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EFFECTS OF CHLORINATION ON FLOUR RHEOLOGICAL PROPERTIES AND ON BAKING QUALITIES OF HIGH-RATIO AND JAPANESE-SPONGE CAKES

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EFFECTS OF CHLORINATION ON FLOUR RHEOLOGICAL PROPERTIES AND ON BAKING QUALITIES OF HIGH-RATIO AND JAPANESE-SPONGE CAKES

By

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ABSTRACT

EFFECTS OF CHLORINATION ON FLOUR RHEOLOGICAL PROPERTIES AND ON BAKING QUALITIES OF HIGH-RATIO AND JAPANESE-SPONGE CAKES

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In this study, thirteen soft wheat flour samples were chlorinated to pH 4.8 and pH 4.3, and were analyzed for their rheological properties and baking potentials. Sedimentation volumes indicated a weakening of the gluten proteins with chlorination, and alkaline water retention capacity (AWRC) tests showed an increase in AWRC (%) with chlorination. Rheological tests were performed on chlorinated and unchlorinated flours. Alveograph measurements indicated modification to starches and proteins causing increased resistance (P) and stability (P/L), and decreasing extensibility (L) and elasticity (G). Farinograph measurements showed increased water absorption in chlorinated flours due to modification to starch granules, and increased peak times which also can be attributed to modifications of the proteins and starch granules. Mixograph measurements showed significant decreases in peak time with chlorination which may be attributed to the constant addition of water to treatments with increasing water absorptions. Decreases in

peak time may be due to decreases in protein strength as seen in sedimentation volumes. Viscoamylograph measurements indicated significant changes to the starch components gelling and pasting properties only when the flour was overchlorinated (pH 4.3). The baking potentials of the flours were measured with high-ratio and Japanese sponge cake formulas. High-ratio cakes had peak volume and symmetry from cakes baked from the pH 4.8 flours. Japanese-sponge cakes produced optimum volumes from unchlorinated flours but better symmetry was observed from the cakes produced from chlorinated flours.

Dedicated to my parents, John and Gayle Worthington, who have made my education possible by their continual love and support.

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1. INTRODUCTION

Since the 1930's, flour chlorination has been used as a means of improving a flour's baking potential. Treating soft wheat flour with chlorine gas bleaches its pigments (mainly carotenoids), lowers the pH, and chemically modifies flour components (primarily protein, starch and lipids) thereby allowing for the production of high quality high-ratio cakes (Tsen and Kulp 1971). The chlorinated flour is capable of holding high ratios of shortening and sugar without collapse (Ngo et al. 1985). Cakes made from unchlorinated flour collapse upon cooling. It is likely that chlorination strengthens interactions between flour components and the other cake ingredients, thus yielding a stronger internal structure in cakes.

A major concern with the use of chlorination is the possible generation of carcinogenic free radicals. However, studies by Fisher et al. (1983) and Ginocchio and Hardy (1983) have shown that mice and rats fed chlorinated flour over a long period of time do not develop cancer. Nevertheless, the suspected presence of carcinogens in chlorinated flour has prompted Japanese companies to discontinue (Buntoko 1969) and the E.C. countries (except the U.K.) to ban the use of chlorinated flour (Russo and Doe 1970). It is likely that the U.S. may also ban the use of chlorinated flour in the future to remain competitive. A ban would influence the quality of cakes. Therefore, in anticipation of such a ban, alternatives to chlorination need to be developed that produce optimum quality cakes. The objective of this study was to characterize the effect of degree of flour chlorination on dough rheology and baking properties.

2. REVIEW OF LITERATURE

2.1 Introduction

Soft wheat flours for cake production are chlorinated to bleach a flour and improve its baking potential. However, the effect of chlorination on the rheological properties of soft wheat flour is not well documented. The following will review physicochemical changes of flour properties due to chlorination, and effects on major constituents of flour (proteins, starches and lipids) due to chlorination.

2.2 Chlorination Procedure and Its Measurement

Chlorine is applied to flour by bubbling chlorine gas through the flour with continuous agitation to ensure uniform modification of the flour components (Wei et al 1984). Currently, flour pH is the primary method used to measure the extent of chlorine treatment (Ash and Colmey 1973). In the past, the degree of chlorination was measured by the quantity of chlorine added relative to the weight of the flour (Tsen and Kulp 1971). However, this method is less accurate than pH measurement. This is because flour proteins, which vary in content among varieties, act as buffers against the chlorination process (Ash and Colmey 1973). This buffering effect causes each flour to require different levels of chlorination to obtain the same degree of modification (Barret and Sollars 1961). Flours brought to the same pH are considered to be similar in their degree of modification regardless of variations in their protein content, thus making pH a dependable measure of the degree of modification by chlorine treatment (Hoseney 1986).

The pH drop caused by the chlorination process does not contribute to the modification of flour components, but is only a side effect of the chlorination process. Bennett and Devlin (1954) demonstrated this principle by adding an alkaline material (chalk) to treated flour, thus raising the pH. Even in the basic pH range, improving effects of the chlorine on flour was still evident. The pH of a flour can be used to monitor the degree of modification, but acidic conditions do not contribute to the specific modifications chlorine has on the flour components.

For baking high-ratio cakes (HRCs), flour chlorinated to a pH of 4.7-4.9 produces optimum results (Hoseney 1986). If the flour is overchlorinated, destruction of grain texture and symmetry of the cake occurs resulting in smaller cakes with bitter taste (Conforti and Johnson 1992). However, cakes baked with underchlorinated flours expand well during baking, but shrink significantly due to insufficient hydration of the starch granules, resulting in low volume and cake collapse (Kissell and Yamazaki 1974). To achieve optimal chlorination, a compromise between expansion and contraction of the cake during baking must be found.

2.3 High-Ratio Cakes Made From Unchlorinated vs Chlorinated Flour

When comparing HRCs from unchlorinated and chlorinated flours, cakes made from chlorinated flour have more desirable color, better symmetry, higher volume, and superior internal grain score (Tsen and Kulp 1971). These improvements are attributed to the destruction of carotene pigments and modification of flour components which allow for increased batter viscosity and strong internal structure.

Volume differences between HRCs baked with chlorinated and unchlorinated flours is not visible until the last few minutes of baking or after removal from the oven, where cakes made from unchlorinated flours shrink and collapse (Bohn 1934). Montzheimer (1931) showed that HRCs made from untreated flour collapsed after removal from the oven and lacked the desired symmetry, grain and color.

Modification of flour components allows for the production of a cake batter with increased viscosity (Ngo et al 1985) which is partly responsible for the improved symmetry, batter expansion, and grain score in cakes. A higher viscosity allows the batter to entrap more air bubbles without the formation of large air pockets in the cake's grain. In the less viscous, untreated batters, the batter is not viscous enough to keep air bubbles separate in small pockets, which can allow for formation of large air pockets (Yamazaki and

Kissell 1978). Ngo and co-workers (1985) demonstrated that batters from chlorine-treated flours had much higher viscosities than batters from unchlorinated flours at 100°C. Kissell and Yamazaki (1974) found that batter expansion for flour chlorinated with low levels of chlorine was superior to that for unchlorinated flour. Higher batter viscosities from chlorinated flours allow for the production of HRCs that do not rise excessively or collapse in the pan (Ngo et al 1985).

2.4 Effect of Chlorination on Individual Flour Components

Chlorine-treated flour has improved cake-baking potential due to modification of flour components (Tsen and Kulp 1971). Alterations imposed on flour by chlorination include the following: decreased water activity, increased hydrophobicity, and increased oil and water binding of starch. These chlorine-induced alterations allow the flour components to interact with each other enabling the flour to produce HRCs with improved grain scores and stronger internal structures.

Immediately upon treatment with chlorine, the natural pigments present in flour are destroyed (Hanson 1932). Flour pigments are carotenoids, which consist mainly of xanthophylls. These pigments give flour a creamy yellow color, and are easily bleached by chlorine (Hoseney 1986). It appears that chlorine oxidizes some of the bonds in the carotenoid pigment structure. This oxidation causes a disruption of the conjugated bonds responsible for color in the pigments. Pigment loss does not appear to have an effect on the baking properties of treated flour; however, pigment destruction does produce a white flour, which some consumers find appealing.

Chlorine action also depolymerizes starch and gluten chains of flour (Haung et al 1982), facilitating changes in the properties of the flour components. Alterations to starch granules and their surface proteins, along with modifications to the gluten proteins are believed to be key contributors to the improvement of HRCs. Modifications and interactions of major flour components (proteins, starches and lipids) will be discussed in detail in the following sections.

2.5 Effects of Chlorination on Flour Proteins

There are two major types of flour proteins: gluten proteins and starch granule proteins. Both types of proteins can be modified by flour chlorination (Haung et al 1982). Gluten molecules in the flour can be oxidatively depolymerized by chlorine (Haung et al 1982). In addition, this depolymerization promotes the formation of more hydrophobic entities on the surface of the starch granule (Seguchi 1985).

Chlorine molecules appear to attack the aromatic amino acids cysteine and methionine on the protein chains in the flour (Ewart 1968). A study by Tsen and Kulp (1971) has shown that sulfhydryl groups are oxidized by chlorine. Their work has also demonstrated an increase in water-soluble proteins (albumins) after chlorine treatment, and a slight decrease in proteins soluble in acetic acid (glutens). Gliadins and glutenins, which are the two main subgroups that make up gluten proteins, were not studied individually in their work. Further research is required to clarify how these two groups are individually affected by chlorination. Chlorine treatment causes significant changes in free proteins of flour, but the role of these proteins during baking is presently unclear.

Donelson (1988) produced HRCs from flours (chlorinated to pH 4.8) that had the gluten removed, with no loss in volume compared to volumes of cakes produced from flour with gluten. Gluten was extracted from the flour and the flour was then baked using the Kissel lean formula (Kissell 1959), which contains no eggs or milk, eliminating all protein sources from the ingredients. According to their results, gluten proteins were not required to produce HRCs of volumes similar to ones produced by flour containing gluten. Further research is required to clarify the role of gluten and its subunits in the production of HRCs.

On the surface of starch granules there are low to medium molecular weight proteins (Sulaiman and Morrison 1990). Chlorine is thought to modify these proteins, bringing about changes that are beneficial in HRC production. Greenwell and co-workers (1985) used amyloglucosidase to demonstrate that chlorine altered these surface proteins. Chlorinated and unchlorinated starch was exposed to amyloglucosidase and the progress of enzymatic degradation was observed using scanning electron microscopy. Results indicated a lack of pitting in chlorinated starch granules, while untreated starch granules were pitted. They hypothesized that the protein layer, after it had been modified by chlorination, formed a protective layer around the starch granule.

A study by Seguchi (1985) helped clarify the changes that occurred to these proteins by demonstrating that certain amino acids on surface proteins of starch granules were modified by chlorination, causing them to become more hydrophobic. To detect increases in hydrophobicity, glass beads were coated with gelatin which has the same strong oil-binding ability as starch when chlorinated. It was determined that these proteins produced a thin water-insoluble hydrophobic layer after chlorination which would account for the increase in surface hydrophobicity. Using paper chromatography, new and more hydrophobic derivatives of lysine, tyrosine, and cystine were shown to be produced by chlorination. Seguchi (1985) attributed this increase in hydrophobicity to chlorine molecules binding to these amino acids. It can be deduced that the increase in hydrophobicity of starch granules can be attributed partially to the modification of these amino acids.

Seguchi (1990) observed via X-ray fluorescence that the amount of starch-granule surface proteins increased with chlorination. The additional proteins are thought to come from the other chlorinated non-starch wheat proteins. The increase in the amount of surface proteins and hydrophobicity of the starch granule may allow it to complex with other lipids and proteins in the flour resulting in stabilization of cake batter during baking (Kulp et al 1972).

2.6 Effects of Chlorination on Flour Starches

Starch is the most prevalent component in flour. Modification of starch by chlorine is believed to play a role in improved batter expansion, increased batter viscosity, and improved structure of HRCs (Variano-Marston 1985). Starch that has been treated with chlorine swells to a greater extent than untreated starch (Hoseney 1986). Before chlorine treatment, the starch granules are dense crystalline structures with amorphous regions and folds. Chlorine acts on the surface by oxidizing the starch which causes the granule to open up (Variano-Marston 1985), and modifying its surface proteins to more hydrophobic entities (Seguchi 1985). Newly opened spaces in the starch granule allow water to enter and hydrogen bond with starch chains, allowing for increased water uptake and improved HRC baking properties.

One mechanism explaining how chlorination depolymerizes the starch granule was postulated by Haung et al (1982) who studied the site of oxidative depolymerization on the starch chain. In an aqueous slurry of flour and water, oxidation of

D-glucosidic carbons C2 and C3 occurred, resulting in ring openings and transformation of these carbon atoms into carbonyl groups. This experiment was done in aqueous conditions, while flour chlorination occurs in semi-dry conditions (Uchino and Whistler 1962). Therefore, Haung and co-workers (1982) performed a second chlorination test in semi-dry conditions (13% moisture), and compared their results with previous data. Under semi-dry conditions, practically no oxidation occurred on C2 and C3, but extensive depolymerization occurred as the glycosidic bonds were cleaved by the chlorine. These conditions produced D-glucose and D-gluconic acids, both as free molecules. Formation of reducing sugars D-glucose and D-gluconic acid on the ends of carbohydrate chains could possibly act as cross-linking agents in the internal structures found in HRC.

Chlorination also results in increased surface hydrophobicity of starch granules (Seguchi 1987). Seguchi (1985) attributed this increase in hydrophobicity to alterations of proteins on the surface of the starch granules (see section 2.4). Hydrophobicity has been linked to a material's ability to hold air bubbles. Research conducted by Tomie and Okubu (1984) demonstrated that the bubble-catching ability of materials such as cotton, silk, acryl, polyvinylchloride, and nylon increased with hydrophobicity. Seguchi (1987) applied this work to cake batters. Different levels of chlorinated prime starch were made into a slurry with isoamyl alcohol. Bubble volume and stability increased with increased chlorination rates. Unchlorinated starch was unable to produce comparable results.

2.7 Effects of Chlorination on Flour Lipids

Chlorinated lipids, like the other components mentioned, are believed to play a role in the improvements facilitated by chlorinated flour in HRCs (Donelson et al 1984). Chlorinated lipids have been linked to smoother batter, improved gas retention, greater batter expansion, and larger volumes with fine cell structure (Kissel et al 1977). Gough et al (1978) proposed that chlorine gas reacts with lipids by addition reactions rather than direct oxidation, because research by Gracza (1959) and FMBRA (1970) provide no experimental evidence for oxidation. The exact mechanism is unknown due to the numerous end products that can be produced by lipid oxidation (FMBRA 1970).

Donelson et al (1984) performed reconstitution tests with extracted lipids to demonstrate the effects of lipids on cake volume. Hexane was used to extract the lipids from chlorinated and unchlorinated flours, leaving defatted or base flours. High-ratio cakes baked from these base flours were small and had sunken contours indicating that lipids were required, at least in part, for cake baking improvement to be seen. When unchlorinated lipids were added to unchlorinated and chlorinated base flours, no improvement in cake volume was seen. However, when chlorinated lipids were added to unchlorinated and chlorinated base flours, cakes with improved volumes and contours were produced. These results indicate chlorinated lipids play a role in the improved volume witnessed for HRCs baked from chlorinated flour in comparison to cakes baked from unchlorinated flour.

A variation of this type of experiment was performed earlier by Kissel and co-workers (1979) to determine the importance of the presence of lipids in the flour at the time of chlorination. When flours were chlorinated to pH of 5.2, 4.8, and 4.0, cake volume was found to improve with increasing chlorination until overchlorination occurred (pH 4.0). In reconstitution tests, lipids chlorinated to pH 5.2 and 4.8 and untreated flours were placed in pH 4.0 base flour. The baking potential of the flour improved as the chlorinated lipids were added. The greatest baking improvements were observed when lipids were reconstituted with the base flours in which they were chlorinated with, indicating that the best baking ability for chlorinated flour occurs when lipids and other flour components have all been uniformly modified.

