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Ozonation Treatment Improves Properties of Wheat Flour and the Baking Quality of Cake

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Changes in the properties of wheat flour after ozonation treatment as a function of exposure time were investigated. Wheat flours were treated by 20 mg SL^{-1} gaseous ozone for 15 s, 30 s, 1 min, 2 min, 5 min, 10 min, 20 min and 30 min. Ozonation treatment improved the pasting properties, texture properties and solvent retention capacity of wheat flour. Lipid component of wheat flour and the chemical components connectivity of protein were affected to different degrees as a function of exposure time. Results of the study showed that ozone-treated wheat flour could be used to improve the quality of high ratio cakes.

Key words: cake quality, expose time, ozone, physicochemical properties, wheat flour

Abbreviations: GRAS – generally regarded as safe, SRC – solvent retention capacity, TPA – texture profile analysis

INTRODUCTION

Ozone, a form of oxygen with three atoms (O_3), is generated in the air following the occurrence of a thunderstorm (Hocking et al. 2007). Commercially, electrical discharge, electrochemical and ultraviolet radiation are the main methods for ozone manufacture. Although people can easily smell the characteristic odor at short exposure time and low concentration condition, the attractive aspect of ozone is that it decomposes rapidly (half-life of 20–50 min) to molecular oxygen without leaving a residue (Kells et al. 2001). Therefore, ozone is of interest to chemists, astronomers and food scientists. But ozone needs to be produced on site for immediate use due to its unstable property. Ozone is a highly reactive form of oxygen where three molecules are bonded together. As it generates electricity on-site where needed, ozone has potent antimicrobial activity and other characteristics. Interest in ozone application for agriculture and food processing has increased in recent years. In 1977, ozone was declared as a generally recognized as safe (GRAS) substance by the FDA after a Food Additive Petition containing safety and efficacy data was submitted to them. Later, the USDA approved its use on meats and on certified organic foods (Cullen et al. 2009).

Ozonation of wheat grain is a quick and easy process that could be realized during storage. The ozone is in direct contact with the grain and immediately modifies the properties of the wheat. However, the ozone has to go through the pericarp and the seed coat to reach the endosperm, which represents the greater proportion of the short grade flour. It is therefore expected that not all of the ozone will penetrate the endosperm and the flour that follows will have specific characteristics (Dubois et al. 2006; El-Desouky et al. 2013).

Several research studies have been conducted to evaluate the effects of ozone gas on rheological properties of dough. Naito (1990) treated wheat flour (medium and soft flour) with an ozone-oxygen stream (0.05 to 50 ppm ozone) at 10 °C for 1 to 6 h. Physical dough testing properties showed in a farinograph test no significant change in the consistency of both flour doughs, with an extensograph, an increase in the resistance to extension of both flours for the 0.5 to 50 ppm ozone treatment and a decrease in extensibility for the 0.05 to 50 ppm (soft flour) and the 5.0 to 50 ppm (medium flour) treatments. Ibanoglu (2001) reported that tempering of wheat grain with ozonated water did not significantly alter the chemical, physical and rheological properties of the flours, but statistically significant reductions in the total bacterial and yeast or mold counts were attained. The effect of ozone treatment on wheat flour, isolated wheat starch and physicochemical properties of wheat starch were determined by Sandhu et al. (2012) who found that chemical analysis of starch isolates indicated depolymerization of high molecular weight amylopectins, with a subsequent increase in low molecular weight starch polymers as a result of starch hydrolysis. El-Desouky et al. (2013) reported that stability and resistance of dough were increased with ozonation of wheat flour at 40 ppm for 20 min. Ozone can react with double bonds found in carotenoid pigments, causing a reduction in yellow color and an increase in flour whiteness. Ozone could also react with double bonds associated with unsaturated fatty acids (Graham 1997). Ozone promotes the oxidation of sulfhydryl groups and the subsequent formation of disulfide bonds between cysteine moieties (Yamada and Preston 1992).

The physical and chemical properties of food can dramatically change during baking processing, including starch gelatinization, and protein denaturation (Sumnu 2001). Cake batter is also a complex emulsion of egg-sugar-water-fat mixture. Flour quality lies at the center of this complex system and will affect the final baking quality product (Johnson and Hoseney 1979). According to Gelinas et al. (1999), the quality of cakes include high volume, uniform cell distribution, satisfying crust and crumb color and texture, high tenderness and longer shelf life and staling tolerance. In the present study, we chose yellow layer high ratio cake as the food model to evaluate the baking property. Yellow layer cakes with untreated flour are not satisfactory in terms of volume, crumb color and texture. Some of the studies tried to improve the quality of cake by adding a few ingredients such as xanthan gum L-cysteine and hydrogen peroxide (Thomasson et al. 1995; Di Stasio et al. 2007). Donelson et al. (2000) modified the properties of cake by chlorine treatment to improve cake volume and produce a stiffer, more resilient cake crumb.

