveness	Springiness	Resilience
Unchlorinated	10.33b	10.63b	1.06b	3.23b	–0.14a	0.787b	1.06b	0.388b
Chlorinated	9.97a	10.90a	1.18a	2.29a	–0.11a	0.795a	1.00a	0.467a
$LSD_{(0.05)}$	0.28	0.15	0.02	0.14	0.04	0.003	0.02	0.006

[a] Means followed by different letters within a column are significantly different at $P < 0.05$

inated flours, other batter and quality traits were also significantly affected.

The results from the first analysis indicated that flour chlorination caused significant changes in several quality attributes of pancakes. To examine how formula ingredients influenced pancake quality in conjunction with chlorination, ingredients were varied singly and systematically. The resultant data were subjected to a second statistical analysis. This analysis was comprised of a series of two-way ANOVA with flour chlorination and ingredient level as the two fixed effects. Separate analyses were conducted for each ingredient (leavening agents were varied together).

Varying sucrose from 3.33 to 13.33% had no significant effect on the quality attributes of pancakes, nor did it interact with flour chlorination (Table V). The standard formula contained 10.67% sucrose.

Dextrose from 0 to 6.67% did not affect batter viscosity, pancake geometry, or pancake springiness, but did influence hardness, adhesiveness, cohesiveness, and resilience (Table V). The interaction of dextrose with flour chlorination was significant for pancake height and especially adhesiveness. The most notable noninteractive effect of dextrose appears to be its effect on pancake cohesiveness with an F-value of 18.91 compared with an F-value for flour chlorination of 7.37. The influence of dextrose on pancake hardness and resilience was relatively small compared with the effect of flour chlorination. The interaction of dextrose and chlorination for pancake height was small relative to chlorination alone and exerted no independent main effect. Graphically, this interaction resulted from nonparallel response slopes between 0% and 1.67% dextrose for the two flour samples (data not shown). The interaction between ingredient and flour was greatest for pancake adhesiveness. Graphically, the interaction resulted from several cross-overs between chlorinated and unchlorinated flours at the various dextrose ingredient concentrations; no consistent response was observed. Although dextrose had some effects on pancake quality, varying this ingredient within the range used here did not substitute for flour chlorination.

Salt from 0 to 2.67% was a significant source of variation only for pancake height, and salt had no significant interaction with flour chlorination. The relative magnitude of F-values for pancake height, 255 for flour and 22.4 for salt, indicated that salt exerts only a minor influence on height. The general trend was increasing pancake height with increasing salt concentration. However, pancakes from unchlorinated flour had less height relative to pancakes produced from chlorinated flour, regardless of salt concentration.

Soy flour was a significant source of variation for all the pancake quality attributes (Table V). Furthermore, F-values indicated that soy flour was a significantly greater source of variation than was chlorination for batter viscosity, pancake diameter, height, and cohesiveness. Soy flour exhibited a significant interaction with chlorination for pancake height, hardness, and resilience, but these were caused by slight nonparallelism of response curves and not by cross-overs (data not shown). Batter viscosity increased dramatically with increasing soy flour concentration. In this instance, there was no significant difference between flours (Table V). Mean viscosities were 12.31, 11.31, 10.25, and 7.38 cm for 3.33, 5.00, 6.33, and 13.33% soy flour, respectively. Pancake diameters decreased with increasing soy flour. Means across flours were 11.66, 10.98, 10.76, and 10.40 cm for 3.33, 5.00, 6.33, and 13.33% soy flour, respectively. The diameter of standard formula pancakes made with chlorinated flour (10.90 cm) was matched with 3.33% soy flour in the unchlorinated flour. With the increase in batter viscosity and decrease in pancake diameter came a dramatic increase in pancake height with increasing soy flour. As much as a 40% increase in pancake height was observed due solely to soy

TABLE V

F-Values from Analysis of Variance of Pancake Quality Attributes Obtained by Varying Individual Formula Ingredients in an Otherwise Standard Pancake Formula Using Chlorinated and Unchlorinated Soft Wheat Flours[a]