Heat treatment of lipids as an alternate method to chlorination was explored by Clements and Donelson (1982). Lipids were extracted from unchlorinated flour and were heated at 100°C for various periods of time. When heat-treated lipids were added to chlorinated base flour, baking tests yielded cakes with volumes that were equivalent to chlorinated control flour. However, when heat-treated lipids were added to unchlorinated base flour, collapse occurred in cakes after baking. These results indicated that heat treatment of lipids alters them allowing improved baking potential to cakes, but only if the other components have also been chlorinated.

Lipid modification by chlorination plays a key role in the improvement seen in cakes baked from chlorinated flour. The exact mechanism for lipid modification by chlorine gas is still unknown. Research has shown that lipid modification, in addition to modification of the other flour components, contributes to improved baking potential in HRCs baked from chlorinated flours.

2.8 Alternate Methods to Chlorination

Two directions can be taken to find alternate methods for chlorination. The first approach is to study the mechanisms of flour chlorination and find a way to mimic the action of chlorine on flour components. The other is to reformulate the methods for HRCs so that they will be able to maintain their volumes after baking without the use of chlorinated flour. At the present time, no adequate reformulation method has been reported. Various researchers have tried aging (Clements and Donelson 1982), heat treatment (Russo and Doe 1970), and use of other oxidizing agents (Terada et al 1982) to modify flour allowing them to bake cakes that are able to hold high ratios of sugar and shortening without collapse. All of these ventures met with some success, but none has been implemented in commercial milling of cake flour. This lack of change can be attributed to the fact that the industry currently is geared toward the use of chlorinated flour, and there are no strong forces pushing for change.

It is known that aging of flour produces cakes of quality similar to chlorinated flour (Hanson 1932). Exposure to air for extended periods of time allows atmospheric oxygen to depolymerize the flour components. In experiments by Clements and Donelson (1982), flour aged for nine to fourteen weeks at room temperature was compared to chlorinated flour. Cakes baked from aged flour exhibited expansions that were equivalent, if not greater, than the chlorinated controls. Studies by Seguchi (1993) indicate that aging a flour (202 days at 25^{0}C) resulted in a 3- to 4-fold increase in starch-granule surface proteins in comparison to the control samples. These results are similar to those of chlorinated starch-granule proteins by Seguchi (1990).

This aging process, however, is not practical for industrial use. Chlorinated flour produces a desirable flour relatively quickly, which is necessary in the fluctuating market facing today's baking companies. This advantage would be lost if companies had to wait for their flour to age. It is not feasible for companies to set aside space in order to store flour for three months while it slowly oxidizes. Furthermore this would allow time for molds and pests such as insects and rodents to contaminate the flour.

Heat treatment of flour is another alternative to chlorination. Russo and Doe (1970) used heated air to bring flour to 120°C which produced cakes that were superior to cakes baked from unchlorinated flour. Use of heated air increases the rate of oxidation, bringing about modification of the flour at a faster rate than aging. This method has potential for industrial use.

Gaseous ammonia as a chemical agent (to facilitate oxidation of the flour components) was used by Terada and co-workers (1982). Flour was placed in a desiccator containing aqueous ammonia for 48-76 hours. Flour from this treatment produced cake batters with increased viscosity and lower specific gravity than batters from untreated flours, and produced cakes with more uniform textures. However, cake volumes from ammonia-treated flours were no better than cake volumes produced from untreated flours. More work is required to determine if ammonia treatment is an acceptable alternative to chlorination relative to the quality of cakes produced and the possible health problems caused by ammonia treatment.

The alternate methods mentioned above have had some success in producing flour with properties similar to chlorinated flour, but have failed to be implemented by the industry. Use of those alternative methods seems to be prevented by time, money, and inferior results. More research is required to work out the problems associated with these alternate treatments.

2.9 Rheological Measurements of Chlorinated Flour

Chlorination alters the rheological properties of a flour, thereby giving it different characteristics. Instruments such as the alveograph, farinograph, mixograph, and viscoamylograph are currently used to evaluate the characteristics of flour for industrial use. The effects of different degrees of chlorination have not been studied to a great extent, but the use of these instruments may help to better clarify the effect chlorination has on flour rheology.

2.9.1 Chopin Alveograph

The Chopin alveograph measures the extent to which a disk of dough can be expanded as a bubble under pressure. Air pressure is applied to a piece of dough which is expanded in all directions (this is different than the uniaxial stretching of a Brabender farinograph) until it ruptures. Several values are used from the alveogram to determine the characteristics of the dough tested. Overpressure (P) is the maximum height of the alveogram multiplied by a factor of 1.1. This measurement has been criticized because the maximum height can vary from inconsistencies in the dough thickness (Hlynka and Barth 1955). Despite this criticism the P value is still used as an indicator of resistance to deformation by dough (AACC 1990, method 54-30).

The L value is the average length of the five curves on the alveogram from when the inflation began until the rupture of the bubble. From the L value, extensibility of a dough can be determined (Faridi and Rasper 1987). The P value divided by the L value yields a ratio which indicates the stability of the dough (Nemeth 1993). The G value is the square root of the volume of air needed to rupture the dough. This measurement has been used to indicate the degree of springiness and shortness of the dough (Nemeth 1993). The W value represents the amount of energy required to inflate the dough until it ruptures (Chopin 1927). This value was derived from the area under the curve (S). The alveograph is primarily used in the characterization of soft wheat flours in North America and of bread wheat flours in Europe.

2.9.2 Brabender Farinograph

The Brabender farinograph measures the mixing properties of a flour. Resistance of a dough to mixing is measured by two Z-shaped paddles, producing a curve from which the mixing potential of a dough can be determined. The following describes parameters obtained from a farinogram and their possible relationship to flour properties.

Optimum water absorption for a flour is determined by the percentage of water needed to produce a maximum resistance at 500 Brabender units (BU). This value is near the amount of water needed to develop optimum consistency of the dough for bread baking and tends to increase with increasing protein content in the flour (Shuey 1984a).

Arrival time is the time required, to the nearest half minute, for the top of the curve to reach the 500 BU line from the first addition of water. This measures the rate at which the flour can take up water; generally a decrease in arrival time is associated with an increase in protein content (by variety) of the flour (Shuey 1984b). Peak time (dough development time) is the amount of time, to the nearest half minute, needed to reach maximum consistency starting from the addition of water. This measurement has been correlated with the crude protein content of the flour by Markley and co-workers (1939) and indicates the relative strength of the flour (Pyler 1988).

Stability of a dough is determined by measuring the time from when the curve first climbs above the 500 BU line until the curve goes below the 500 BU line, to the nearest half minute. This value gives a good indication of a flour's tolerance to mixing (Shuey 1984b). Departure time is the time, to the nearest half minute, from the addition of water to when the top of the curve drops below the 500 BU line. Generally, the longer the departure time the stronger the flour (Shuey 1984b).

Mixing tolerance index (MTI) is the difference in BU from the middle of the curve at the peak resistance to the middle of the curve five minutes later. Flours with good tolerance to mixing have low MTIs while the converse is true for weaker flours. Breakdown time of a dough is measured from the addition of water until the curve drops 30 BU below the BU value at maximum consistency. This value is an indicator of the dough strength. A low breakdown value indicates a weak dough while a stronger flour will have a higher breakdown time. Use of this value has been criticized because it can vary greatly between operators (Shuey 1984a).

2.9.3 Mixograph

The mixograph measures a dough's resistance to mixing. A curve is produced which allows for the determination of dough characteristics. Measurements which can be read from the mixogram are: peak time (the time required for dough to reach optimum development), tolerance (width of the curve after two minutes of mixing), stability (time curve above the center line), and peak height (maximum height at the center of the curve). Finney and Yamazaki (1967) were able to predict optimal mixing time, loaf volume, oxidative requirement, and water absorption with the mixograph. Protein content of the flour appears to have the maximum effect in determining the mixograph pattern (Johnson and Swanson 1946). The sensitivity of this instrument is low, allowing it to aid in classifications of flours where fine distinctions are not required (Johnson and Swanson 1946).

2.9.4 Brabender Viscoamylograph

The viscoamylograph measures changes in a flour's viscosity and pasting properties during prolonged heating. Viscoamylograph readings can detect compositional changes in starch granules, such as hydrogen bond breakage, by measuring changes in the flour's gelatinization properties (Rasper 1980). Peak viscosity is the point where maximum viscosity is reached during heating regardless of temperature. This value is important because it determines the minimum cooking temperature in order to reach a useable consistency (Tipples 1980). Breakdown viscosity is measured after the paste has been held at 95°C for 30 minutes. This value indicates the stability of the starch during cooking (Tipples 1980). Setback value is the difference between the peak viscosity and breakdown viscosity. This value reflects the retrogradation potential of the flour (Tipples 1980). Setback viscosity is the viscosity measurement after the paste has been held at 50°C for 30 minutes. This value can be used as an indicator of the stability of the paste (Pomeranz 1987). Setback is the difference between the setback viscosity and peak viscosity. Total setback is the difference between the setback viscosity and peak viscosity.

2.10 Summary

Chlorine treatment chemically alters flour components through oxidation, imparting on them the ability to produce HRCs with desirable color, symmetry, and texture that does not collapse after baking. The process of chlorination could be discontinued in the U.S. as it has already been in most industrialized countries of the world due to the possible presence of carcinogens in the flour. Such a ban would be especially detrimental to cakes baked in the U.S. because Americans desire high levels of sugar and shortening in their cakes. High levels of sugar and shortening require strong internal cake structure to prevent collapse. Presently, only flour modified by chlorination can produce an internal structure strong enough to provide satisfactory results. Currently, alternative methods to chlorination are being developed with the hope that these methods can produce flours and cakes with properties that mimic those of chlorinated flours and cakes. However, a practical alternative has not yet been developed, and it is unlikely one will be, until the basis for chlorination's positive effect on cake-baking potential is uncovered. Thus, there is a need for more research in the area of chlorination so that mechanisms of flour chlorination can be better understood.

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Wheat Samples

Thirteen wheat samples from the 1992 and 1993 crops were used in this study. The nine varieties of the 1992 crop were Western-grown Club (Crew and Rely), Eastern Soft White (Frankenmuth), Western Soft White (Kmor and Lewjain), and Eastern Soft Red (Caldwell, Clark, Dynasty, and Excel). The four varieties of the 1993 were Club (Tres), Western Soft White (Lewjain), Eastern Soft White (Frankenmuth), and Eastern Soft Red (Dynasty). These varieties provided a broad range of genetic variability.

3.1.2 Chemicals

All were of reagent grade or better.

3.2 Methods

3.2.1 Milling and Chlorination

The wheat samples were milled and chlorinated at the USDA, ARS Soft Wheat Quality Laboratory (SWQL) in Wooster, Ohio. To ensure the wheat samples were not sprouted, alpha-amylase activity of each sample was determined according to AACC 22-06 by personnel from SWQL. All 13 samples were sound (data not shown). Grain was cleaned using a Carter dockage tester. After cleaning, the moisture content of wheat was determined according to AACC 44-15A (1990). The wheat was then tempered to 15% moisture basis (mb) using the moisture content data. The wheat was milled in a Miag mill with a 45% extraction rate. A portion of each flour was set aside to be used as an unchlorinated control, and two additional samples were chlorinated to pH 4.8 and 4.3 ± 0.1 according to (Kissell and Marshal 1972) by personnel from SWQL. A reactor box chlorinator (modified Wallace and Tiernan Laboratory Demonstrator) was used to chlorinate the flour. Low amounts of Rely pH 4.3 flour samples prevented its characterization with farinograph and viscoamylograph.

3.2.2 Analytical tests

3.2.2.1 Flour Ash Content

Flour ash content (14% moisture basis) was determined according to the AACC Approved Method (method 08-01, AACC 1990).

3.2.2.2 Flour Moisture Content

Flour moisture content (14% moisture basis) was determined according to the AACC Approved Method (method 44-15, AACC 1990).

3.2.2.3 Flour Protein Content

Protein Content was determined by micro-Kjeldahl according to the AACC Approved Method (method 46-13, AACC 1990).

3.2.2.4 Zeleney Sedimentation Volume

Zeleney Sedimentation Volume was determined according to the AACC Approved Method (method 56-61A, AACC 1990).

3.2.2.5 Alkaline Water Retention Capacity

Alkaline water retention capacity was determined according to the AACC Approved Method (method 56-10, AACC 1990).

3.2.3 Rheological Tests

3.2.3.1 Alveograph Test

Alveography was performed according to AACC Approved Method (method 54-30, AACC 1990).

3.2.3.2 Farinograph Test

Farinography was performed according to AACC Approved Method (method 54-21, AACC 1990).

3.2.3.3 Mixograph Test

Mixography was performed according to AACC Approved Method (method 54-40, AACC 1990).

3.2.3.4 Viscoamylograph Test

Viscoamylography was performed according to AACC Approved

Method (method 22-10, AACC 1990).

3.2.4 Baking Tests

3.2.4.1 High-ratio Cakes

The high-ratio cakes were baked according to AACC Approved Method (method 10-90, AACC 1990).

3.2.4.2 Japanese-sponge cakes

The Japanese-sponge cakes were baked according to Nagao et al (1976).

3.2.4.3 Cake Symmetry

The symmetries of cakes were measured according to AACC Approved Method (method 10-90, AACC 1990).

3.2.5 Statistical Analyses

In this study, determinations were made from the mean of 13 flour samples. For cakes, each variety was baked in duplicate and results averaged, while singular measurements for each sample were taken for rheological measurements. Mean, standard deviation, one factor ANOVA, and correlation were done using SuperANOVA software (Berkeley, CA). Mean separations were performed using Fisher protected LSD with mean square error term at 5% level of probability.

4 RESULTS AND DISCUSSION

4.1 Soft Wheat Flour Properties

4.1.1 Flour Protein Content

The flour protein contents, as determined by micro-Kjeldahl, of the 13 samples used in this study ranged from 6.6 to 8.7% (Table 1). This protein range of flour is suitable for products such as cakes and cookies. These products made from soft wheat flour have greater tenderness, softer texture and a more uniform internal structure than when made from hard wheat flour (Montzheimer 1931, Hoseney et al 1988).

4.1.2 Flour Ash Content

The ash content of the flour samples analyzed ranged from 0.27 to 0.40% (Table 1). This is within the acceptable ash content range (0.36 ± 0.04%) for a typical cake flour (Pyler 1988).

4.1.3 Flour Moisture Content

The moisture content of the flour samples ranged from 12.0 to 13.9% (Table 1). Moisture contents of good quality flours at acceptable extraction rates (70-75%) are usually within the 13-15% range. Very damp flour (>14.5% moisture) will not store well for more than a week or two due to increased microbial activity. Flours around 13% moisture content have better storage properties under cool dry conditions (Manley 1991).

Table 1. Ash, Moisture and Protein Contents of 13 Control Flour Samples

Variety	Ash* (%)	Moisture (%)	Protein* (%)
Fall 1992			
Rely	0.40	12.4	8.2
Crew	0.39	12.0	7.2
Kmor	0.37	12.2	7.8
Lewjain	0.39	12.2	7.9
Dynasty	0.30	12.2	7.5
Excel	0.30	12.4	7.3
Caldwell	0.30	12.4	6.7
Clark	0.36	12.3	7.3
Frankenmuth	0.40	12.2	8.2
Fall 1993			
Tres	0.39	13.4	8.7
Lewjain	0.28	13.9	8.1
Dynasty	0.27	13.9	7.9
Frankenmuth	0.29	13.9	6.6

* based on 14% moisture content

4.1.4 Alkaline Water Retention Capacity

The alkaline water retention capacity (AWRC) measures the amount of alkaline water held by flour at 14% moisture basis after centrifugation and is expressed as percent of flour weight (AACC 1990). It is a predictive test of general soft wheat quality. In this study, AWRC of flour samples analyzed ranged from 50.2 to 60.5% (Table 2). Two different trends appear between the 1992 and 1993 crops, however in this study, variations from chlorine treatment were the focus rather than varietal or environment differences. Yamazaki (1953) tested the cookie-baking potential of soft wheat flours with AWRC values from 40 to 60%. Optimum cookie baking was obtained from flours closer to 50% AWRC. The relation of AWRC to the cake-baking quality of a soft wheat flour has not been studied extensively in the literature. Low water absorption is an important quality factor of soft wheat flour since water absorption affects dough and batter viscosity during baking (Gaines 1986).