Ozonation procedure was used in order to modify flour properties in high ratio cakes, sponge cakes, and bread without addition of ascorbic acid or amylase. These modifications improved baking performance by acting as an oxidative agent during kneading and baking. Chittrakorn (2008) treated soft wheat flour with ozone for 10, 20, 30, 36, and 40 min with an application rate of 0.06 L min^{-1}. Ozone-treated flour had a lower pH with a slight increase in lightness (L) values. Additionally, these treated flours produced cakes with improved cake volume, brightness, and softness. When compared with chlorinated flour, ozone-treated flour produced similar cake structure with increased volumes.

This study investigated the effect of exposure time of gaseous ozone on the physical and chemical properties of wheat flour and its baking properties.

MATERIALS AND METHODS

Ozone Treatment of Wheat Flour

Ozone generator was programmed as follows: gas flowing rate 3 L h^{-1}, voltage control button at the scale of 70% with alternating current (A. C.) of c.a. 0.5 A, while the settings for the ozone monitor were as follows: range 100 mg SL^{-1}, recorder scale X, pressure 760 mm Hg. The flour used was commercial cake flour Puratos, obtained from Guangzhou Purato Food Co., Ltd. Cake wheat flour (~100.00 g) samples were weighed in 1 gallon GLAD® plastic bags. As much air was expelled from the plastic bags by placing them on top of a table and rolling them tightly toward the opened end and then zip locked. Ozone was introduced into the bag by placing the ozone outlet tube in one corner of the plastic bag, where it was tightly gripped by a metal clip. Once the bag was fully filled with ozone at 20 mg SL^{-1}, the exposure time was counted. The cake wheat flour was exposed in ozone environment for 15 s, 30 s, 1 min, 2 min, 5 min, 10 min, 20 min and 30 min. The plastic bags were continuously agitated by hand to mix the flour content during the ozonation process. To prevent bursting of the bag, the pressure was released occasionally.

Pasting Properties

The pasting properties of the flour samples were determined using a Rapid Visco Analyser (RVA) (Model 3, Newport Scientific, Australia). Prior to analysis, the flour samples were analyzed for moisture content, to ensure 14% moisture content. Wheat flour (3 g, d. b.) was mixed with distilled water (25 g) in the aluminum RVA sample canister. The mixture was stirred to make a 10.7% flour suspension (ww^{-1}). The pH of the aqueous flour mixture was taken before the mixture was loaded to the RVA machine. The programmed heating and cooling cycle was used, where the sample was held at 50 °C for 1 min, heated to 95 °C for 7.5 min, held at 95 °C for 5 min, cooled to 50 °C for 8.5 min, and then held at 50 °C for 3 min. Test results were recorded directly in the computer with the results displayed on-screen as a viscosity-time chart. The parameters of peak viscosity (PV), hot paste viscosity (HPV), cold paste viscosity (CPV), breakdown (BD) and setback (SB) were recorded after testing. The test was repeated twice for each sample.

Flour Gel Texture Analysis

After RVA test, flour gels were allowed to cool and left at 25 °C for 24 h. Flour gel texture was determined from triplicate measurements using a TA-XT2 Texture Analyzer (Stable Micro Systems, Godalming, Surrey, England). A cylindrical flattened probe of 5 mm diameter was pressed into the flour gel at a speed of 1 mm s^{-1}. The test was stopped after 10 mm of travel. Hardness, gumminess, chewiness, stickiness, adhesiveness, and springiness were recorded to evaluate the physical properties of the normal and ozonation flour gel.

Solvent Retention Capacity (SRC)

Solvent retention capacity flour (14% moisture basis) was determined in distilled water, 50% sucrose, 5% sodium carbonate solution, and 5% lactic acid according to AACC Method 56-11(2000).

Mixograph of Ozone-Treated Flours

Ozonation of flour was weighed into 2.00 g portions moistened with 1.20 g of distilled water. The mixograph was collected and analyzed for the normal and ozone-treated flours with increasing exposure time. The data given were not corrected for moisture content.

Color Measure of Ozone-Treated flour

A Minolta CR-300 colorimeter (Minolta Co. Ltd., Tokyo, Japan) was used to measure the color of the flour samples. The instrument was calibrated against a standard white tile (No. 17033201, L = 97.83, a = -0.41 and b = 1.90). Each flour sample was placed in the granular materials attachment and compacted by tapping 20 times. The Minolta Chroma Meter was placed in the granular attachment, and measurements were subsequently taken and recorded. Flour color results were reported in terms of 3-dimensional color values: L*, a*, b*. Lightness was determined by L* values (0 = black and 100 = white). Red and green hues were attributed to a* values (+60 red color and -60 green color). Yellow and blue colors were indicated by b* values (+60 yellow color and −60 blue color). The instrument was calibrated against a standard white tile (No. 17033201, L = 97.83, a = −0.41 and b = 1.90).