Ingredient	Source[b]	Viscosity	Diameter	Height	Hardness	Adhesiveness	Cohesiveness	Springiness	Resilience
Sucrose	Model	0.43ns	1.67ns	28.37***	14.53**	0.65ns	5.65*	9.37*	45.91***
	Flour	0.31ns	8.03*	183.4***	97.74***	3.87ns	29.48**	58.04***	316.4***
	Ingredient	0.61ns	0.67ns	2.76ns	0.57ns	0.13ns	2.23ns	1.52ns	0.45ns
	Interaction	0.29ns	0.54ns	0.24ns	0.75ns	0.09ns	1.12ns	1.00ns	1.22ns
Dextrose	Model	2.56ns	1.30ns	21.12***	10.84**	18.83**	9.56*	5.20*	35.94***
	Flour	10.94*	6.23*	121.37***	53.06***	17.23*	7.37*	30.80**	204.5***
	Ingredient	1.81ns	0.64ns	3.46ns	6.00*	10.14*	18.91**	1.62ns	14.42*
	Interaction	0.52ns	0.30ns	5.36*	1.61ns	28.04***	0.93ns	0.25ns	1.26ns
Salt	Model	3.70*	1.43ns	46.73***	5.37*	1.54ns	1.10ns	5.30*	74.24***
	Flour	10.13*	2.25ns	255.2***	20.63*	0.24ns	1.78ns	30.51**	500.2***
	Ingredient	3.71ns	2.53ns	22.40**	3.71ns	2.26ns	1.16ns	1.63ns	1.14ns
	Interaction	1.54ns	0.05ns	1.58ns	1.95ns	1.26ns	0.81ns	0.56ns	5.35ns
Soy Flour	Model	40.78***	24.19***	241.97***	17.32**	3.64*	105.39***	11.82*	58.10***
	Flour	5.12ns	29.85**	214.83***	86.82***	7.56*	51.62***	38.27**	316.6***
	Ingredient	93.07***	43.48***	477.51***	4.60*	5.29*	227.94***	10.99*	16.44**
	Interaction	0.37ns	3.01ns	15.48*	6.87*	0.69ns	0.77ns	3.84ns	13.60*
Egg Yolk	Model	7.09*	3.72*	15.36**	41.95***	0.33ns	5.60*	14.09**	99.23***
	Flour	0.86ns	13.41*	70.38***	164.68***	0.74ns	24.14*	67.93***	610.72***
	Ingredient	9.78*	1.10ns	12.12*	27.98***	0.18ns	1.50ns	4.27*	8.28*
	Interaction	6.47*	3.11ns	0.27ns	15.02**	0.33ns	3.53ns	5.97*	19.68**
Buttermilk	Model	1.03ns	0.10ns	5.72*	31.90***	1.34ns	2.56ns	15.06**	274.38***
	Flour	4.90ns	0.16ns	29.54**	107.02***	0.02ns	13.10*	86.25***	1670.0***
	Ingredient	0.29ns	0.15ns	2.37ns	21.38**	0.50ns	0.28ns	5.95*	48.45***
	Interaction	0.47ns	0.03ns	1.14ns	17.38**	2.61ns	1.34ns	0.44ns	35.12***
Shortening	Model	0.81ns	1.24ns	17.02**	27.64***	0.98ns	1.60ns	6.87*	87.39***
	Flour	0.64ns	3.33ns	114.5***	173.0***	0.64ns	4.31ns	38.82**	586.61***
	Ingredient	0.69ns	0.97ns	1.41ns	3.04ns	0.95ns	1.82ns	1.65ns	0.54ns
	Interaction	0.98ns	0.82ns	0.14ns	3.46ns	1.12ns	0.47ns	1.43ns	7.83*
Leavening	Model	50.07***	5.12*	15.24***	33.98***	2.37ns	7.13*	12.70**	105.3***
	Flour	54.00***	10.75*	113.1***	92.16***	8.95*	42.81***	63.02***	755.4***
	Ingredient	96.00***	6.95*	4.34*	38.73***	2.01ns	3.60*	7.48*	28.81***
	Interaction	3.17ns	1.88ns	1.67ns	14.68**	1.08ns	1.75ns	5.34*	19.19***

[a] *, **, *** = Significant at $P < 0.05$, $P < 0.001$, $P < 0.0001$, respectively; ns, not significant. F-values derived from type III sums of squares.