Results of AWRC demonstrated significant differences ($F= 9.68$, $p<0.05$) between the pH 4.3 flour and the other flour treatments (Figure 1). The AWRC values increased with increasing chlorine treatment, indicating that flour pH may have an influence on AWRC.

Table 2. Alkaline Water Retention Capacity (AWRC) of Unchlorinated and Chlorinated Flours*

Variety	AWRC (%)		
	Control Flour	pH 4.8 Flour	pH 4.3 Flour
Fall 1992			
Rely	53.4	54.8	58.3
Crew	52.2	55.5	58.8
Kmor	55.0	57.9	61.0
Lewjain	55.0	57.9	61.2
Dynasty	54.4	55.1	57.6
Excel	55.3	54.9	56.5
Caldwell	56.2	56.8	61.2
Clark	52.5	55.3	57.3
Frankenmuth	50.2	56.0	56.7
Fall 1993			
Tres	60.5	54.2	58.0
Lewjain	58.8	56.5	60.0
Dynasty	57.2	55.6	57.0
Frankenmuth	56.5	55.6	56.6

* based on 14% moisture content

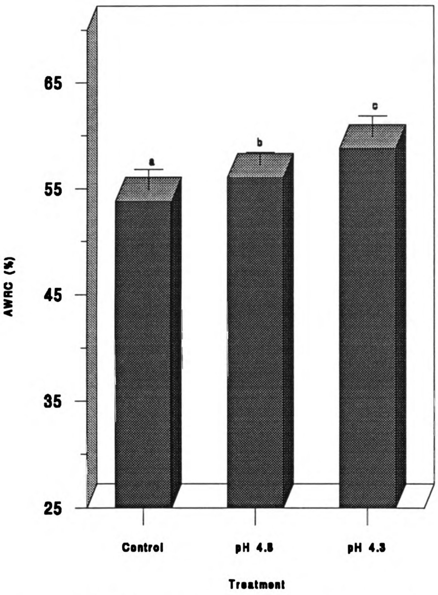

Figure 1. Effect of chlorination on alkaline water retention capacity (AWRC) of flour samples (average of 13 samples). Values with different letters are significantly different at the 5% level.

4.1.5 Zeleney Sedimentation Volume

The Zeleney sedimentation test measures sedimentation volume (predominantly swollen protein and occluded starch) of flour in dilute acetic acid (AACC 1990).
It reflects gluten strength of the tested flours. Values (in ml) vary from three for very weak wheat to seventy or more for very strong wheat (Halverson and Zeleney 1988). In this study, sedimentation volumes for flours analyzed ranged from 10.0 to 26.0 ml (Table 3). These values are typical for soft wheat flours (Halverson and Zeleney 1988).

Significant differences ($F= 6.09$, $p<0.05$) were observed between the control and chlorinated flours, but no significant differences were observed between the pH 4.3 and pH 4.8 flours (Figure 2). The control values were significantly higher than the chlorinated flour values suggesting that the gluten strengths of the flours were reduced by chlorination.

4.2 Rheological Properties of Unchlorinated and Chlorinated Flours

4.2.1 Alveograph Measurements

In this study, alveograph measurements for control, pH 4.8, and pH 4.3 flour samples ranged, respectively, as follows: the resistance to deformation values (P) ranged from 21.3 to 44.4 mm, 31.1 to 75.8 mm, and 53.3 to 103.7 mm; the extensibility (L) from 69.5 to 118.1 mm, 46.9 to 87.8 mm, and 22.2 to 47.2 mm; the stability (P/L) from 0.11 to 0.44, 0.36

Table 3. Zeleney Sedimentation Volumes of Unchlorinated and Chlorinated Flours*

Variety	Sedimentation Volume (ml)		
	Control Flour	pH 4.3 Flour	pH 4.8 Flour
Fall 1992			
Rely	17.0	14.7	14.7
Crew	12.5	11.7	11.7
Kmor	26.0	16.7	18.4
Lewjain	21.3	16.4	14.7
Dynasty	16.5	9.6	12.0
Excel	16.0	10.0	10.0
Caldwell	16.0	12.7	14.2
Clark	15.3	12.2	12.5
Frankenmuth	21.0	15.6	15.5
Fall 1993			
Tres	10.0	9.5	9.5
Lewjain	21.3	14.5	16.5
Dynasty	17.0	10.5	12.5
Frankenmuth	10.5	9.0	9.0

* based on 14% moisture content

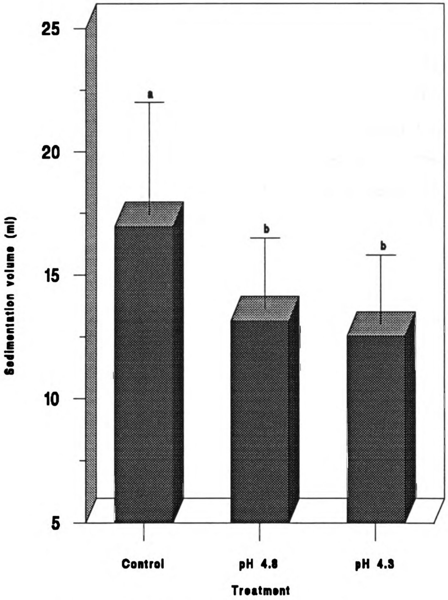

Figure 2. Effect of chlorination on sedimentation volumes of flour samples (average of 13 samples). Values with different letters are significantly different at the 5% level.

to 1.59, and 1.14 to 3.71; the swelling index (G) from 18.5 to 30.4 ml, 15.2 to 22.7 ml, and 10.8 to 15.5 ml; areas under the curve (S) from 6.5 to 19.1 cm^2, 11.4 to 21.0 cm^2, and 15.7 to 2.5 cm^2; and work of deformation (W) from 42.5 to 127.5, 58.9 to 137.3, and 49.7 to 163.7 Joules. Alveograph measurements for individual flour varieties are listed in Appendix I.

Alveograph results indicate significant differences ($p<0.05$) for P, L, P/L and G values for each flour treatment. These measurements primarily reflect the effect of chlorination in protein and starch components of flour. There may be oxidation of the sulfhydryl groups of the proteins (Bushuk and Hlynka 1962) and modification of the starch granules (Preston et al 1987).

The P values indicated significant differences ($F=37.41$, $p<0.05$) among all three flour treatments (Figure 3A), with the P values increasing with the degree of chlorination, indicating an increase in the dough's resistance to deformation with the degree of chlorination. The L values were significantly different ($F=57.33$, $p<0.05$) among all three treatments (Figure 3B) with the L value significantly decreasing as the degree of chlorination increased, indicating a loss in the dough's extensibility as the degree of chlorination increased. This increase in resistance and decrease in extensibility could be attributed to the oxidation of sulfhydryl groups by the chlorine and to modification of the starch. Bushuk and Hlynka (1962) have shown that the

Figure 3. Effect of chlorination on alveograph measurements of flour samples (average of 13 samples); A= resistance to deformation (P), B= extensibility (L), C= stability (P/L), D= swelling index (G), E= area (S), F= work of deformation (W); values with the same letter are not significantly different from each other at the 5% level.

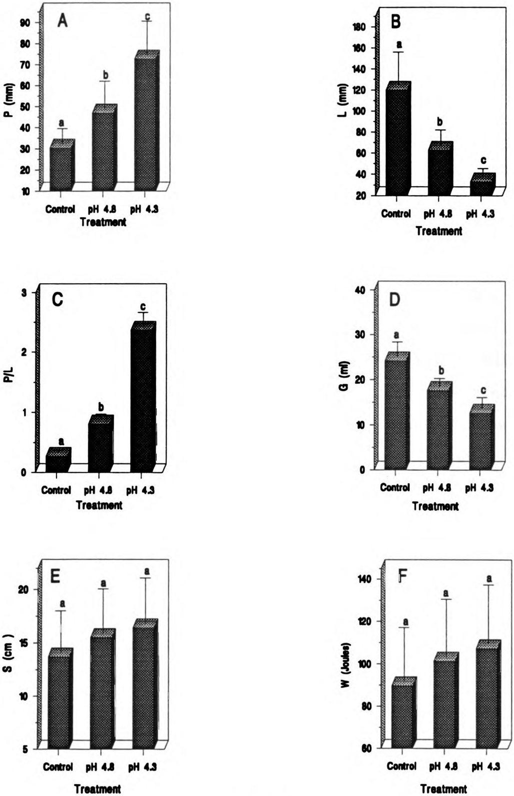
A
P (mm)
Control
pH 4.8
pH 4.3
Treatment
B
L (mm)
C
P/L
D
G (ml)
E
S (cm)
F
W (Joules)
a
b
c

Figure 3

addition of an oxidizing agent to hard wheat oxidized the sulfhydryl groups, increasing the dough's resistance and decreasing its extensibility. Research by Preston and co-workers (1987) has shown that damaged starch, which may be similar to chlorinated starch in structural depolymerization, causes increases in the dough's resistance (P) and decreases in its extensibility (L).

The P/L and G values are indicators of a dough's stability and swelling index, respectively. The P/L ratios were significantly different ($F=54.46$, $p<0.05$) among flour treatments (Figure 3C). This value increased significantly ($p<0.05$) as the degree of chlorination increased, indicating that the dough's stability increased with chlorine treatment. Preston and co-workers (1987), however, reported that this value decreased with increased starch damage. This discrepancy in the literature may be due to modification of the flour proteins by chlorination which did not occur in Preston and co-workers (1987) damaged starch study.

The G values decreased significantly ($F=67.16$, $p<0.05$) as the degree of chlorination increased (Figure 3D). The decrease in G values suggests a loss of dough extensibility with chlorination (Kent-Jones and Amos 1967). Preston and co-workers (1987) found that increased starch damage or decreased water absorption (section 4.2.2) would result in lower G values; both of these were seen in results of chlorinated flours in this study.

No significant differences ($p<0.05$) were seen among the flour treatments for S (Figure 3E) and W (Figure 3F) values. Both of these values increased as the degree of chlorination increased.

The above results from alveograph measurements indicate that chlorination affected properties of the flour proteins and starches resulting in increased stability, increased resistance and decreased extensibility of cake dough with increased chlorine treatment.

4.2.2 Farinograph Measurements

In this study, farinograph measurements for control, pH 4.8, and pH 4.3 flour samples ranged, respectively, as follows: the water absorption from 48.3 to 54.2%, 48.5 to 55.9%, and 49.3 to 57.0%; the peak time from 0.7 to 2.0 minutes, 0.2 to 1.5 minutes, and 1.0 to 1.5 minutes; the stability from 1.4 to 9.2 minutes, 1.1 to 3.3 minutes, and 1.4 to 2.8 minutes; and the mixing tolerance index from 100 to 210 BU, 50 to 210 BU, and 75 to 210 BU. Measurements for individual flour varieties are listed in Appendix II.

Water absorption values increased significantly ($F=14.63$, $p<0.05$) between the control and chlorinated flours (Figure 4A). Farrand (1964) reported that damaged starch can absorb much more water than undamaged starch. It is likely that chlorination affected starch components in a similar way.

Figure 4. Effect of chlorination on farinograph measurements of flour samples (average of 13 samples); A= water absorption, B= peak time, C= stability, D= mixing tolerance; values with the same letter are not significantly different from each other at the 5% level.

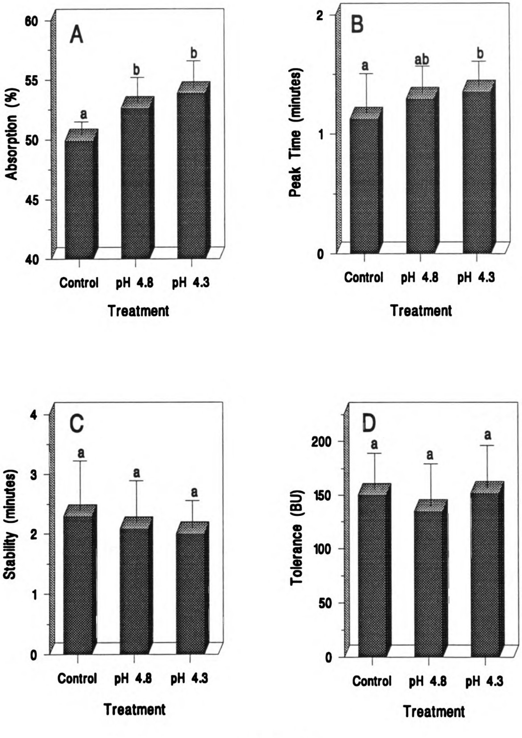
A
Absorption (%)
60
55
50
45
40
a
b
b
Control
pH 4.8
pH 4.3
Treatment
B
Peak Time (minutes)
2
1
0
a
ab
b
Control
pH 4.8
pH 4.3
Treatment
C
Stability (minutes)
4
3
2
1
0
a
a
a
Control
pH 4.8
pH 4.3
Treatment
D
Tolerance (BU)
200
150
100
50
0
a
a
a
Control
pH 4.8
pH 4.3
Treatment

Figure 4

The results of this study are in agreement with Hoseney (1986) who reported an increase in water uptake by chlorinated starch granules.

Pyler (1988) correlated peak time values with flour protein strength of a flour . In this study, peak time values were significantly different ($F= 2.45$, $p<0.05$) between the control flour and pH 4.3 flour (Figure 4B); the pH 4.8 flour was not significantly different ($p<0.05$) from the other two treatments. Meredith and Bushuk (1962) observed that oxidizing agents increase the time required to reach farinograph peak time in hard wheat. They postulated that the increase was due to the oxidation of sulfhydryl groups by the oxidizing agent. No significant difference ($p<0.05$) was observed for stability (Figure 4C) and tolerance (Figure 4D) among the flours. However, the stability showed a decreasing trend with increasing chlorination, while the tolerance data showed no trends at all.

4.2.3 Mixograph Measurements

In this study, mixograph measurements for control, pH 4.8, and pH 4.3 flour samples ranged, respectively, as follows: the peak time from 1.1 to 5.1 minutes, 0.8 to 4.2 minutes, and 0.5 to 4.5 minutes; the peak height from 30 to 50 mm, 31 to 47 mm, and 32 to 44 mm; the stability from 1.4 to 9.2 minutes, 1.1 to 8.0 minutes, and 1.3 to 5.6 minutes; and the tolerance from 3.0 to 10.0 mm, 3.0 to 6.0 mm, and 2.0 to 5.0 mm. Mixograph measurements for individual flour varieties are listed in Appendix III.

Mixograph results indicate significant differences ($p<0.05$) between the control and chlorinated flours for tolerance, and between control and pH 4.3 flours for peak time. Significant decreases ($F=3.320$, $p<0.05$) for peak time between control and pH 4.3 flours were observed, while the pH 4.8 flour was not significantly different ($p<0.05$) from the other two treatments (Figure 5A). Peak times show a decreasing trend with increasing chlorination. Constant additions of water to flour treatments with increasing farinograph water absorption (see section 4.2.2) may account for the decrease in peak time. If the gluten proteins are not fully hydrated they do not reach maximum consistency, thus affecting the peak time values (Hoseney 1986).

Tolerance measurements show significant differences ($F=10.01$, $p<0.05$) between the control and chlorinated flours with no significant difference ($p<0.05$) seen between the two chlorinated treatments (Figure 5B). This decrease in tolerance may also be due to insufficiently hydrated gluten proteins. No significant difference ($p<0.05$) among the flours was demonstrated for stability (Figure 5C) or peak height (Figure 5D). Observations of mixograms suggest that the flour components have been modified by chlorination. Further research needs to be done to differentiate between component modifications and water absorption. The results are

Figure 5. Effect of chlorination on mixograph measurements of flour samples (average of 13 samples); A= peak time, B= tolerance, C= stability, D= peak height; values with the same letter are not significantly different from each other at the 5% level.