Preparation of the Cake Batter and Baking

The baking quality of the treated flour was done using a basic yellow layer cake recipe using ingredients available in Hong Kong. The standard formation was: sifted cake flour (225 g), granulated sugar (250 g), double acting baking powder (12 g), iodized salt (7 g), vegetable shortening (95 g), milk (250 g), vanilla (5 g) and eggs (120 g). The oven was pre-heated to 180 °C. Two layer cake pans were lined with waxed paper. The dry ingredients were sifted together and then shortening, vanilla, and 200 g full cream milk were mixed lightly until well distributed. Then the mixture was beaten at high speed with an electric mixer for 2 min. The rest of the milk and the eggs were then added and the mixture was further beaten for 2 min more. The batter was portioned into two by pouring 440 g of batter into each prepared pan and then baked. The cakes were cooled in racks for 30 min in pans on wire racks after which they were removed from the pans and cooled completely.

Baking Properties

Volume and symmetry of the cake. The volume and dimension of the cakes were determined by a plastic measurement template according to AACC method 10-91 (AACC 2000). The diameter and height at designated position at the edge (A, E), at 3.5 cm from the edge (B, D) and at the center (C) were determined by caliper to assess symmetry of the cake.

Cake crust and crumb color. Cake crust color was measured in triplicate by a chroma meter (CR-300, Minolta Co. Ltd., Tokyo, Japan). Then the crusts of the cake samples were removed by a sharp knife. The color of cake crumb was measured with a Minolta colorimeter (CR-300). L*, a*, b* values were recorded.

Cake texture analysis. A texture profile analysis (TPA) was performed on each cake to measure firmness using a TA-XT2 texture analyzer (Stable Micro Systems, Godalming, United Kingdom). The cakes were cut into pieces of 50×50×30 mm rectangular shape and used in the tests. The specimens were placed on a flat plate under a cylindrical flattened probe of 5 mm diameter. The probe was allowed to travel for 10 mm at a constant speed of 1.7 mm s^{-1}. After resting for 30 s, the probe was pressed into the specimen again similar to the first slices analyzed 2 h post baking.

Statistical Analysis

Differences between the functional properties of samples before and after ozonation treatment were established using analysis of variance (ANOVA). Data were analyzed with the SAS program version 6.10 (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Pasting Properties of Ozonated Wheat Flour

Pasting properties of wheat flours before and after ozonation treatment are presented in Table 1. Pasting property of wheat flour is the critical factor affecting the baking quality and the final product quality of the cake. On the other hand, pH values dramatically dropped with increasing ozonation exposure time from 6.2 to 4.6 (Table 1). The results suggested that triacylglycerols contained in wheat flour may have been oxidized to free fatty acids during ozonation treatment which may occur from the oxidation of flour components by ozonation promoting the formation of acid products. These results concur with those of Langlais et al. (1991) who reported that ozone has the ability to oxidize carbohydrate, amino acid, and unsaturated fatty acid components leading to

Table 1. Effect of ozonation exposure time on pasting and color characteristics of cake flour.

Ozonation Exposure Time	Peak Viscosity (Pa.s)	Breakdown (Pa.s)	Final Viscosity (Pa.s)	Setback (Pa.s)	pH	Color		
						L*	a*	b*
0 min	299.0 ± 1.4^{e}	166.0 ± 8.5^{f}	2000.0 ± 4.2^{g}	1867.0 ± 2.8^{e}	6.2 ± 0.0^{a}	93.5 ± 0.1^{c}	-0.5 ± 0.1^{e}	7.7 ± 0.1^{b}
15 s	552.0 ± 32.5^{cd}	271.5 ± 23.3^{d}	2096.5 ± 0.7^{f}	1816.0 ± 8.5^{fg}	5.7 ± 0.0^{b}	97.0 ± 0.0^{bc}	0.0 ± 0.0^{a}	5.7 ± 0.1^{e}
30 s	538.5 ± 4.9^{d}	251.5 ± 0.7^{e}	2093.0 ± 22.6^{f}	1806.0 ± 28.3^{g}	5.7 ± 0.0^{b}	97.0 ± 0.0^{bc}	0.0 ± 0.0^{a}	5.7 ± 0.0^{e}
1 min	574.0 ± 1.4^{c}	262.0 ± 1.4^{de}	2220.0 ± 7.1^{d}	1908.0 ± 4.2^{d}	5.5 ± 0.0^{c}	97.1 ± 0.0^{b}	-0.1 ± 0.0^{c}	5.7 ± 0.0^{e}
2 min	562.0 ± 17^{cd}	247.5 ± 10.6^{e}	2168.0 ± 29.7^{e}	1853.5 ± 23.3^{ef}	5.5 ± 0.0^{d}	97.1 ± 0.0^{b}	-0.1 ± 0.0^{bc}	5.5 ± 0.0^{f}
5 min	673.5 ± 6.4^{ab}	301.5 ± 0.7^{c}	2353.0 ± 35.4^{c}	1981.0 ± 28.3^{c}	5.5 ± 0.0^{e}	97.4 ± 0.0^{a}	-0.2 ± 0.0^{d}	5.1 ± 0.0^{g}
10 min	656.5 ± 19.1^{b}	328.5 ± 4.9^{b}	2680.5 ± 6.4^{b}	2352.5 ± 7.8^{b}	4.9 ± 0.0^{f}	97.4 ± 0.0^{a}	-0.5 ± 0.0^{e}	6.7 ± 0.1^{d}
20 min	682.0 ± 0^{ab}	328.0 ± 4.2^{b}	2711.0 ± 26.9^{b}	2357.0 ± 31.1^{b}	4.6 ± 0.0^{g}	97.3 ± 0.0^{a}	-0.6 ± 0.0^{f}	7.0 ± 0.1^{c}
30 min	697.0 ± 5.7^{a}	355.0 ± 2.8^{a}	2794.0 ± 12.7^{a}	2452.0 ± 15.6^{a}	4.6 ± 0.0^{g}	96.9 ± 0.3^{c}	-1.0 ± 0.0^{g}	8.8 ± 0.1^{a}