[b] Model = ANOVA whole model significance; flour = chlorinated vs. unchlorinated; ingredient = concentration series for that ingredient.

flour. The height of standard formula pancakes made with chlorinated flour (1.16 cm) was expected between 6.33 and 13.33% soy flour in the unchlorinated flour. Hardness of pancakes made with chlorinated flour was minimally affected by varying soy flour concentration. However, with pancakes made from unchlorinated flour, hardness decreased dramatically as soy flour concentration increased. The hardness of chlorinated flour pancakes (≈2.2–2.4 g) was approached with unchlorinated pancakes containing the highest level of soy flour (13.33%, 2.6 g). Within the unchlorinated flour soy flour ingredient concentration series, there was a dramatic decrease in hardness (3.82–2.64 = 31%) as soy flour increased. Cohesiveness of pancakes generally decreased with increasing soy flour, and the effect was greater than was flour chlorination alone. Springiness had a modest trend of increasing with increasing soy flour. Generally, pancakes made from the chlorinated flour were less springy than were pancakes made from unchlorinated flour. However, at the highest concentration of soy flour, pancakes from both flours had equal and the highest springiness observed (1.10). Soy flour had a modest effect on pancake resilience, and no strong trend was evident within or between flours. At none of the soy flour concentrations used here was the resilience of pancakes made from unchlorinated flour equal to the resilience of pancakes made from the chlorinated flour. In summary, soy flour had a large effect on batter viscosity, much larger than chlorination; it reduced pancake diameter and cohesivenss, increased pancake height, and reduced hardness in the pancakes made from unchlorinated flour. In all of these but hardness, the level of soy flour could be manipulated to obtain equivalent values between chlorinated and unchlorinated flours. Across traits, however, soy flour could not substitute for chlorination.

Dried egg yolk at 0–2.16% was a significant source of variation for pancake batter viscosity, height, hardness, springiness, and resilience (Table V). However, all but height also had significant interactions with flour chlorination. Batter viscosity increased with increasing dried egg yolk, the increase was dramatic in the chlorinated flour (11.63 to 9.38 cm) and slight in the unchlorinated flour (10.75 to 10.50 cm). Pancake height increased with increasing dried egg yolk for both flours; however, in no instance were any of the pancakes made from unchlorinated flour as thick as any of those made from chlorinated flour (the closest comparison came with unchlorinated flour at 2.67% egg yolk with 1.10 cm, and chlorinated flour with 0% egg yolk with 1.11 cm). Hardness and springiness of pancakes made from unchlorinated flour decreased dramatically with increasing egg yolk (4.65 to 2.72 g for hardness, and 1.13 to 1.04 for springiness). However both hardness and springiness were only slightly affected by changes in egg yolk concentration in the pancakes made from chlorinated flour. Again, the hardness and springiness of pancakes made from this series of egg yolk concentrations did not overlap between the two flours. Resilience of pancakes made from chlorinated flour tended to decrease somewhat with increasing egg yolk concentration, whereas with unchlorinated flour, pancake resilience increased dramatically (0.350 to 0.410). But as seen with hardness and springiness, the series between the two flours did not overlap.

Buttermilk at 0–2.67% was a significant source of variation for pancake hardness, springiness, and resilience, and significant interactions between buttermilk and flour chlorination were present for hardness and resilience (Table V). For the unchlorinated flour, hardness increased dramatically (2.60 to 4.25 g) with increasing buttermilk concentration. In contrast, for the chlorinated flour, there was only a small increase in hardness (2.39 to 2.47 g). For both flours, there was a trend of increasing pancake springiness as buttermilk concentration increased (data not shown). In opposition to hardness, pancake resilience decreased dramatically (0.407 to 0.357) in the unchlorinated flour as buttermilk concentration increased, whereas again in the chlorinated flour, the effect (decrease) was very slight.

Shortening at 0–6.67%, similar to sucrose, had no significant effect on pancake batter viscosity, geometry, or texture. A statistically significant interaction with flour chlorination was detected, but relative to the chlorination effect (*F*-value 587) and the lack of a shortening main effect, the interaction was not considered important.