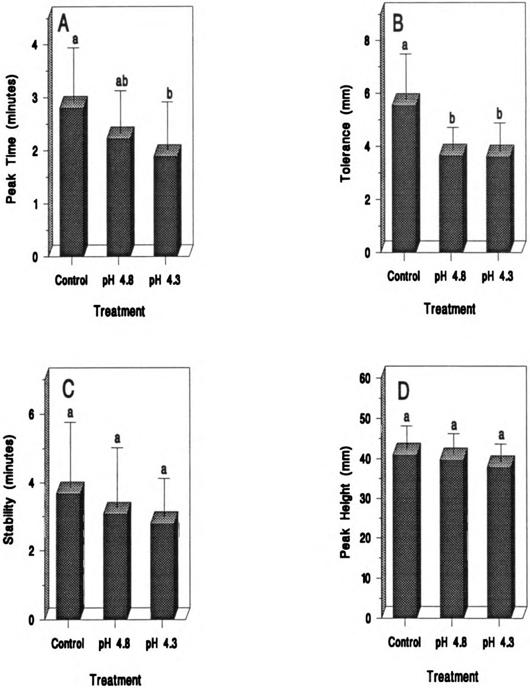
A
Peak Time (minutes)
a
ab
b
0
1
2
3
4
Control
pH 4.8
pH 4.3
Treatment
B
Tolerance (mm)
a
b
b
0
2
4
6
8
Control
pH 4.8
pH 4.3
Treatment
C
Stability (minutes)
a
a
a
0
2
4
6
Control
pH 4.8
pH 4.3
Treatment
D
Peak Height (mm)
a
a
a
0
10
20
30
40
50
60
Control
pH 4.8
pH 4.3
Treatment

Figure 5

similar to findings from the farinograph studies in section 4.2.2.

4.2.4 Viscoamylograph Measurements

In this study, viscoamylograph measurements for control, pH 4.8, and pH 4.3 flour samples ranged, respectively, as follows: the peak viscosity from 370 to 1090 BU, 375 to 1175 BU, and 1030 to 1390 BU; the break viscosity from 330 to 870 BU, 325 to 875 BU, and 670 to 890 BU; the breakdown from 30 to 280 BU, 30 to 385 BU, and 220 to 675 BU; the setback viscosity from 820 to 1680 BU, 810 to 1820 BU, and 1285 to 1690 BU; the setback from 450 to 790 BU, 435 to 905 BU, and -5 to 390 BU; and the total setback from 490 to 875 BU, 485 to 970 BU, and 470 to 850 BU. Measurements for individual flour varieties are listed in Appendix IV.

Contrary to results in this study, Miller and co-workers (1973) found that chlorine treatment of flour results in a drastic decrease in a flour's viscosity. A significant increase in viscosity ($p<0.05$) between the pH 4.3 and control flours for setback, breakdown viscosity, breakdown, and peak viscosity but no significant increase between the pH 4.8 and control flours was observed. The results are in agreement with Variano-Marston (1985) who reported that the viscosity of a flour increases with chlorination, and Kulp et al (1972) who observed that the pasting and gelling properties of chlorinated starch exhibited few changes in their viscoamylograms until starch from heavily chlorinated flour was used. However, Miller and co-workers (1973) reported decrease in viscosity with chlorination.

Significant increases ($F=22.04$, $p<0.05$) in peak viscosity between the pH 4.3 and the other two treatments were noted, while the control and pH 4.8 treatments were practically identical (Figure 6A). This suggests that in the pH 4.3 flour, the starch was modified to an extent where its viscosity was significantly higher than the other two treatments. Chlorination has been reported to increase the swelling rate of starch (Variano-Marston 1985), but increased swelling does not affect viscosity (Miller et al 1973). Increased viscosity has been observed to be undetectable in chlorinated flour until it is heavily chlorinated (Kulp et al 1972).

The breakdown viscosities from the pH 4.3 flour were significantly higher than those from the other treatments ($F=3.32$, $p<0.05$), with the control and pH 4.8 flours being very similar (Figure 6B). This increased viscosity may suggest that the pH 4.3 starch would be more stable (Tipples 1980) during cooking than the other two treatments. Breakdown measurements for the pH 4.3 flour were also significantly higher ($F=37.48$, $p<0.05$) than those from the other two treatment flours, with the pH 4.8 flour being slightly higher than the control flour (Figure 6C). This could suggest that the pH 4.3 flour has better retrogradation properties than the

Figure 6. Effect of chlorination on viscoamylograph measurements of flour samples (average of 13 samples); A= peak viscosity, B= breakdown viscosity, C= breakdown, D= setback, E= setback viscosity, F= total setback; values with the same letter are not significantly different from each other at the 5% level.

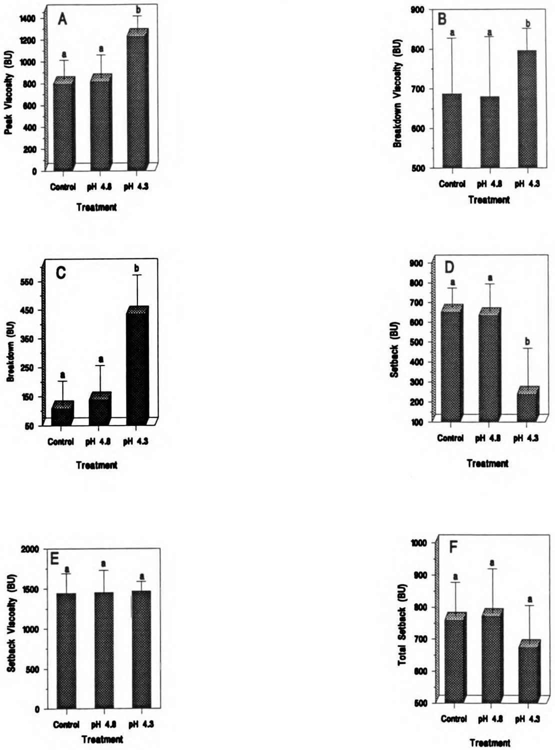
A
Peak Viscosity (BU)
1400
1200
1000
800
600
400
200
0
Control pH 4.8 pH 4.3
Treatment
B
Breakdown Viscosity (BU)
900
800
700
600
500
Control pH 4.8 pH 4.3
Treatment
C
Breakdown (BU)
550
450
350
250
150
50
Control pH 4.8 pH 4.3
Treatment
D
Setback (BU)
900
800
700
600
500
400
300
200
100
Control pH 4.8 pH 4.3
Treatment
E
Setback Viscosity (BU)
2000
1500
1000
500
0
Control pH 4.8 pH 4.3
Treatment
F
Total Setback (BU)
1000
900
800
700
600
500
Control pH 4.8 pH 4.3
Treatment

Figure 6

other two treatments (Tipples 1980). The oxidizing nature of chlorine could oxidize bulky hydroxyl groups on the starch molecule to less bulky carboxyl or aldehydic groups which can reassociate faster allowing for improved retrogradation properties (Rasper 1980).

The setback measurements show a significant ($F=27.91$, $p<0.05$) decrease for the pH 4.3 treatment compared to the other two treatments, with no significant difference ($p<0.05$) seen between the pH 4.8 and control flours (Figure 6D). This may suggest the pH 4.3 flour has a greater stability than the other two treatments which is a reflection of its improved retrogradation properties. The setback viscosity (Figure 6E) and total setback (Figure 6F) show no significant differences ($p<0.05$) between flour treatments. Differences in the viscoamylograph data indicate that the starch in the pH 4.3 chlorinated flour has been modified to a greater extent than the other two treatments, causing differences in the pasting ability of the starch.

4.3 Baking Results

4.3.1 High-Ratio Cakes

The high-ratio cake (HRC) formula (AACC 10-90) was designed to measure a flour's cake-baking potential. This formula contains shortening, and higher levels of sugar and water than the Japanese-sponge cake formulation (4.3.2).

Cakes of this type yield optimum volumes when made from flours chlorinated between pH 4.7-4.9 (Hoseney 1986).

Nine varieties of the 1992 flour samples were used for baking at SWQL, and subsequently there were inadequate amounts remaining of these samples for baking at Michigan State University (MSU). The four varieties of 1993 flour samples were used for baking at MSU. Due to the differences in baking location, the results will be statistically analyzed separately.

Cake measurements for control, pH 4.8, and pH 4.3 flour samples ranged, respectively, as follows: the volume of cakes baked at Wooster from 801 to 909 ml, 899 to 1006 ml, and 853 to 951 ml; the volumes of cakes baked at MSU from 915 to 1029 ml, 970 to 1043 ml, and 918 to 980 ml; the volume index for MSU HRCs from 8.15 to 10.4 cm, 10.6 to 12.55 cm, and 9.6 to 10.5 cm; and the symmetry index for MSU HRCs from 0.55 to 0.35 cm, 0.35 to 0.45 cm, and 0.3 to 7.6 cm. Volume index and symmetry index measurements were not taken for the HRCs baked at Wooster. Measurements for individual flour varieties are listed in Appendices V and VI.

The nine cake samples baked in Wooster demonstrated significant differences ($F=3.43$, $p<0.05$) between the pH 4.8 flours and the other flour treatments: the control and pH 4.3 flours produced cakes that were significantly lower in volumes ($p<0.05$) (Figure 7A). Peak cake volumes were obtained for the pH 4.8 flours in comparison to the other two treatments.

Figure 7. Effect of chlorination on high-ratio cake measurements of flour samples (average of 13 samples); A= volume of cakes baked at SWQL, B= volume of cakes baked at MSU (Michigan State University), C= volume index of cakes baked at MSU; values with the same letter are not significantly different from each other at the 5% level.

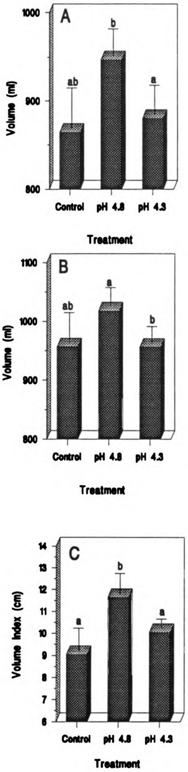
A
1000
900
800
Volume (ml)
ab
b
a
Control
pH 4.8
pH 4.3
Treatment
B
1100
1000
900
800
Volume (ml)
ab
a
b
Control
pH 4.8
pH 4.3
Treatment
C
14
13
12
11
10
9
8
7
6
Volume Index (cm)
a
b
a
Control
pH 4.8
pH 4.3
Treatment

Figure 7

Cakes baked from the four flour samples at MSU demonstrated significant differences in volumes ($F=3.43$, $p<0.05$) between the pH 4.8 and pH 4.3 flours, while cakes produced from the control flours were not significantly different from cakes produced from the chlorinated flours (Figure 7B). A peak volume was obtained from the pH 4.8 flour, but it was not significantly different from the control flours. A higher volume index was obtained for the cakes baked from chlorinated flours (at MSU) compared to the control flour (Figure 7C). No significant differences were observed between the flour treatments in the symmetry index for MSU baked cakes (data not shown). The control flours produced a cake with lower volume and poorer symmetry (dipped center), while the pH 4.3 flours produced cakes with lower volumes. The pH 4.8 flour produced peak volumes for the HRC's baked at MSU and SWQL, indicating that pH 4.8 is an optimum degree of chlorination for production of AACC 10-90 HRCs with optimum volume and symmetry. These results are in agreement with findings from Montzheimer (1931), Bohn (1934), and Hoseney (1986) that peak volumes were obtained from flour chlorinated to a pH of approximately 4.8.

4.3.2 Japanese-Sponge Cake

Japanese-sponge cake (JSC) has a simple formula which consists of a 1:1:1 ratio of sugar, egg, and flour. This formula is similar to ones currently being used in Japan, where the use of chlorinated flour has been discontinued.

In this study, cake measurements for control, pH 4.8, and pH 4.3 flour samples ranged, respectively, as follows: the volumes from 1050 to 1205 ml, 965 to 1068 ml, and 958 to 1145 ml; the volume index from 18.8 to 20.5 cm, 17.9 to 19.7 cm, and 17.34 to 20.55 cm; and the symmetry index from 0 to 1.25 cm, 0.7 to 1.7 cm, and 0.9 to 1.3 cm. Measurements for individual flour varieties are listed in Appendix VII.

Volumes of Japanese-sponge cakes were significantly different ($F=13.58$, $p<0.05$) between the unchlorinated and chlorinated flours. There was no significant difference ($p<0.05$) between the average cake volumes of pH 4.3 and pH 4.8 flours (Figure 8A). The volume index shows that the cakes baked from the control flours had significantly higher ($F=24.62$, $p<0.05$) volume indices than the cakes baked from the chlorinated flours (Figure 8B). However, the symmetry index showed that the control flour had significantly lower ($p<0.05$) symmetry than the cakes produced from chlorinated flours (Figure 8C). Peak volumes were obtained for the control flours but better symmetry was obtained from the chlorinated flours. In this study, Japanese-sponge cakes exhibited significant differences ($p<0.05$) in volume index and symmetry index among the control flours and treated flours at both levels.

Figure 8. Effect of chlorination on Japanese sponge cake measurements of flour samples (average of 13 samples); A= volume, B= volume index, C= symmetry index; Values with the same letter are not significantly different at 5% level.

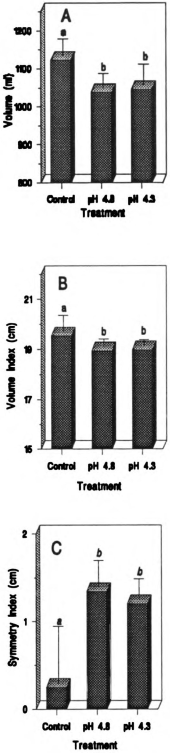
A
1200
1100
1000
900
800
Volume (ml)
a
b
b
Control
pH 4.8
pH 4.3
Treatment
B
21
19
17
15
Volume Index (cm)
a
b
b
Control
pH 4.8
pH 4.3
Treatment
C
2
1
0
Symmetry Index (cm)
a
b
b
Control
pH 4.8
pH 4.3
Treatment

Figure 8

The chlorination appears to have modified the flour so that it constrains the volume of the JSC, yet provides enough internal structure to produce a rounded top in comparison to the flat or dipped peaks of the control flour cakes. The constraints on the volume in the cakes produced from chlorinated flour could be attributed to the increased resistance in flour proteins and starches which were observed with the alveograph P measurements (Figure 3A). In contrast to high-ratio cakes, Japanese-sponge cakes do not need flour chlorinated to pH 4.8 to bake cakes of optimum volumes, but the symmetry of cakes produced from unchlorinated flour is inferior to cakes baked from the chlorinated flour. An astringent odor was also observed in the JSCs produced from the chlorinated flours.

4.4 Relationship Among Technological and Baking Data

4.4.1 Correlations with Volumes of High-Ratio Cakes Baked at SWQL.

The volumes of high-ratio cakes baked at SWQL correlated significantly with: mixograph peak time ($p<0.05$, $r=0.42$); viscoamylograph break viscosity ($p<0.05$, $r=0.42$); and AWRC ($p<0.05$, $r=0.55$). Break viscosity is the only measurement that is constant between the HRCs baked at the two different locations (i.e., SWQL and MSU). This may indicate that the increased retrogradation potential of the starch measured by the break viscosity correlates with the volume of HRCs. Faster retrogradation of the starch may contribute to the increased structural strength observed in cakes baked from chlorinated flour. The correlation of AWRC with volume could be a useful indicator of a soft wheat flour's cake-baking potential. Higher AWRCs enable the flour to produce optimal HRCs. Research needs to be done to establish windows for low (underchlorinated) or high (overchlorinated) AWRCs that will not produce optimum HRCs. The correlation with mixograph peak time could reflect the different water absorptions of the flour treatments under constant additions of water.

4.4.2 Correlations with Volumes of High-Ratio Cakes Baked at MSU.

The volumes of high-ratio cakes baked at MSU correlated significantly with: alveograph P value ($p<0.05$, $r=0.63$), viscoamylograph peak viscosity ($p=0.02$, $r=0.65$), and break viscosity ($p<0.05$, $r=0.38$). The viscosity measurements indicate the gelatinization and pasting properties of chlorinated starch play an important role in the production of HRCs of optimum volume. The correlation of the alveograph P value also indicates the importance of modified starch and protein in HRC production.