**Mean values in a column with the same letter are not significantly different at 0.05 level the development of acid products. The acid environment may increase the bonding force between H^+ and/or some alkali ions and starch granules.

The pasting parameters of peak viscosity, breakdown, final viscosity and setback values at the longest exposure time (30 min) were 2.33, 2.13, 1.40, and 1.31 times higher, respectively, than those of untreated wheat flour. Interestingly, peak viscosity value was dramatically increased 1.85 times at very short ozonation exposure treatment condition, i.e., 15 s, and then became more or less constant at longer exposure time from 10 to 30 min treatment, ranging from 656.5 to 697 Pa.s ($F = 172.81$, $p<0.05$). The results were in agreement with those of Donelson et al. (2000) that peak viscosity of wheat flour increased during chlorination treatment. Varriano-Marston (1985) reported oxidative polymerization of starch ruptured chains connecting crystallites and the amorphous region. This disruption increases the surface porosity of starch and allows this open starch structure to bind tightly with water and bind more oil. Hoseney (1994) stated chemical modification through oxidation results in greater swelling capacity of starch and increases batter viscosity. This increase in the starch swelling properties helps prevent cakes from collapsing during cooling by occupying the void space in the structure as the cake temperature and the gas cell pressure decrease. The increase in peak viscosity in ozonated sorghum flour may be due to the oxidation of starch by ozone leading to an increase in starch granule swelling during heating. Ozonation resulted in the swelling of the starch granules and greater resistance to gelatinization. Breakdown results were similar to the peak viscosity results for all the treatments ($F = 26.17$, $p < 0.05$). This decrease in viscosity is caused by the alignment of polymer molecules with the shear field. Flour with a sharp drop in viscosity indicates weakening by mechanical disruption. In this experiment, breakdown decreased as exposure to ozonation increased. For high paste viscosity, cool paste viscosity and setback, the value continuously increased from 15 s to 30 min treatment.

Color of Ozonated Wheat Flour

Wheat flour color is an important factor for quality evaluation. The ozone-treated flour was lighter in color as indicated by the higher brightness value (L*) ranging from 96.9 to 97.4 compared with that of the untreated flour with an L* value of 93.5 (Table 1). The results suggested that, as a strong oxidant, ozone may have similar function as bleacher to increase the whiteness of the wheat flour. The 30 min treatment resulted in the lowest redness (a*) and highest yellowness (b*). This finding indicates that ozone is able to decolorize some food components by oxidizing pigments such as carotenoids in the flour. Xu and Zheng (2008) investigated the effect of ozone treatment on the color of wheat flour and found that flour treated with ozone improved in terms of flour color by increasing L* values and decreasing yellowness values. Pyler (1988) states that the color of flour has a significant influence on the ultimate crumb color of baked goods. Based on this observation, it could be hypothesized that wheat flour with higher L* values would improve brightness values in the final product.

Solvent Retention Capacity

The combined pattern of the four SRC values established practical flour quality/functionality profile useful for predicting baking performance and specification conformance. Lactic acid SRC is well known to be associated with glutenin characteristics. Glutenin, highly related to the strength and elasticity of the dough system, is contributory to holding the gases which are produced during fermentation and in baking (Thomasson et al. 1995; Khatkar 1994). Table 2 shows that the lactic acid SRC value had no effect at the lower exposure period from 0 to 5 min, whereas the value was significantly increased at higher exposure time ($F = 19.0$, $p < 0.05$; LSD = 3.85). Sodium carbonate SRC is associated with the levels of damaged starch. The degree of damaged starch is a critical factor for water distribution and absorption, the texture and fermentation properties (Di et al. 2007). As a result, the sodium carbonate SRC slightly increased with increasing exposure time ($F = 116.82$, $p < 0.05$; LSD = 1.85). Sucrose SRC is related to pentosan characteristics, which are related to starch gelatinization, hardness and moisture of the dough (Maeda and Morita 2003). The value of sucrose SRC was gradually increased with increasing exposure time ($F = 135.09$, $p < 0.05$; LSD = 1.67). Water SRC is influenced by all of those flour constituents (Agrawal and Lucas 2003). The water SRC was significantly increased with increasing time and then tended to go constant from 10 min to 30 min treatment ($F = 287.5$, $p < 0.05$; LSD = 1.52). Generally, there was a general trend of increased solvent retention capacity for the four different solvents used in the study indicating a considerable effect on the protein, starch damage, and pentosan of the treated flour. Glutenin was more resistant to the ozonation treatment.