The leavening agents sodium bicarbonate, SAPP 40, and MCP were analyzed together as a single factor and were held in constant ratio. Their level was varied from 3/4X to 2X. The leavening agents were a significant source of variation for all the pancake quality attributes except adhesiveness. However, only for batter viscosity were leavening agents a greater source of variation compared with flour chlorination (Table V). Interactions were significant for pancake hardness, springiness, and resilience. Batter viscosity increased dramatically with increasing leavening in both flours. The viscosity of the unchlorinated flour batter matched that of the standard formula chlorinated flour batter when the concentration of leavening agents was increased to 1.25X. Pancake diameter was only minimally affected by leavening and there was no strong trend in either flour. Pancake height was similarly only modestly influenced by varying the leavening concentration and in no instance did the height of pancakes prepared from unchlorinated flours attain the height of any of the pancakes made from the chlorinated flour, regardless of leavening concentration. Increasing the leavening concentration dramatically reduced the hardness of pancakes from both flours (5.58 to 2.10 g, unchlorinated, 2.73 to 1.91 g, chlorinated). The hardness of standard formula chlorinated pancakes (2.31 g) was obtainable in the unchlorinated pancakes between 1.5X and 2X level of leavening. Pancake cohesiveness was minimally affected by leavening concentration. Pancake springiness and resilience, however, increased in the unchlorinated pancakes with increasing leavening, whereas the springiness and resilience of chlorinated pancakes was minimally affected. The springiness and resilience of the unchlorinated pancakes never obtained the level of springiness and resilience of any of the chlorinated pancakes, regardless of leavening concentration.

To summarize this section on ingredients, none of the formula ingredients could wholly substitute for chlorination. However, individual ingredients did exert dramatic influences on pancake batter viscosity, geometry, and texture, in some instances an effect greater than chlorination alone.

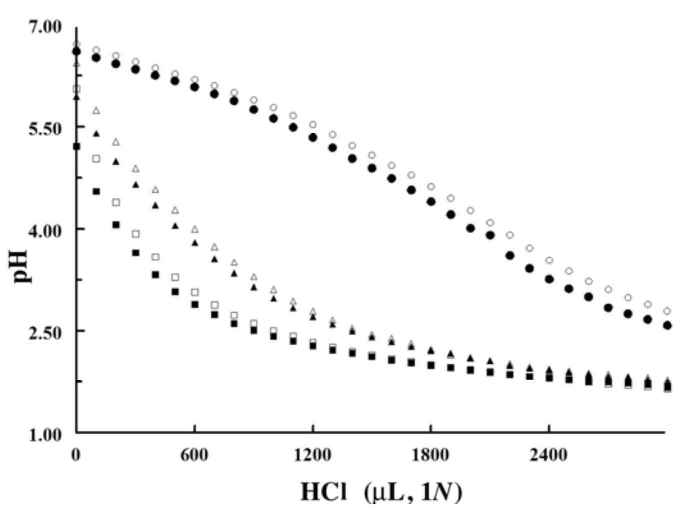

Fig. 3. Acid titration of soft white wheat pancake flours, chlorinated (■) and unchlorinated (□); pancake flours plus the standard formula pancake ingredients, without leavening agents (Table I), chlorinated (▲) and unchlorinated (Δ); and pancake flours plus the standard formula pancake ingredients, including leavening agents, chlorinated (●) and unchlorinated (○).

The results on the leavening agent concentration series suggested that the chemical decomposition (acid – base reactions) and gas liberation were key influences on pancake quality. To partially address one aspect of this process, the buffering capacity of the two flours, the flours plus the standard formula pancake ingredients without leavening agents (and no shortening), and the flours plus the standard formula pancake ingredients including leavening agents (no shortening) was evaluated. Titration curves for these six materials are presented in Fig. 3. The two flours had little buffering capacity and the addition of HCl rapidly decreased the pH. The beginning difference in pH (at zero HCl) due to the chorine treatment was evident. However, this difference grew smaller as more acid was added. Including all of the standard pancake formula ingredients except leavening agents increased the starting pH and exerted a greater capacity to resist a drop in pH (increased buffering capacity) compared with the flours alone, although the effect of chlorination was still evident in the upper part of the curves. Inclusion of the leavening agents raised the beginning pH to near neutrality and provided substantial buffering capacity against the addition of HCl. This result suggests that the acidification of flour due to chlorination is not, in and of itself, the source of enhanced flour quality but rather it is the effect of chlorination on flour constituents that provides the enhancement.