4.4.3 Correlations with Volumes of Japanese-Sponge Cakes

The volumes of Japanese sponge cakes correlated significantly with: alveograph P value ($p<0.05$, $r=0.47$), L value ($p<0.001$, $r=0.58$), P/L value ($p<0.01$, $r=0.42$), G value ($p<0.001$, $r=0.57$); farinograph water absorption ($p<0.05$, $r=0.34$); mixograph tolerance ($p=<0.04$, $r=.04$); viscoamylograph peak viscosity ($p<0.01$, $r=0.48$), breakdown viscosity ($p<0.05$, $r=0.38$), and breakdown ($p<0.05$, $r=0.44$). The alveograph measurements appear to be good indicators of the volume of Japanese-sponge cakes under the given experimental conditions. These values reflect the modifications of the starches and proteins by chlorination and the contribution of these components to JSC volume. Farinograph water absorption indicates the importance of the hydration of the starch and protein in JSC volume. Viscosity measurements show the importance of the modified starch components to cake volume as was also seen in the HRCs. Positive correlations between mixograph tolerance to JSC were also observed.

5. GENERAL DISCUSSION

The purpose of this study was to observe the rheological and baking properties among 13 varieties of unchlorinated and chlorinated (pH 4.8 and 4.3) soft wheat flours. Functional properties of the flours were determined with analytical and rheological tests. Modifications to the flour's components (proteins and starches) account for the differences observed in the results of these tests. Baking potentials of the flours were determined using high-ratio and Japanese-sponge cake formulas, which are markedly different in their formulation, resulting in cakes with different volumes and indices from chlorinated flour in comparison to unchlorinated flours.

The properties of the soft wheat flour samples were determined for protein content, ash content, moisture content, alkaline water retention capacity, and Zeleney sedimentation volume. The protein, ash and moisture contents for these flours fell within the acceptable parameters for soft wheat flours used for cake production. Chlorinated flours, because of their high alkaline water retention capacity, would not be suitable for cookie baking (Yamazaki 1953). The relationship between AWRC and cake-baking potential has not been extensively reported in the literature. Sedimentation volumes decreased with chlorination indicating that protein strength decreases with increasing chlorination. This is in agreement with Bass (1988) who observed that gluten strength weakened with chlorination. The transfer of gluten proteins to the starch-granule surface of chlorinated starch, causing a 3- to 4-fold increase in the amount of proteins on the starch granule (Seguchi 1993), may contribute to the weakening of the gluten strength evidenced by Zeleney sedimentation volumes.

The rheological properties of the flour samples were measured by the alveograph, farinograph, mixograph and viscoamylograph. Past research using these instruments (Bushuk and Hlynka 1962, Meridith and Bushuk 1962, and Preston et al 1987) has primarily focused on hard wheat varieties. These studies used oxidizing agents other than chlorine on the hard wheat samples, but their results are in agreement with the results of this study.

Alveograph results indicate significant increases in resistance (P) and extensibility (L) with increasing chlorination. These results are in agreement with Bushuk and Hlynka (1962) who found increases in resistance and decreases in extensibility (an extensograph was used) of hard wheat flours with the addition of an oxidizing agent (N-ethylmaleimide). The increase in resistance indicates an increase in dough strength with chlorination. This discrepancy between results of alveograph and sedimentation measurements may be attributed to the oxidation of sulfhydryl groups by chlorination increasing dough strength. Results similar to this were observed by Tsen and Kulp (1971). By increasing the number of disulfide bonds in the dough the resistance of the dough increased with chlorination.

Farinograph results indicate significant increases in water absorption between control and chlorinated flours, and significant increases in peak height between control and pH 4.3 flours. The increased water absorption can be attributed to the modification of chlorinated starch (Variano-Marston 1985). This increased water absorption for chlorinated flour may also have an effect on mixograph results where a constant amount of water is added. Increased farinograph peak time from the control to pH 4.3 flour may be due to similar reasons as the increase in alveograph P value.

Mixograph results indicate a significant decrease in peak time between the control and pH 4.3 flours, and in tolerance between control and chlorinated flours. The decrease in peak time contradicts the farinograph peak time measurements. This may be due to the difference in water absorptions between the treatments. The chlorinated flour would require higher levels of water for the flour to reach optimum resistance to mixing, but constant additions of water (mixograph) to all treatments may cause a decrease in the peak time values for the chlorinated flours. The decrease in tolerance to mixing with chlorination conflicts with the increased stability in the alveograph (P/L) measurements. This difference may be attributed to the mixograph's lack of sensitivity toward starch, like the alveograph, and may reflect the decreasing protein strength seen from sedimentation volumes.

Viscoamylograph results indicated significant differences between the pH 4.3 flours and the other treatments for peak viscosity, breakdown viscosity, breakdown and setback. Kulp and co-workers (1972) found that the pasting and gelation properties were not altered greatly until the flour was heavily chlorinated. This agrees with our experimental results where significant changes were not observed until the flour was overchlorinated (pH 4.3). Differences between the pH 4.8 and control flours may be detectable if the viscoamylograph were run in a high sucrose environment similar to a HRC batter.

High-ratio cakes (AACC 10-90) can be used as an indicator of baking quality for soft wheat flour. This formula is typical of an American high-ratio cake which contains higher levels of sugar, shortening and water than Japanese-sponge cake. The advent of chlorination allowed for the development of these types of cakes, and chlorination is necessary to produce high-ratio cakes of optimum volume and symmetry. Past research by Montzheimer (1931) confirms experimental results that optimum volumes and symmetry were obtained from the pH 4.8 flour. Modification of the flour proteins and starches as indicated by the sedimentation and rheological tests contribute to this improvement causing increased swelling and interactions among the flour components (Kulp et al 1972).

Japanese-sponge cake formula, with its low levels of sugar and no shortening added, allow this cake formula to produce optimum cake volumes from unchlorinated flour or possibly a flour chlorinated to a lesser degree than in this study. This formula contains a high proportion of eggs in comparison to high-ratio cakes. The additional amount of eggs may form a stabilizing network when the eggs are coagulated during baking (Guy and Pithawala 1981), lending structural support to the cake and helping to maintain its volume. This support along with lower amounts of shortening and sugar in comparison to high-ratio cakes allow the Japanese-sponge cake to produce optimum volumes from unchlorinated flours. Unchlorinated flours produced optimum volumes with this formula but the symmetry of cakes produced from the unchlorinated flours were inferior to cakes baked from chlorinated flours. Unchlorinated cakes had flat tops and some were even slightly dipped in comparison to the dome shaped cakes produced from the chlorinated flours. Chlorination appeared to constrain cake volume but also allows for a stronger internal cake structure which may be due to increasing resistance from the proteins, and interactions of the modified starch granule surface with the other flour components.

6. SUMMARY

1. Sedimentation volumes indicate a weakening of the gluten proteins with chlorination. Chlorination appears to oxidize the gluten proteins possibly allowing them to associate with the starch-granule surface.

2. Alkaline water retention capacity (%) increased with chlorination. This increase correlated with the volumes of high-ratio cakes (HRCs). Currently the relationship between AWRC (%) and cake volume has not been extensively reported in the literature.

3. Alveograph measurements indicated modification to starches and proteins causing increased resistance (P) and stability (P/L), and decreasing extensibility (L) and elasticity (G). These trends are consistent with other researchers who studied the effect of other oxidizing agents on these properties in hard wheat and the effect of starch damage on hard wheat.

4. Farinograph measurements showed increased water absorption and increased peak times in chlorinated flours. The increase in water absorption is most likely due to modification of the starch granules. Increased

water absorption with chlorination was in agreement with previously reported findings. Increased peak times may be attributed to modifications to the starch and protein components of chlorinated flours.

5. Mixograph measurements showed significant decreases in peak time and tolerance with chlorination. The decrease in peak time which conflicts with farinograph peak times may be attributed to the constant addition of water to treatments with increasing water absorptions which prevented complete hydration of the flour proteins. The decrease in tolerance may be due to decreases in the protein strength that were seen in the sedimentation volumes.

6. Viscoamylograph measurements indicated significant changes in the starch components gelling and pasting properties of the pH 4.3 flour. These results are in agreement with past research which observed significant changes in a starch's gelling and pasting properties when it was overchlorinated.

7. High-ratio cakes had peak volume and symmetry when baked from the pH 4.8 flours. These results are in agreement with past research which found optimum HRCs were baked from flour chlorinated to about pH 4.8.

8. Japanese-sponge cakes (JSCs) produced optimum volumes from unchlorinated flours but better symmetry was observed for the cakes produced from chlorinated flours. The lower sugar, shortening and water levels and higher egg content in comparison to the HRC formula allow unchlorinated flours to produce optimum JSC volumes. However, differences in formulations do not allow unchlorinated flours to maintain optimum symmetry in their cakes as was seen for the chlorinated flours.

7. Future Studies

1. Future studies should look into viable alternatives to chlorine treatment because of its potential carcinogenic effect.
2. Chlorine treatment has a profound effect on the starch component of a flour. Chlorination results in increased surface hydrophobicity of the starch granule and increased water absorption via depolymerization of the granule. Creating a modified starch with these properties and substituting the starch from an unchlorinated flour with this modified starch would be a study of interest.
3. Reformulation of high-ratio cake (HRC) is also an area where future research can be focused. Modification of HRC formula ingredients which weaken the internal structure of the HRC (e.g. shortening and sugar) along with the addition of strengthening agents (e.g. egg whites and gums) would be another way to replace chlorinated flour. The use of different ingredients may allow the HRC to maintain its volume, symmetry and internal structure, imparted by chlorinated flour.

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9. Appendices

Appendix I. Alveograph Measurements for Unchlorinated and Chlorinated Flours

Variety	P (mm)			L (mm)			P/L			G (ml)			S (cm²)			W (Joules)		
	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3
Fall 1992																		
Rely	37.1	53.9	66.9	133.5	61.5	31.5	0.28	0.88	2.22	25.7	17.4	12.4	14.9	16.6	14.6	97.0	108.5	95.5
Crew	35.5	40.7	62.3	69.5	47.8	27.6	0.51	0.85	2.26	18.5	15.4	11.7	9.5	10.0	11.3	62.0	65.1	74.0
Kmor	35.3	55.2	84.7	153.7	53.8	27.8	0.22	1.03	3.05	27.6	16.2	11.5	17.0	17.0	17.5	111.0	111.4	114.5
Lewjain	30.6	59.4	75.9	113.2	57.0	27.0	0.27	1.04	2.81	23.6	16.7	11.6	13.8	17.3	14.6	90.0	113.1	95.6
Dynasty	24.1	33.9	59.7	128.0	89.0	49.0	0.19	0.38	1.22	25.1	20.8	15.5	11.1	14.8	15.7	76.0	96.5	102.7
Excel	22.0	31.9	58.3	146.0	87.8	42.3	0.15	0.36	1.29	26.8	20.8	15.0	11.2	13.7	17.3	73.0	89.9	113.4
Caldwell	36.2	55.2	87.6	108.5	52.5	23.6	0.33	1.05	3.71	23.1	16.0	10.8	16.7	19.6	17.9	109.0	128.1	116.9
Clark	29.8	45.3	73.3	110.5	59.6	31.0	0.27	0.76	2.36	23.3	17.0	12.3	13.8	16.3	19.4	90.0	106.7	127.1
Frankenmuth	31.9	51.9	93.8	128.0	70.8	35.0	0.25	0.73	2.68	25.2	18.6	13.1	19.1	22.4	25.0	125.0	146.3	163.7
Fall 1993																		
Tres	24.2	37.8	53.8	75.2	57.0	22.2	0.32	0.66	2.42	19.2	16.8	10.5	6.5	9.0	7.6	42.5	58.9	49.7
Lewjain	44.4	75.8	103.7	108.6	47.8	29.7	0.41	1.59	3.49	23.1	15.4	12.3	19.5	21.0	20.7	127.5	137.3	135.4
Dynasty	21.3	31.1	53.7	188.1	83.6	47.2	0.11	0.37	1.14	30.4	22.7	15.2	15.0	12.5	16.5	98.1	81.8	107.9
Frankenmuth	22.9	37.8	68.3	95.3	46.9	32.8	0.24	0.81	2.08	21.7	15.2	12.7	10.0	11.4	15.0	65.4	74.6	98.1
Average	30.4	46.9	72.7	119.8	62.7	32.8	0.27	0.81	2.36	24.1	17.6	12.7	13.7	15.5	16.4	89.7	101.4	107.3
Std. Dev.	7.2	13.1	15.8	32.1	15.2	8.5	0.10	0.34	0.81	3.3	2.4	1.6	3.9	4.1	4.3	25.3	27.0	27.9
Range	21.3-44.4	31.1-75.8	53.3-103.7	69.5-188.1	46.9-87.8	22.2-47.2	0.110.44	0.36-1.59	1.14-3.71	18.5-30.4	15.2-22.7	10.8-15.5	6.5-19.1	21.0-11.4	15-2.5	42.5-127.5	58.9-137.3	49.7-163.7

P= resistance to deformation, L= extensibility, P/L= stability, G= swelling, S= area, W= energy
C= control flour, 4.8= pH 4.8 flour, 4.3= pH 4.3 flour

Appendix II. Farinograph Measurements for Unchlorinated and Chlorinated Flours

Variety	Water Absorption (%)			Peak Time (minutes)			Stability (minutes)			Mixing Tolerance Index (BU)		
	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3
Fall 1992												
Rely	49.2	53.5	NA	2.0	1.5	NA	3.5	1.8	NA	100	120	NA
Crew	51.8	52.6	53.3	1.0	1.3	1.0	2.5	1.8	1.8	150	120	135
Kmore	48.9	53.8	54.8	1.0	1.5	1.5	2.0	1.6	2.3	160	150	150
Lewjain	50.1	55.9	57.0	1.5	1.5	1.5	3.0	1.8	2.0	110	160	130
Caldwell	50.9	51.7	53.2	1.2	0.9	1.0	1.7	3.3	2.8	160	50	75
Excel	50.1	52.8	54.2	1.0	1.3	1.5	2.0	2.0	1.6	190	130	170
Dynasty	49.8	55.0	56.4	1.0	1.5	1.5	1.5	2.0	1.8	210	120	150
Clark	49.3	53.4	54.6	1.0	1.5	1.3	3.5	2.0	2.3	120	110	210
Frankenmuth	48.9	54.0	55.4	1.0	1.1	1.5	3.0	2.5	2.2	160	110	130
Fall 1993												
Tres	51.0	51.6	53.7	1.0	1.1	1.1	1.3	1.1	1.2	160	160	210
Lewjain	51.4	52.2	54.0	1.1	1.5	1.5	1.7	3.3	2.4	115	160	150
Dynasty	49.0	49.0	50.2	1.0	1.3	1.3	3.0	2.8	2.3	130	180	210
Frankenmuth	48.3	48.5	49.3	0.7	1.0	1.0	1.1	1.1	1.4	185	210	190
Average	49.9	52.6	53.8	1.1	1.3	1.4	2.3	2.1	2.0	150	135	152
Std Dev	1.1	2.1	2.2	0.3	0.2	0.2	0.8	0.7	0.5	33	39	39
Range	48.3-54.2	48.5-55.9	49.3-57.0	0.7-2.0	0.2-1.5	1.0-1.5	1.1-3.5	1.1-3.3	1.4-2.8	100-210	50-210	75-210

C= Control Flour, 4.8= pH 4.8 Flour, 4.3 =pH 4.3 Flour
NA= Not enough sample; sample lost at Wooster