Mixograph of Ozone-Treated Flours

Mixograph of the wheat flour before and after treatment was presented in Figure 1. Mixograph is a universal instrument for recording the mixing properties of wheat flour. The main parameters of peak height, peak time and peak width were used to describe the mixing properties and protein property (Spies 1990). When wheat flour was exposed to shorter ozone treatment from 15 s to 5 min, the peak time was slightly affected and ranged from 1.28 to 2.48 min, whereas the peak height was minimally affected and ranged from 17.6 to 26.3. When wheat flour was exposed to higher exposure times from 10 to 30 min, there was marked increase in peak time from 5.44 to 9.73, while the peak height failed to develop as indicated in the very low values. The values of peak width had little effect from 0 min to 20 min, but increased as a result of longer exposure time, i.e., 30 min. The property of glutenin was slightly changed until the longest 30 min treatment. Compared with glutenin property, starch damage and pentosan content were more sensitive to the ozonation exposure time. This result implies that ozone treatment conducted at longer exposure time forced some

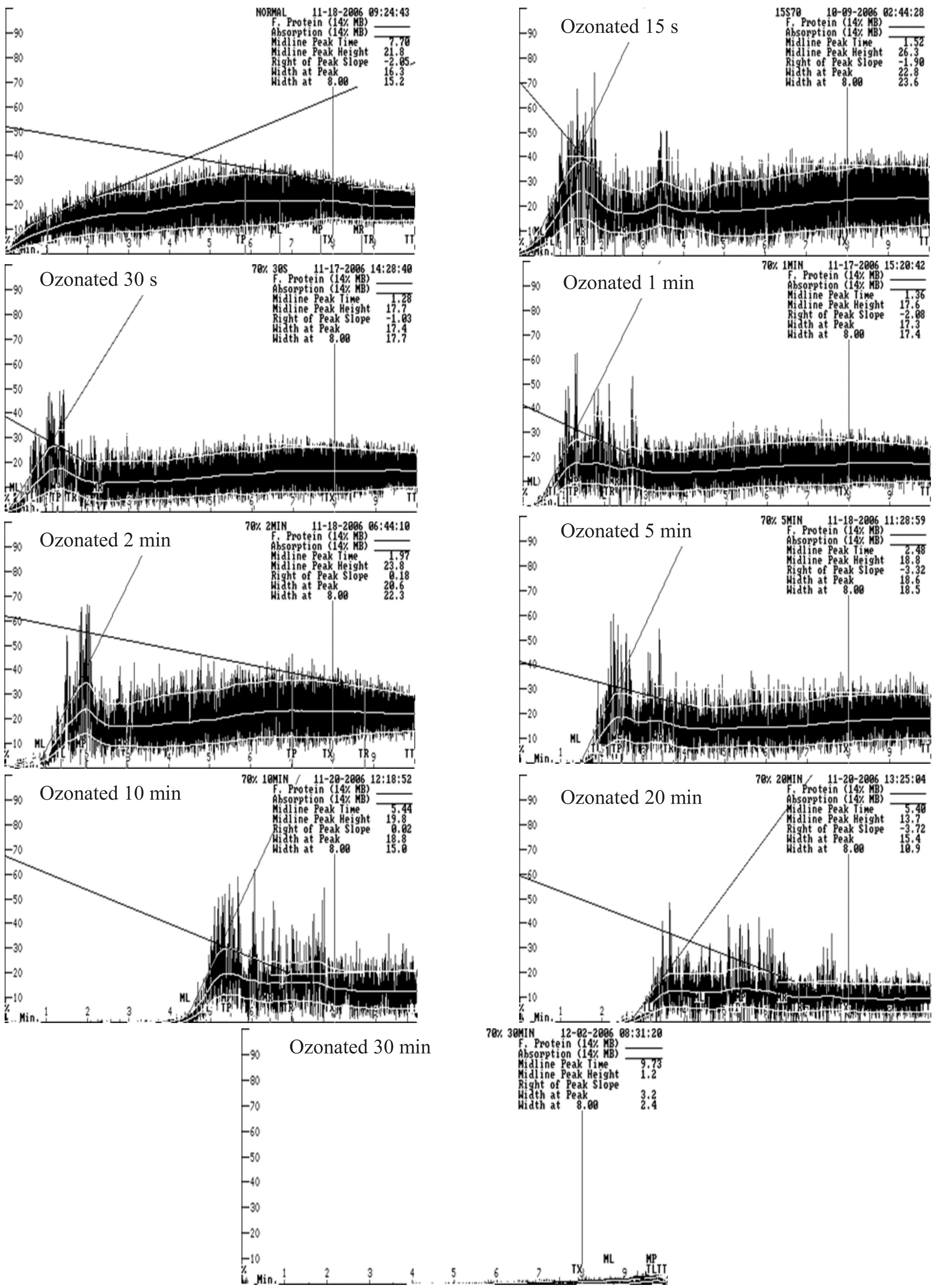

Fig. 1. Mixogram curves for ozonated flour from 0 to 30 min.