DISCUSSION

The production of high-quality pancakes requires an understanding of flour and formula ingredient functionality. A complicating factor superimposed upon the flour as the primary ingredient in a pancake dry mix is the common practice of treating the flour with chlorine gas. Here we developed a laboratory protocol to produce North American-style pancakes based on a consensus standard formula. Furthermore, we obtained a commercial soft white wheat pancake flour, both before and after it was commercially chlorinated. The results obtained provide a basis for understanding the response of pancake batter, geometry and texture to chlorination, as well as how chlorinated and unchlorinated soft wheat flours respond to changes in formula ingredient concentrations.

Visual differences in the gas cell structure between standard formula pancakes made with chlorinated and unchlorinated flour (Fig. 2) were similar to differences in gas cell structure of cakes (Ohtsubo et al 1978; Grinder et al 1983; Rabe and Meyers 1995; Greenwell and Brock 1996). Pancakes from chlorinated flour had a preponderance of ruptured, interconnected gas cells, whereas pancakes made with unchlorinated flour contained relatively larger, less interconnected cells (Fig. 2). Understanding the mechanisms of how flour chlorination influences these differences in gas cell formation is needed.

To relate the observed differences in the pancake gas cell structure to other quality attributes, an analysis of pancake batter viscosity, geometry, and texture was conducted. The results indicated the great importance of flour chlorination on the quality attributes of pancakes, where pancake batter viscosity, diameter, height, hardness, cohesiveness, springiness, and resilience all differed significantly between chlorinated and unchlorinated flours (Tables III–V). Flour chlorination had a greater influence on pancake quality than most of the other ingredients. The only ingredients that exhibited a greater influence on individual pancake quality attributes were dextrose, soy flour, and leavening agents (Table V).

Soy flour was most notable as having the most extensive and major influence on pancake batter viscosity, diameter, height, and cohesiveness (Table V). The water-holding capacity, lipid-absorption capacity, and increased foam stability that soy proteins provide (Wong and Kitts 2003) may have contributed to the significant influence that soy flour had on pancake quality attributes, all of which are related to, or potentially derived from, surfactant/foaming properties. Second only to soy flour, the leavening agents had a major influence on batter viscosity (Table V), which is in agreement with the research of Heidolph (1996), who stated that leavening systems have the potential to affect batter volume as well as batter viscosity.

Sucrose, salt, and shortening had little influence on the pancake quality attributes examined here. However, color and organoleptic traits (taste, mouthfeel) were not assessed. Pancake surface browning tended to increase as both sucrose and dextrose concentrations increased, however this feature was not quantified. Sodium chloride is an important consideration in the flavor enhancement of the pancakes (Pyler 1988) but this aspect was not studied. From our results it appears that salt level can be manipulated for flavor with minimal effect on other pancake quality traits. Kissell and Marshall (1962) reported that shortening had no effect on cakes made with chlorinated flour, which is in agreement with the pancake results in this research. On the other hand, Johnson and Hoseney (1979) found that shortening had a significant influence on the volume and crumb structure of cakes made with unchlorinated flour, which was not observed in our pancake results.

To date, very little research has been reported on the influence of formula ingredients on pancake quality. Information on how chlorination affects the constituents of wheat flour and how these changes contribute to the quality attributes of pancakes is needed. Here we documented a number of effects of chlorination of a commercial soft white wheat flour on pancake quality. Here too, we describe the development of a robust laboratory pancake method that is sufficiently sensitive and reproducible to detect differences in pancake quality due to flour treatment and formula ingredient level. In commercial practice, a long-term goal might be the complete elimination of flour chlorination. However, in this study, no single ingredient was able to substitute fully for the various effects of chlorination on pancake quality.

Our more immediate goal is to establish a laboratory-scale method that would rank a series of unchlorinated flours for pancake quality the same as when they are chlorinated. In this regard, cereal chemists routinely use methods such as sugar snap cookie and pup loaf methods (Approved Methods 10-50D and 10-10B, respectively, AACC International 2000) that are not, in and of themselves, "commercial" products or formulas.

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