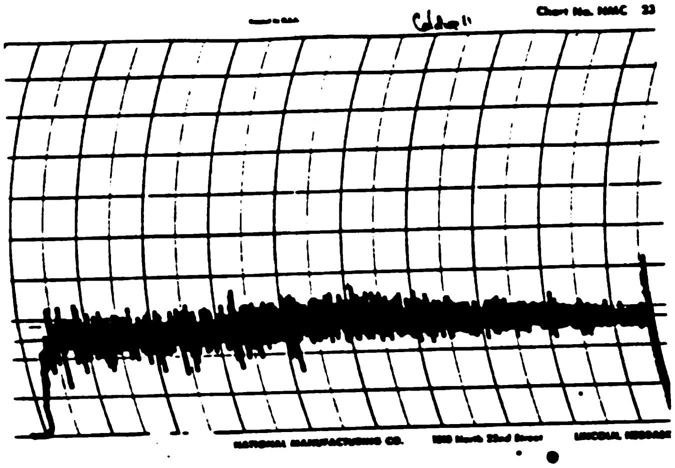
Appendix III. Mixograph Measurements for Unchlorinated and Chlorinated Flours

Variety	Peak Time (minutes)			Peak Height (mm)			Stability (minutes)			Tolerance (mm)		
	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3
Fall 1992												
Rely	2.1	1.9	2.0	43	43	40	2.5	2.5	2.1	5	5	4
Crew	2.1	1.9	1.8	41	38	32	3.1	2.6	2.1	6	3	3
Kmor	2.7	2.2	2.3	47	45	42	1.8	1.8	2.5	4	4	3
Lewjain	2.2	1.9	1.3	50	47	44	2.5	1.8	1.8	4	3	3
Dynasty	2.5	1.8	1.8	41	38	38	4.0	2.6	2.3	5	3	3
Excel	2.0	1.9	1.7	39	38	36	3.3	2.4	2.0	5	3	2
Caldwell	5.1	4.2	4.5	32	33	32	9.2	8.0	5.6	10	6	5
Clark	3.7	2.2	1.5	42	37	35	4.0	5.0	4.0	6	3	3
Frankenmuth	2.5	2.0	1.9	46	42	40	3.5	3.2	2.6	7	4	4
Fall 1993												
Tres	1.1	0.8	0.5	43	44	43	1.4	1.1	1.3	3	3	4
Lewjain	3.7	2.9	1.6	43	45	42	3.5	3.0	3.4	6	4	6
Dynasty	3.5	2.3	1.3	35	35	35	4.7	2.7	2.7	6	3	4
Frankenmuth	3.2	2.9	2.3	30	31	32	4.3	3.8	3.9	5	4	3
Average	2.8	2.2	1.9	41	6	38	3.7	3.1	2.7	6	4	4
Std. Dev.	1.0	0.8	0.9	6	2	4	1.9	1.7	1.1	2	0.85	1
Range	1.1-5.1	0.8-4.2	0.5-4.5	30-50	3-10	32-44	1.4-9.2	1.1-8.0	1.3-5.6	3-10	3-6	2-5

C= Control flour, 4.8= pH 4.8 flour, 4.3 = pH 4.3 flour

Farinograms of unchlorinated and chlorinated flours from Caldwell 1992 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.

1



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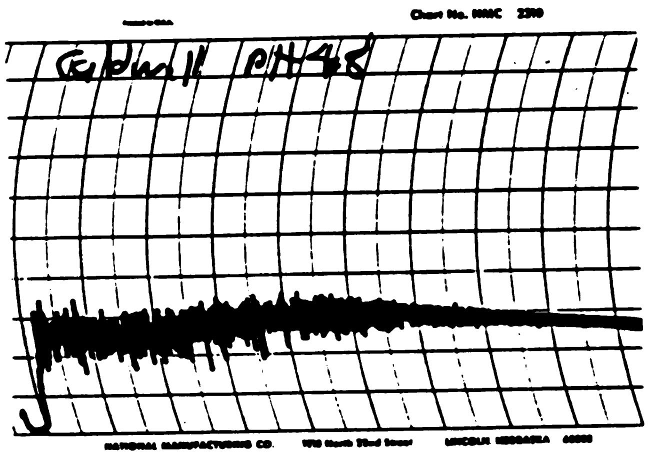

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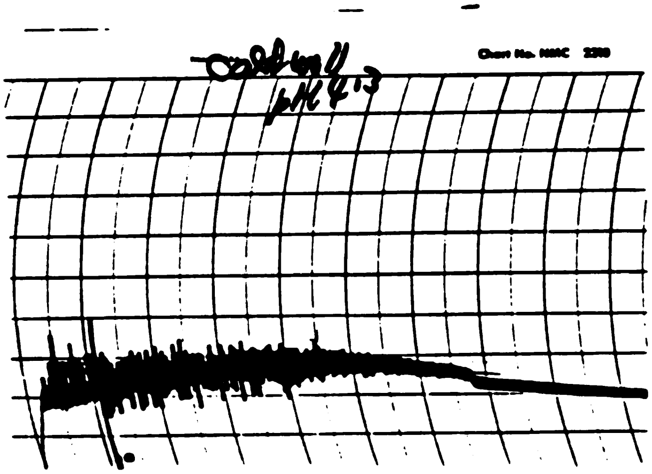
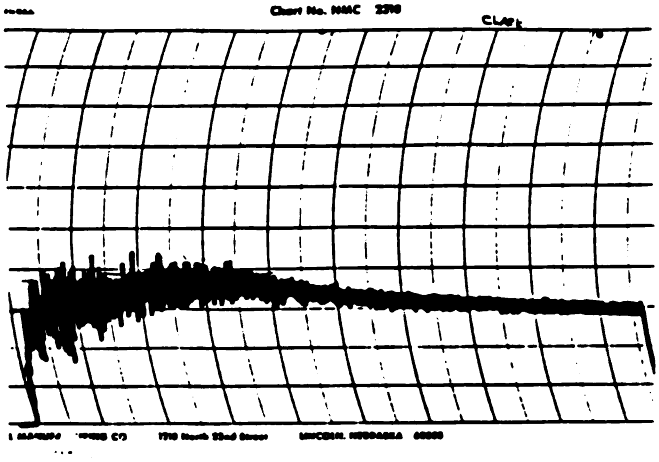


Farinograms of unchlorinated and chlorinated flours from Clark 1992 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.

1



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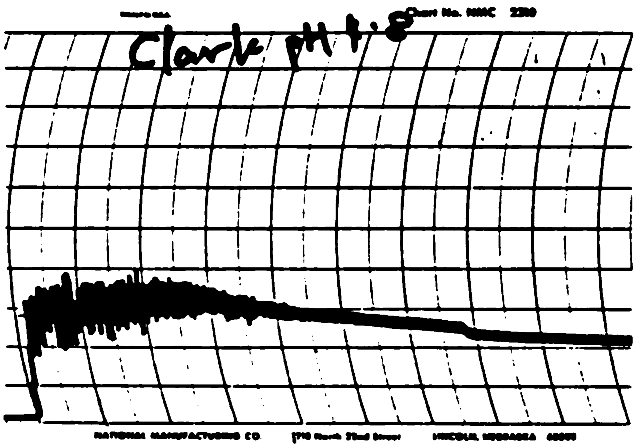

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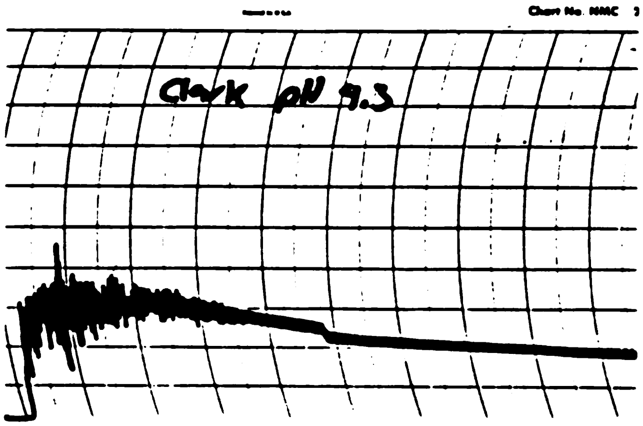
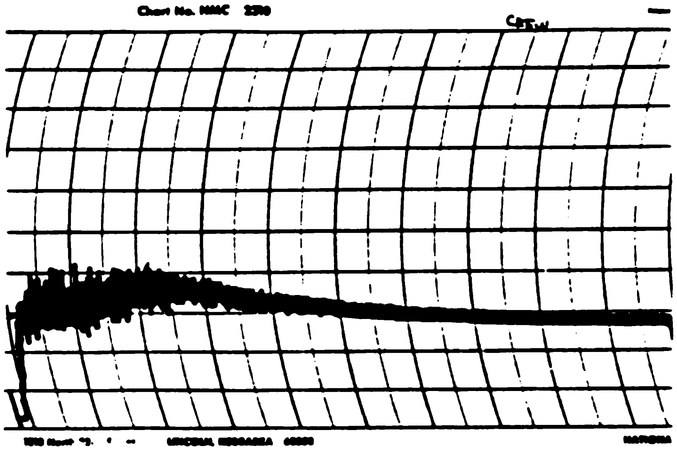


Farinograms of unchlorinated and chlorinated flours from Crew 1992 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.

1



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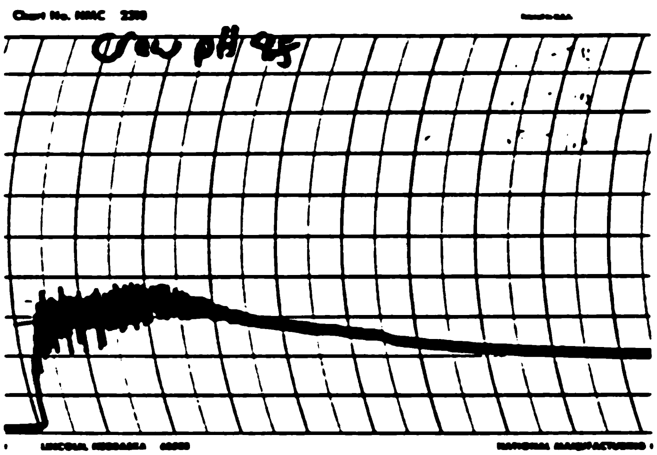

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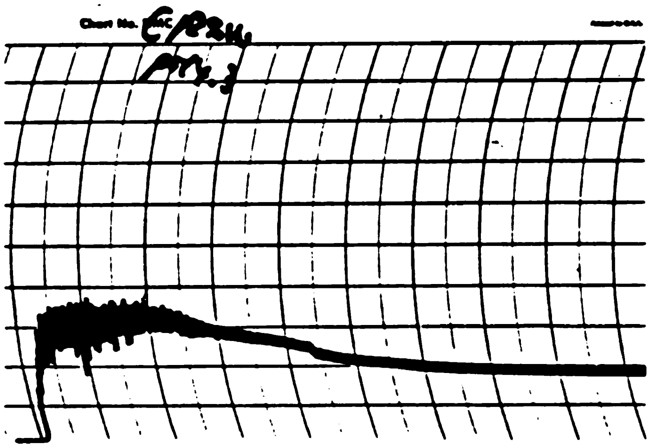
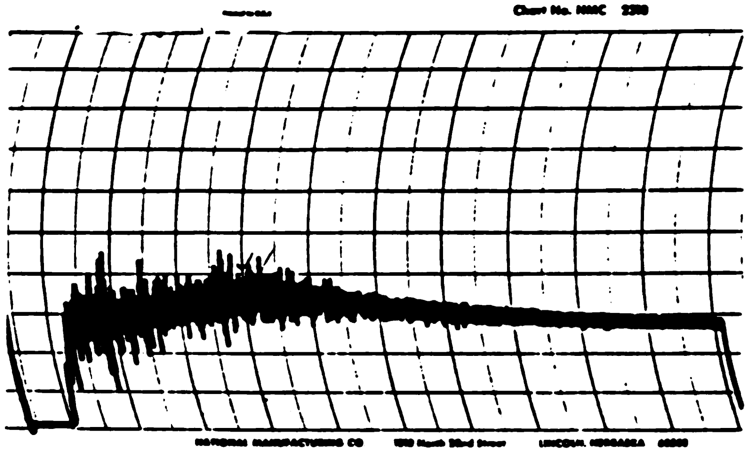


Farinograms of unchlorinated and chlorinated flours from Dynasty 1992 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.

1



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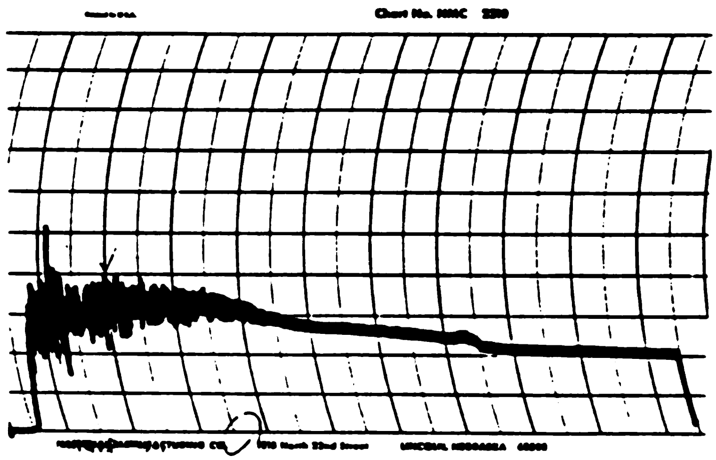

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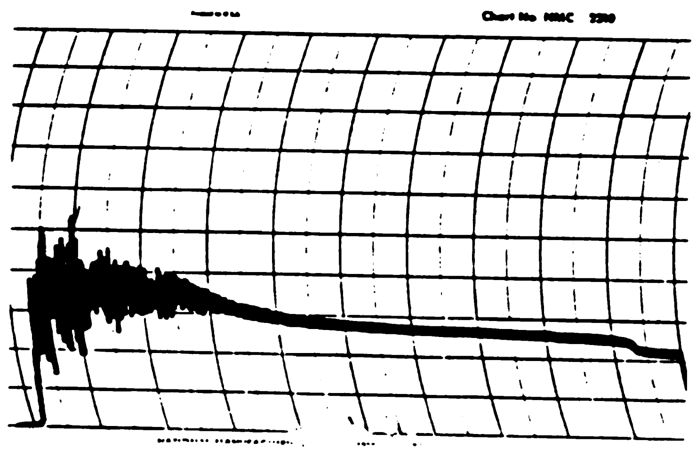
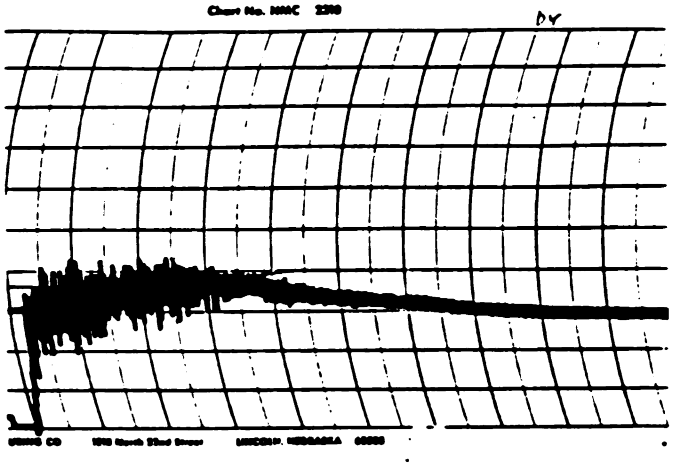


Farinograms of unchlorinated and chlorinated flours from Dynasty 1993 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.