Table 2. Effect of ozonation exposure time on solvent retention capacity characteristics of cake flour.

Ozonation Exposure Time	SRC (%)			
	Water	50% Sucrose	5% Na_2CO_3	5% Lactic Acid
0 min	42.1 ± 0.1[e]	56.0 ± 0.9[f]	55.9 ± 1.3[f]	61.2 ± 0.4[d]
15 s	43.9 ± 0.7[d]	61.4 ± 0.3[e]	67.6 ± 0.1[e]	62.2 ± 1.8[d]
30 s	45.4 ± 0.7[d]	61.9 ± 0.6[e]	68.5 ± 0.3[e]	61.6 ± 1.7[d]
1 min	48.5 ± 0.5[c]	64.8 ± 0.2[d]	71.0 ± 0.5[cd]	63.0 ± 0.4[cd]
2 min	47.8 ± 0.2[c]	65.1 ± 0.0[d]	71.2 ± 0.0[c]	61.9 ± 2.3[d]
5 min	56.6 ± 0.2[b]	67.8 ± 0.4[c]	68.6 ± 0.1[de]	62.3 ± 2.8[d]
10 min	60.3 ± 1.0[a]	71.3 ± 1.2[b]	77.0 ± 0.2[a]	66.2 ± 0.6[bc]
20 min	61.2 ± 0.1[a]	72.1 ± 1.2[ab]	73.3 ± 2.0[bc]	66.9 ± 0.7[b]
30 min	61.3 ± 1.1[a]	74.2 ± 1.3[a]	75.7 ± 2.0[ab]	77.4 ± 1.3[a]

**Mean values in a column with the same letter are not significantly different at 0.05 level.

protein molecules to unfold and form a relatively disorderly structure.

Textural Properties of Ozone-Treated Wheat Flour Gel

Food texture is a critical factor for consumers in evaluating the quality property of food. Textural properties of the wheat flour gel are attributed to predict the physical properties of the final product and indicate how the chemical components are related under various cooking applications. In general, hardness, adhesiveness, gumminess, chewiness and springiness were used to describe the firmness, ability to stick and elasticity of the starch or flour gel. Table 3 showed that hardness, gumminess and chewiness of treated wheat flour slightly decreased at the lower exposure time from 15 s to 1 min, but significantly increased at the longer exposure time from 2 min to 30 min, indicating that ozone treatment decreased the stability of starch gels by oxidative degradation of protein and starch molecules. When wheat flours were treated with longer exposure time, starch-protein molecules formed cross linking structure. Therefore, the ozonation treatment did not affect the elasticity of the flour gel but increased the firmness and decreased the stickability.

The flour gel network formation is based on the connection between protein matrix and starch granule, where starch gelatinization can dramatically increase the degree of the connectivity. The degree of flour gel formation increased with increase in treatment time. The reason may due to the increased force between free ion and the starch granules, that is, not only the increase in the peak viscosity but also the strength of the gel formation and the increase in the gel resistant ability to fracture. As shown in the mixograph, protein properties were significantly different at 30 min treatment compared with the control (Fig. 1). At the longest exposure time of 30 min, part of the protein matrix may be broken or destroyed in the strong oxidant-ozone treatment to lead to the decrease of the connectivity between starch granules and the protein matrix and make the flour gel easier for fracture. For high ratio cakes, sugar plays an important role in the complex system that will help to increase its firmness.

Baking Properties of the Ozonated Wheat Flour

Cake crust and crumb color. When consumers select cake products, the appearance and color of the cake is an important factor affecting their first choice. Table 4 shows that the whiteness of the crumb generally increased with increasing exposure time, while the value for the crust dropped. The trend for redness went in the opposite way with decrease in crumb and increase in crust, while the yellowness was more or less constant. Similar bleaching effects were found by Chittrakorn (2008) in the ozonation of soft wheat flours for white layer cake production. This bleaching action through oxidative treatments is believed to destroy the carotenoid and flavonoid pigments found in the endosperm. This decolorization step subsequently produces a whiter flour (Hoseney 1994).

Symmetry of the cakes. Brandt et al. (1963) pointed out that the main parameters for describing the textural characteristics of foods are fat and moisture content, geometrical properties and mechanical properties, where the last one is the most critical (Brandt et al. 1963). For cakes, the symmetry is very important to evaluate the characteristics of the final product. The ozone-treated flour had better symmetry than the untreated flour. The treated samples had a very distinct indention at the middle section of the cake. The differences in dimension and symmetry of the cakes are evident in Table 4. Ozone-treated flour had sufficient strength to support the overall cake structure without collapsing during cooling. This added strength may be due to ozone oxidizing and modifying the properties of flour components such as starch, protein, and lipids. Oxidative treatments like chlorination have been shown to increase the hydrophobicity on the surface of wheat starch (Seguchi 1990). It helps improve the bubble stability while allowing the oxidized starch to swell to a greater extent compared with unoxidized starch. This increased viscosity of the batter helps prevent the cake from collapsing during baking as well as cooling (Hoseney 1994).

Textural properties of ozone-treated wheat flour cake. Rosenthal (1999) defined texture as the mouthfeel of a food and is the result of the sensory assessment of its physical properties. Sachs (1988) investigated the importance of the intimate connection between the teeth and the food. Chewing process is always followed with the food crack, where crack initiation usually happens at the first bite. Ozonation produced a variety of effects on the textural properties of high ratio yellow cakes, i.e., either an increase, a decrease, or no effect (Table 5). The different textural properties demonstrated different

Table 3. Effect of ozonation exposure time on the textural characteristics of cake flour gel.

Ozonation Exposure Time	Hardness (g)	Adhesiveness (g.s)	Springiness	Gumminess	Chewiness
0 min	4.2 ± 0.4^{c}	-17.3 ± 0.6^{a}	0.9 ± 0.1^{a}	2.2 ± 0.1^{d}	2.1 ± 0.2^{d}
15 s	2.6 ± 0.3^{d}	-31.4 ± 0.6^{bc}	0.8 ± 0.1^{b}	1.3 ± 0.1^{e}	1.0 ± 0.0^{d}
30 s	3.4 ± 1.1^{cd}	-29.5 ± 7.6^{b}	0.9 ± 0.1^{ab}	1.7 ± 0.6^{de}	1.6 ± 0.6^{d}
1 min	3.9 ± 0.8^{cd}	-31.9 ± 9.9^{bc}	0.9 ± 0.0^{a}	2.1 ± 0.5^{d}	1.9 ± 0.5^{d}
2 min	13.7 ± 1.5^{b}	-34.8 ± 9.4^{bcd}	0.9 ± 0.0^{a}	7.1 ± 1.0^{c}	6.5 ± 1.2^{c}
5 min	15.2 ± 0.6^{ab}	-37.0 ± 7.8^{bcde}	0.9 ± 0.0^{a}	8.2 ± 0.5^{ab}	7.4 ± 0.7^{abc}
10 min	15.8 ± 1.2^{a}	-43.0 ± 7.9^{de}	0.9 ± 0.0^{a}	8.4 ± 0.8^{a}	7.6 ± 0.8^{ab}
20 min	16.0 ± 1.2^{a}	-44.7 ± 6.9^{e}	0.9 ± 0.0^{a}	8.5 ± 0.8^{a}	7.8 ± 0.8^{a}
30 min	14.3 ± 0.7^{b}	-39.9 ± 4.9^{cde}	0.9 ± 0.0^{a}	7.6 ± 0.4^{bc}	6.8 ± 0.5^{bc}

**Mean values in a column with the same letter are not significantly different at 0.05 level.

Table 4. Effect of ozonation exposure time on the cake color characteristics of cake crumb and crust and cake height.