1



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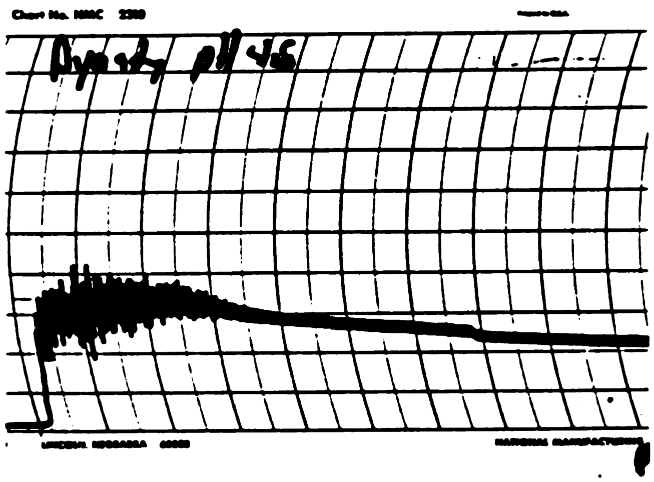

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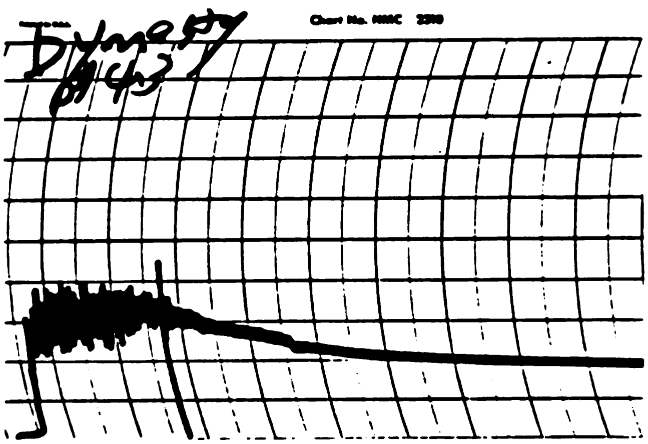
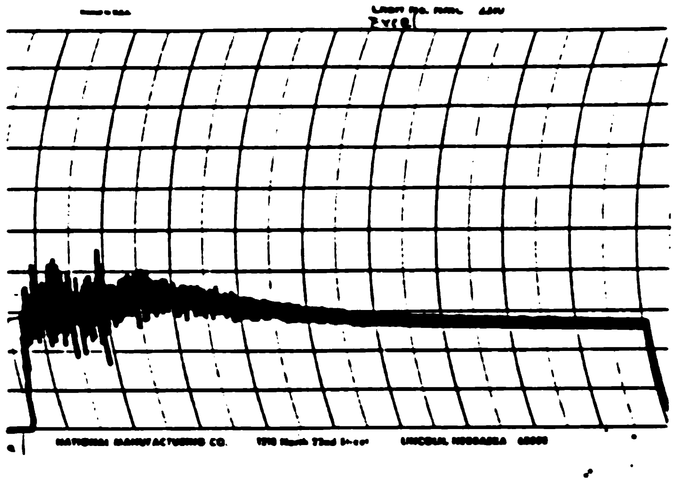


Farinograms of unchlorinated and chlorinated flours from Excel 1992 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.

1



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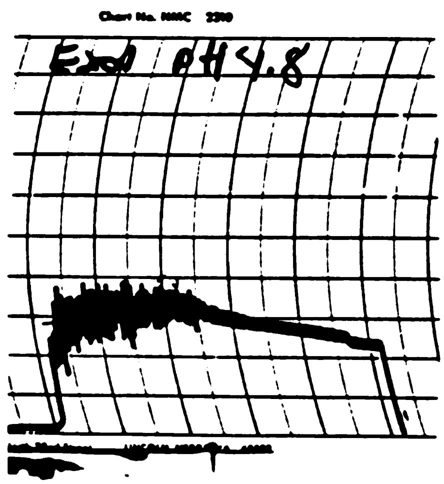

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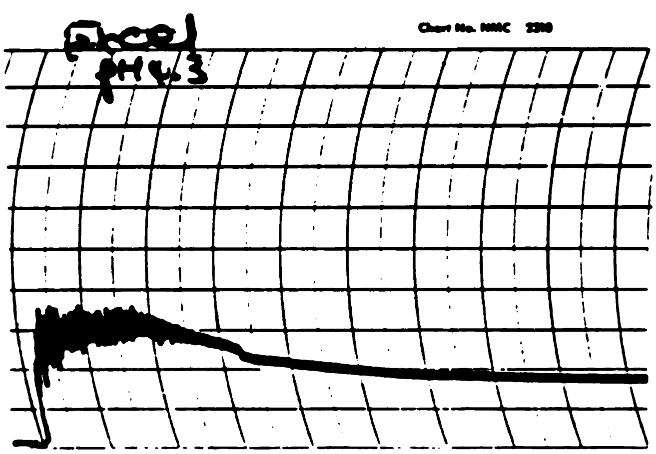
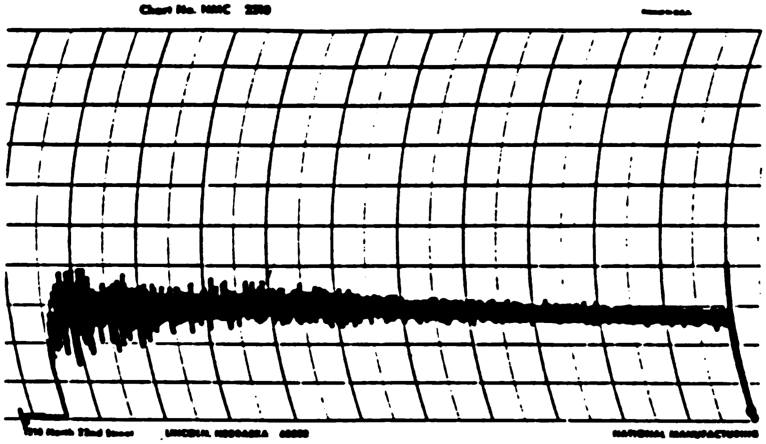


Farinograms of unchlorinated and chlorinated flours from Frankenmuth 1992 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.

1



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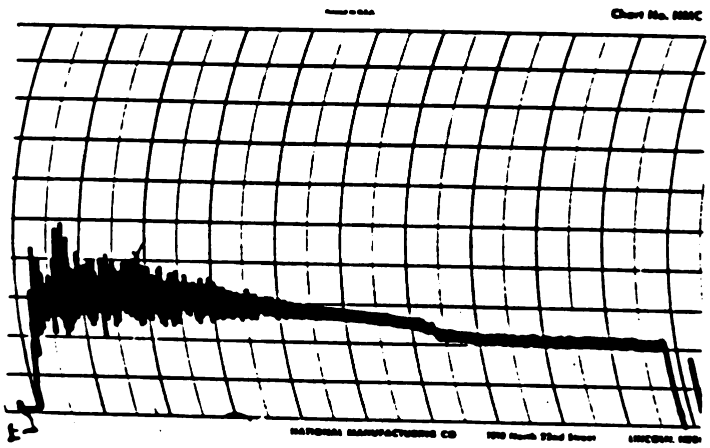

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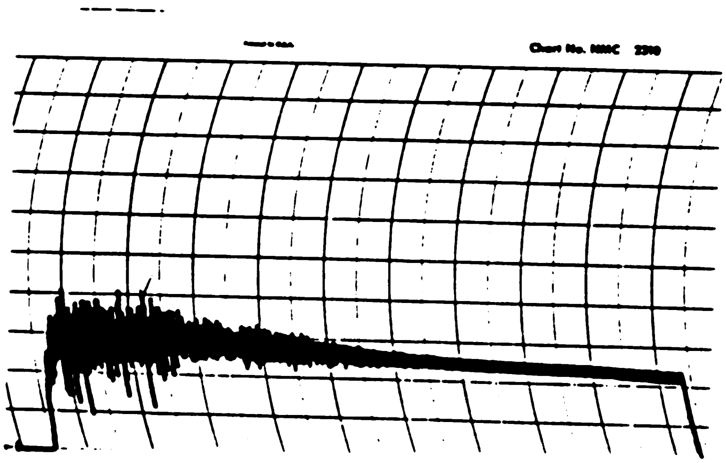
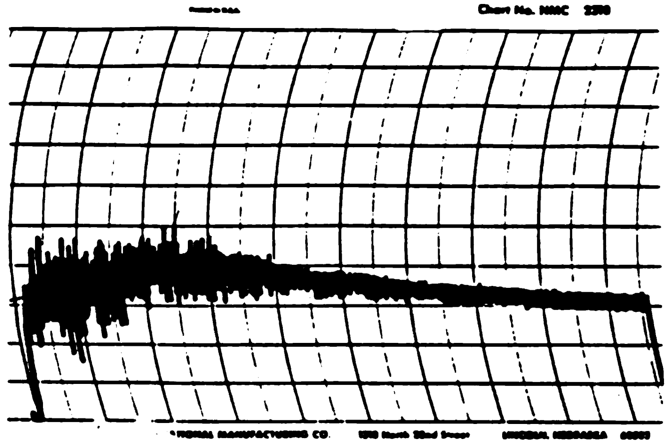


Farinograms of unchlorinated and chlorinated flours from Frankenmuth 1993 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.

1



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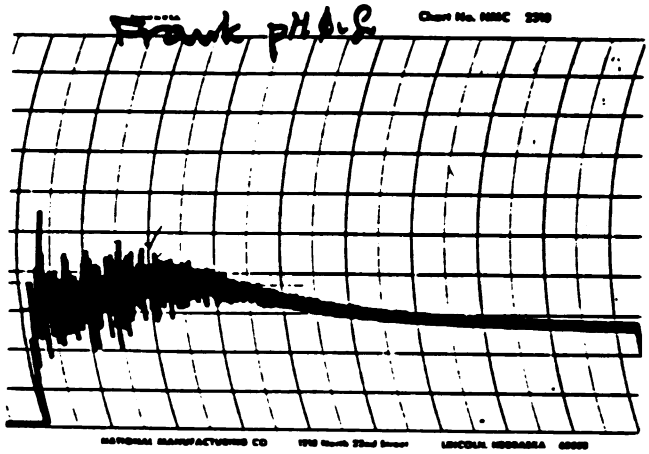

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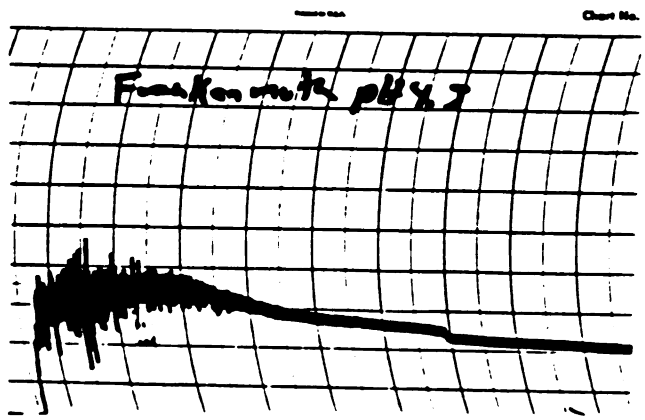
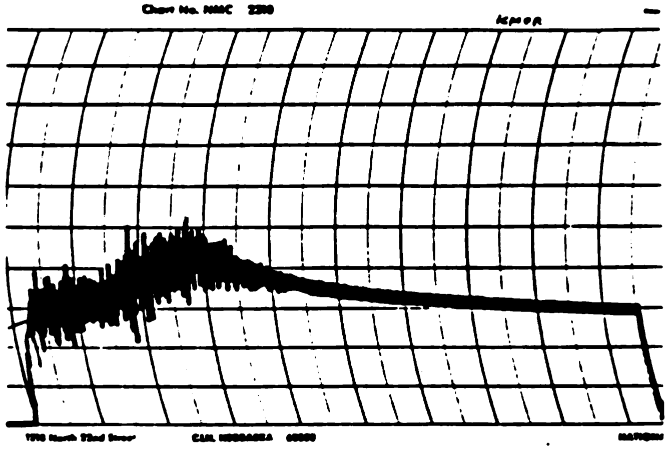


Farinograms of unchlorinated and chlorinated flours from Kmor 1992 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.



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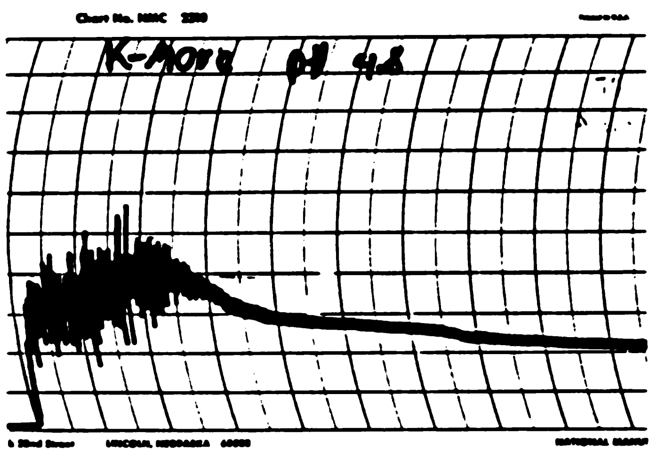
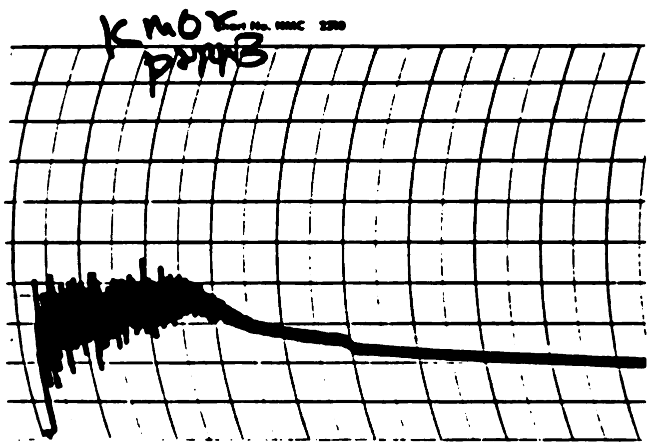


2



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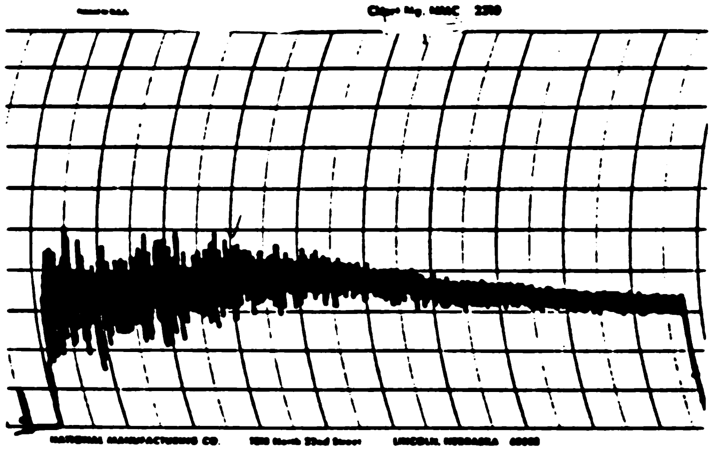
Farinograms of unchlorinated and chlorinated flours from Lewjain 1992 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.



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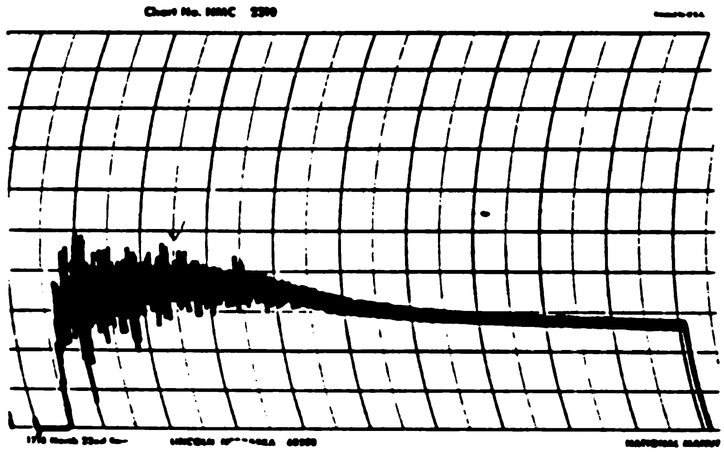

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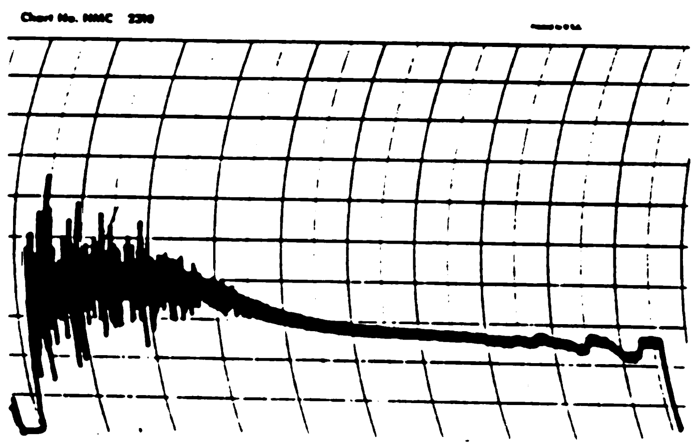

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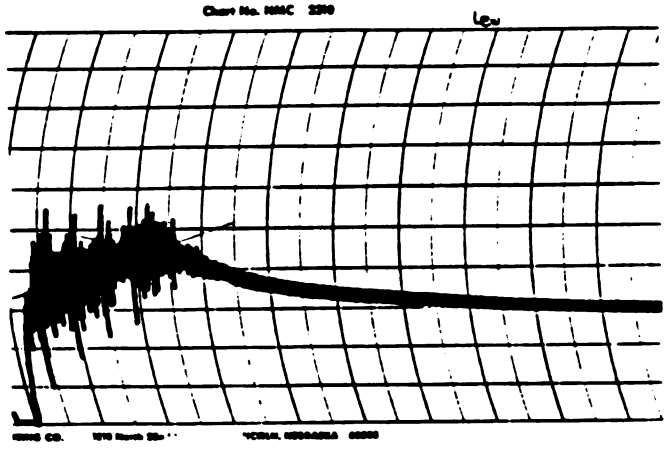
Farinograms of unchlorinated and chlorinated flours from Lewjain 1993 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.



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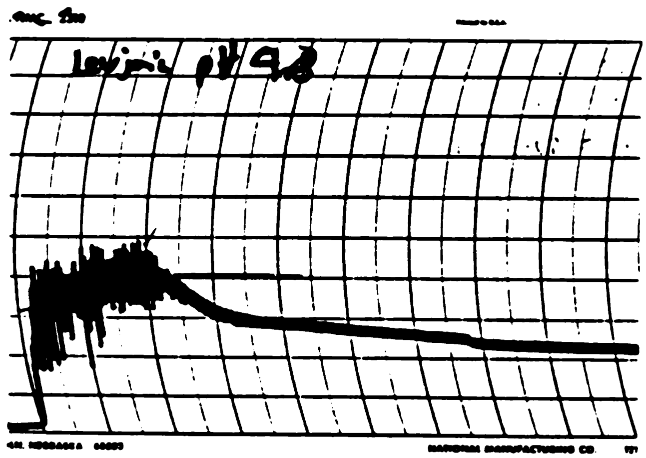

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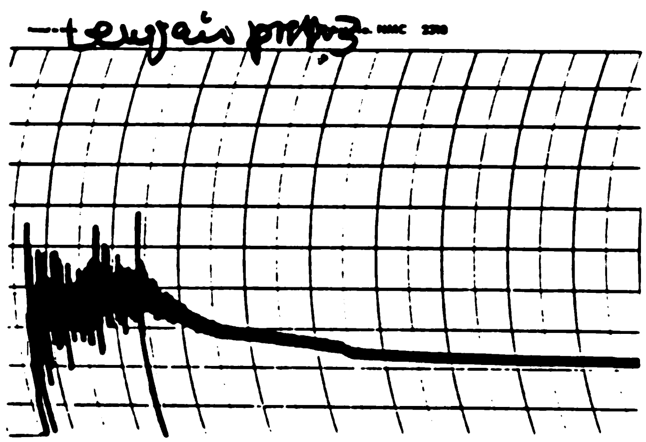

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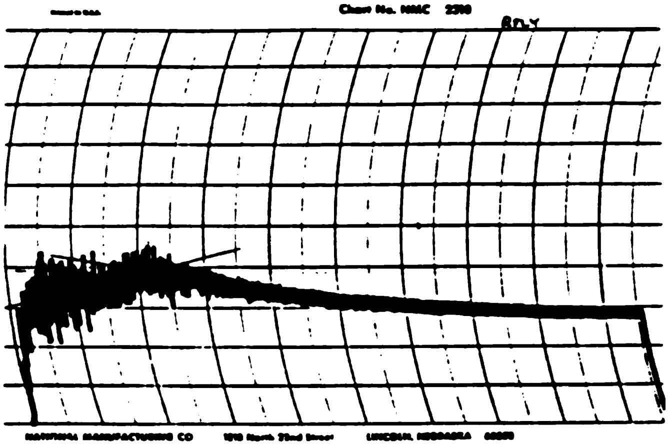
Farinograms of unchlorinated and chlorinated flours from Rely 1992 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.



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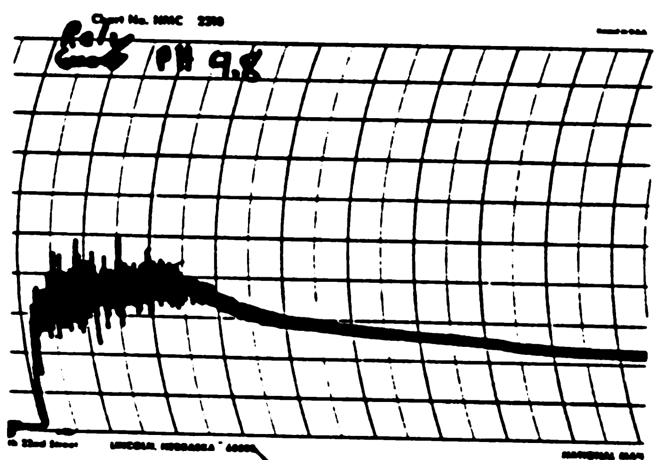

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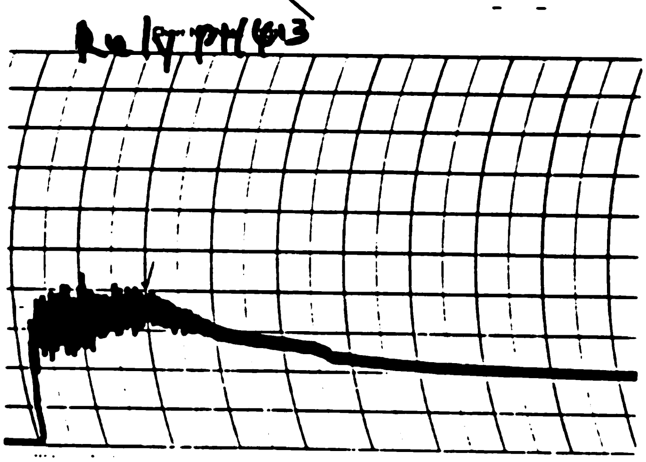
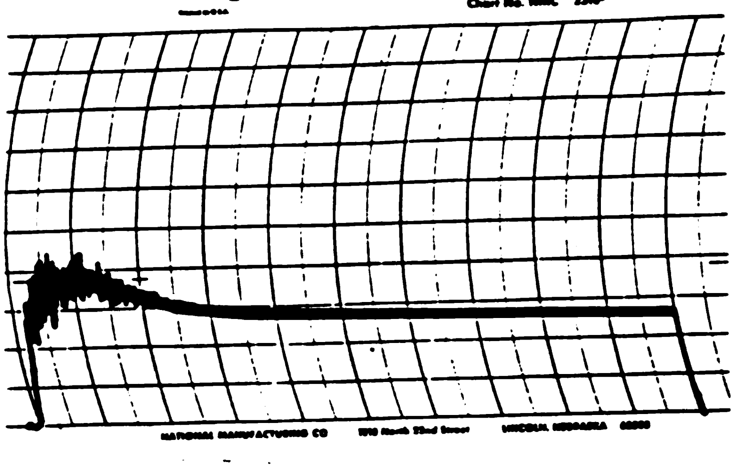


3

Farinograms of unchlorinated and chlorinated flours from Tres 1993 variety: 1) Control, 2) pH 4.8, 3) pH 4.3.

1



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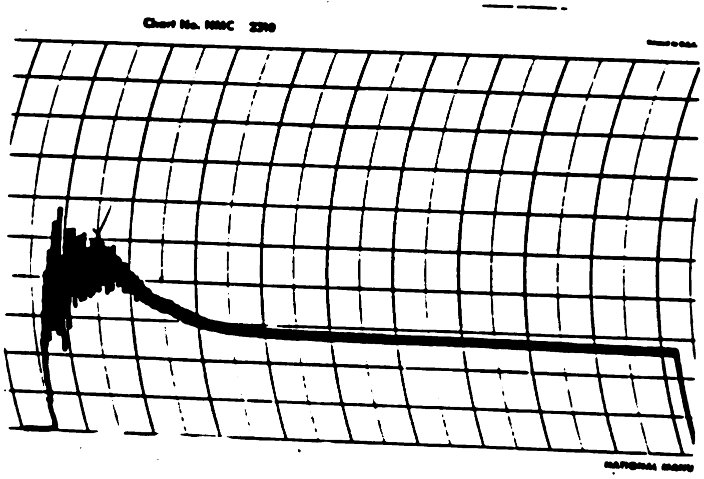

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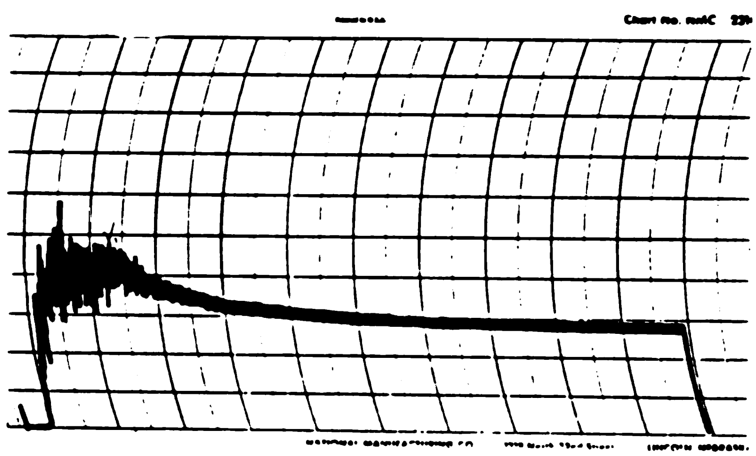

Appendix IV. Viscoamylograph Measurements for Unchlorinated and Chlorinated Flours

Variety	Peak Viscosity (BU)			Breakdown Viscosity (BU)			Breakdown (BU)			Setback Viscosity (BU)			Setback (BU)			Total Setback (BU)		
	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3	C	4.8	4.3
Fall 1992																		
Rely	810	975	NA	755	875	NA	55	100	NA	1570	1660	NA	760	685	NA	815	785	NA
Crew	910	1010	1300	830	850	840	80	160	460	1700	1820	1690	790	810	390	870	970	970
Kmor	595	745	1120	560	675	840	35	130	310	1250	1500	1500	655	755	380	732	825	825
Lewjain	675	725	1030	705	730	810	30	155	220	1410	1480	1540	735	755	235	705	750	750
Dynasty	735	720	1360	575	565	795	160	155	565	1290	1230	1475	755	755	115	850	850	850
Excel	840	750	1280	720	610	800	120	140	480	1470	1325	1360	630	575	80	750	715	715
Caldwell	830	680	1215	735	570	780	95	110	435	1585	1250	1450	555	570	235	715	680	680
Clark	1090	1175	1515	810	790	840	280	385	675	1680	1670	1310	590	495	-205	870	880	880
Frankenmuth	1040	1100	1390	870	835	890	170	265	500	1745	1760	1385	705	660	-5	875	925	925
Fall 1993																		
Tres	770	785	1130	695	755	800	75	30	330	1430	1690	1570	660	905	440	732	935	935
Lewjain	370	375	1050	330	325	670	40	50	380	820	810	1285	450	435	235	490	485	485
Dynasty	840	840	1285	640	625	790	200	215	495	1365	1375	1580	525	535	295	725	750	750
Frankenmuth	835	760	1090	705	635	720	130	125	370	1500	1310	1490	665	550	400	795	675	675
Average	795	818	1230	687	680	795	108	138	435	1447	1452	1469	651	633	239	760	772	772
Std. Dev.	184	207	150	140	150	56	81	104	122	243	277	119	100	140	209	106	135	135
Range	370- 1090	375- 1175	10301 390	330- 870	325- 875	670- 890	30- 280	30- 385	220- 675	820- 1680	810- 1820	12851 690	450- 790	435- 905	5-390	490-875	485- 970	485- 970

C= control flour, 4.8= pH 4.8 flour, 4.3= pH 4.3 flour

NA= Not enough sample; sample lost at SWQL

Appendix V. High-Ratio Cake Volu

Appendix V. High-Ratio Cake Volumes (ml) from Unchlorinated and Chlorinated Flours Baked at USDA SWQL

Variety	Control Flour	pH 4.8 Flour	pH 4.3 Flour
Fall 1992		Volume (ml)	
Rely	884	945	858
Crew	851	930	865
Kmor	900	930	874
Lewjain	909	948	876
Dynasty	840	973	902
Excel	846	1006	951
Caldwell	936	954	844
Clark	801	938	900
Frankenmuth	810	899	853
Average	864	947	880
Std. Dev.	46	30	33
Range	801-909	899-1006	853-951

Appendix VI. High-Ratio Cake Measurements for Unchlorinated and Chlorinated Flours Baked at Michigan State University

Variety	Volume (ml)			Volume Index (cm)			Symmetry Index (cm)		
	Control Flour	pH 4.8 Flour	pH 4.3 Flour	Control Flour	pH 4.8 Flour	pH 4.3 Flour	Control Flour	pH 4.8 Flour	pH 4.3 Flour
Fall 1993									
Tres	953	970	918	9.15	10.6	9.8	-0.55	0.45	0.5
Lewjain	1029	1029	951	10.40	12.6	10.4	0.35	1.50	7.6
Dynasty	928	1028	980	8.15	11.2	10.5	-0.35	0.35	1.5
Frankenmuth	915	1043	973	8.45	12.2	9.6	-1.40	-0.35	-0.3
Average	956	1017	955	9.04	11.6	10.0	-0.04	0.18	-0.03
Std. Dev.	51	33	27	1.00	1.0	0.4	0.05	0.25	0.09
Range	915-1029	970-1043	918-980	8.15-10.40	10.6-12.6	9.6-10.5	.55-.35	.35-.45	.3-7.6

Appendix VII. Japanese Sponge Cake Measurements for Unchlorinated and Chlorinated Flours

Variety	Volume (ml)			Volume Index (ml)			Symmetry Index (cm)		
	Control Flour	pH 4.8 Flour	pH 4.3 Flour	Control Flour	pH 4.8 Flour	pH 4.3 Flour	Control Flour	pH 4.8 Flour	pH 4.3 Flour
Fall 1992									
Rely	1087	965	1002	19.4	17.9	20.55	0.55	1.35	1.5
Crew	1097	1030	1077	19.6	19.0	19.31	0.65	1.10	1.2
Kmor	1122	982	1052	19.6	18.0	18.85	0.25	1.05	0.8
Lewjain	1113	1037	1020	19.5	19.0	18.35	0	1.65	1.3
Dynasty	1157	1075	1145	19.8	19.7	19.95	0.05	1.35	0.9
Excel	1180	1067	1080	19.7	19.8	19.05	0	1.40	1.5
Caldwell	1090	1040	1007	19.9	18.9	18.35	1.25	1.55	1.2
Clark	1050	1060	1095	20.5	19.1	19.30	0.10	1.20	1.3
Frankenmuth	1095	1072	1060	19.5	19.1	18.95	1.10	1.50	1.0
Fall 1993									
Tres	1142	1062	962	19.5	18.4	18.20	0.25	0.70	1.2
Lewjain	1092	974	957	18.8	19.2	17.34	0.40	1.25	1.1
Dynasty	1205	1070	1082	19.8	19.4	19.70	-0.30	0.90	1.3
Frankenmuth	1165	1049	1052	19.0	19.1	19.30	-0.40	1.50	1.1
Average	1123	1037	1046	19.5	19.0	18.95	0.25	1.35	1.2
Std. Dev.	44	39	54	0.4	0.6	0.85	0.65	0.30	0.2
Range	1050-1205	965-1067	957-1145	18.8-20.5	17.9-19.7	17.34-20.55	0-1.25	.7-1.65	.9-1.3