Ozonation Exposure Time	Crumb			Crust			Height				
	L*	a*	b*	L	a*	b*	A	B	C	D	E
0 min	56.6 ± 3.3^{d}	12.7 ± 2.5^{a}	38.7 ± 2.4^{d}	73.7 ± 1.1^{b}	-2.2 ± 0.1^{c}	28.0 ± 1.1^{b}	2.9 ± 0.1^{a}	3.0 ± 0.1^{c}	3.1 ± 0.1^{bc}	3.0 ± 0.3^{c}	2.8 ± 0.2^{a}
15 s	58.4 ± 1.7^{c}	11.4 ± 1.2^{ab}	38.9 ± 1.2^{d}	76.2 ± 0.5^{a}	-2.4 ± 0.1^{d}	25.3 ± 0.4^{d}	2.7 ± 0.0^{abc}	3.3 ± 0.2^{b}	3.7 ± 0.1^{ab}	3.5 ± 0.0^{ab}	2.7 ± 0.0^{a}
30 s	61.1 ± 1.3^{c}	9.1 ± 1.8^{c}	40.2 ± 1.1^{abc}	74.1 ± 0.7^{b}	-2.6 ± 0.1^{e}	24.3 ± 0.2^{e}	2.5 ± 0.2^{d}	3.6 ± 0.1^{ab}	3.9 ± 0.0^{a}	3.7 ± 0.1^{ab}	2.3 ± 0.3^{c}
1 min	62.8 ± 2.2^{a}	8.5 ± 3.0^{cd}	39.3 ± 1.7^{cd}	75.7 ± 0.7^{a}	-2.8 ± 0.1^{f}	24.9 ± 0.3^{de}	2.7 ± 0.0^{bcd}	3.8 ± 0.1^{a}	4.1 ± 0.2^{a}	3.9 ± 0.5^{a}	2.7 ± 0.1^{ab}
2 min	62.3 ± 4.8^{a}	8.4 ± 3.6^{cd}	40.7 ± 3.4^{ab}	72.2 ± 1.4^{c}	-2.8 ± 0.2^{f}	26.4 ± 2.2^{c}	2.9 ± 0.0^{ab}	3.4 ± 0.0^{b}	3.6 ± 0.2^{abc}	3.7 ± 0.0^{ab}	2.9 ± 0.0^{a}
5 min	62.2 ± 1.4^{a}	6.6 ± 1.7^{d}	39.7 ± 1.2^{bcd}	67.6 ± 1.6^{de}	-2.5 ± 0.3^{d}	27.2 ± 1.5^{c}	2.8 ± 0.0^{abc}	3.4 ± 0.1^{b}	3.7 ± 0.1^{ab}	3.5 ± 0.2^{ab}	2.6 ± 0.2^{abc}
10 min	61.4 ± 3.2^{a}	9.6 ± 2.6^{bc}	41.1 ± 0.7^{a}	68.3 ± 1.4^{d}	-2.1 ± 0.2^{c}	31.2 ± 0.6^{a}	2.8 ± 0.1^{abc}	3.3 ± 0.3^{bc}	3.6 ± 0.1^{abc}	3.5 ± 0.1^{ab}	2.6 ± 0.1^{abc}
20 min	59.5 ± 2.2^{bc}	9.7 ± 3.0^{bc}	39.9 ± 1.7^{bcd}	67.3 ± 1.1^{e}	-1.6 ± 0.2^{a}	31.3 ± 0.2^{a}	2.6 ± 0.1^{cd}	3.3 ± 0.0^{bc}	3.0 ± 0.8^{c}	3.2 ± 0.1^{bc}	2.4 ± 0.0^{bc}
30 min	59.1 ± 2.1^{c}	9.1 ± 1.5^{b}	37.6 ± 1.8^{e}	67.4 ± 1.9^{de}	-1.9 ± 0.2^{b}	26.6 ± 0.9^{c}	2.6 ± 0.0^{bcd}	3.3 ± 0.2^{bc}	3.7 ± 0.1^{ab}	3.4 ± 0.0^{abc}	2.7 ± 0.0^{ab}

**Mean values in a column with the same letter are not significantly different at 0.05 level.

Table 5. Effect of ozonation exposure time on the textural characteristics of cake flour.

Ozonation Exposure Time	Hardness (g)	Adhesiveness (g.s)	Springiness	Gumminess	Chewiness
0 min	871.1 ± 32.7^{a}	-9.4 ± 2.5^{a}	0.8 ± 0.0^{e}	397.0 ± 25.6^{b}	333.6 ± 23.4^{cd}
15 s	854.7 ± 84.0^{a}	-37.9 ± 12.0^{bc}	0.9 ± 0.0^{c}	447.2 ± 25.0^{a}	392.0 ± 45.3^{b}
30 s	673.5 ± 64.2^{b}	-55.9 ± 10.8^{cd}	0.9 ± 0.0^{bc}	347.9 ± 31.8^{c}	325.4 ± 32.1^{cd}
1 min	664.5 ± 32.9^{b}	-201.4 ± 53.1^{f}	1.0 ± 0.0^{ab}	344.1 ± 17.8^{c}	332.0 ± 16.4^{cd}
2 min	683.9 ± 58.0^{b}	-34.0 ± 5.5^{b}	0.9 ± 0.0^{d}	328.8 ± 25.5^{c}	288.9 ± 27.1^{e}
5 min	700.7 ± 55.9^{b}	-38.4 ± 9.9^{bc}	0.8 ± 0.0^{d}	354.6 ± 32.9^{c}	297.5 ± 42.0^{de}
10 min	908.2 ± 50.6^{a}	-5.4 ± 1.4^{a}	0.8 ± 0.0^{e}	463.5 ± 32.4^{a}	389.5 ± 30.2^{b}
20 min	909.4 ± 93.4^{a}	-112.7 ± 35.9^{e}	1.0 ± 0.0^{bc}	474.2 ± 44.4^{a}	446.3 ± 58.3^{a}
30 min	693.3 ± 51.8^{b}	-62.7 ± 19.0^{d}	1.0 ± 0.0^{a}	355.7 ± 27.3^{c}	348.8 ± 30.8^{c}

**Mean values in a column with the same letter are not significantly different at 0.05 level.

interactions of protein and starch, which in turn depended upon the physicochemical properties of wheat flour before and after treatment. The texture of high ratio cakes made from ozone-treated wheat flour tended to become more loose compared with those of untreated flour, indicating that the treated wheat flour could be used in industry to develop better quality high ratio cakes.

CONCLUSION

Wheat flour treated with ozone showed improvement in chemical and physical properties as well as texture of layer cakes. In addition, the strong oxidation capacity of ozone probably affected not only the lipid components of wheat flour but also that of the protein. The major finding of this study showed the marked effect of ozonation on wheat flour and its effects on baking quality.

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