Effects of ozone treatment on medium hard wheat (Triticum aestivum L.) flour quality and performance in steamed bread making

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ABSTRACT
The quality characteristics of medium hard wheat flour were investigated after treatment with ozone gas (5 mg/L at 3.3 L/min) as a function of time (0, 0.5, 1.0, 1.5 and 2.0 h) in the study. Results indicated that the wet gluten content and whiteness of wheat flour increased significantly (P < 0.05) compared with the control. However, α-amylase activity, peak viscosities, hot paste viscosity, and cold paste viscosity decreased significantly (P < 0.05) during oxidation. For the microstructure, starch granules were reduced in size with ozone treatment and all became single starch granules after 1.5 h treatment. Ozone treatment time for 1.0 h had positive effects on quality scores, volume/weight, height, skin color, skin structure, external appearance and internal structure. Ozone treatment was beneficial in wheat flour to obtain improved steamed bread properties.

Introduction
Cereal grains are the major component of the human diet throughout the world. Among cereals, the production of wheat is third highest globally (Keskin & Ozkaya, 2015). Chinese steamed bread, also known as 'Mantou,' is a type of steamed bun or bread-like item in Chinese cuisine and produced from the flour obtained from wheat (Laohasongkram, Poonnakasem, & Chaiwanichsiri, 2011). Oxidizing agents are generally added to the wheat flour to accelerate the natural maturing and the flour becomes paler and yields dough with improved baking properties (László et al., 2008). The conventionally used oxidants are azodicarbonamide, calcium peroxide and benzoyl peroxide. However, increasing concern about their adverse effects has highlighted the need for the development of selective oxidant alternatives. Ozone is an environmentally friendly alternative for food processing, as it decays rapidly and leaves no toxic residues (Shah, Rahman, Chuan, & Hashim, 2011). As an oxidizing agent, ozone has wide applications in food processing, water treatment and environmental concerns (Guzelseydim, Greene, & Seydim, 2004). Ozone can alter the amino acid and fatty acid profile by oxidizing the sulfhydryl group (–SH) of amino acids and oxidation of polyunsaturated fatty acids to peroxides, thus influencing the nutritional and metabolic value of grain (Guzel-Seydim, Greene, & Seydim, 2004). It was reported that ozone treatment of moistened wheat grain enhanced dehulling of wheat grain (Mendez, Maier, Mason, & Woloshuk, 2003). Desvignes et al. found that ozone treatment (10 g/kg) of common wheat grains before milling significantly reduced (by 10–20%) the required energy at the breaking stage without changing flour yield. Reduction of coarse bran yield was also observed concomitantly with an increase in the yield of white shorts (Desvignes et al., 2008). The rheological properties of wheat flours with ozone treatment were similar to those observed with other conventional oxidizing agents, and different types of wheat flour behaved similarly (László et al., 2008).

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Abbreviations: AACC: American Association of Cereal Chemists; RVA: Rapid Visco Analyser; ozone treatment for 0.5 h (O-0.5), 1.0 h (O-1.0), 1.5 h (O-1.5), 2.0 h (O-2.0).
Most of the research to date has been done using ozone as an oxidant on isolated starch (An & King, 2009; Chan et al., 2011) (Sandhu, Manthey, & Simsek, 2012). However, limited research is published on using ozone as an oxidant on medium hard wheat flour and its performance in steamed bread making. Therefore, the aim of the current study was to evaluate ozone treatment on the physicochemical properties, α-amylase activity, microstructure and rheological property of wheat flour and its performance in steamed bread making.

**Materials and methods**

**Wheat and flour samples**

Non ozone treated wheat (*Triticum aestivum* L.) grains from Zhengmai 9023 (medium hard) grains from China in 2014 and kindly supplied by Huangguo Food Industry Co., Ltd. (Zhengzhou, China). The pre-cleaned sample was tempered for 24 h at 20 °C and the moisture content was set to around 16.0%. Subsequently, the wheat samples were milled with a Buhler Dolomit MDDP mill (Wuxi, China) and ground to a flour extraction rate of around 70%. The freshly milled flour samples were divided into five parts, one for control (C) measurements and the others for ozone (O$_3$) treatment.

The wheat flour was treated with ozone gas using an ozone generator (SK-CFG-1C, Sankang Environmental Science and Technology Co., Ltd., Jinan, China) equipped with an ozone monitor. Flour samples (about 200 g) were placed in a cylindrical acrylic container (6.0 cm × 50.0 cm) having an inlet valve at one end and an outlet valve at the opposite end. The outlet valve was attached to the ozone monitor. All samples were exposed to ozone gas (5 mg/L, flow rate 3.3 L/min). A cylindrical acrylic container was rotated back and forth and sideways once every 5 min during treatment to promote uniform exposure of the sample to ozone. The wheat flour samples were exposed to ozone for 0.5 h (O-0.5), 1.0 h (O-1.0), 1.5 h (O-1.5) and 2.0 h (O-2.0). The ozone treated samples were placed in plastic bags, which were left open for 10 min before closing to allow residual ozone to dissipate. All samples were then stored at 4 °C before usage.

**Wheat flour quality tests**

Protein was determined according to AACC 46-13; a conversion factor of 6.25 was used. Fat was determined according to AACC 30-10. Damaged starch content was determined according to AACC 76-30A. The wet gluten content of the flour was tested using AACC 38-12A.

Flour whiteness was evaluated using a WSB-IV whiteness tester (Hualu Instrument Limited Company, Suzhou, China). A white board made from barium sulfate (100% reflectance) was used as the standard. Samples were placed in the sample holder and reflectance was auto-recorded for wavelength ranging from 360 to 800 nm. The values were expressed in terms of percent whiteness. Hagberg falling number (AACC 56-81B) was measured as the total time (in seconds).

**Scanning electron microscope (SEM) of wheat flour**

SEM was used to analyze the morphology of wheat flour following the method of Cornejo-Ramírez et al. (Cornejo-Ramírez et al., 2015). The instrument is a Hitachi S-3000N Scanning Electron Microscope (S-3000N, Hitachi, Tokyo, Japan), which photographed at an accelerating voltage of 5 kV.

**Steamed bread making process**

The steamed bread was made in three steps according to Li et al. (Li, Deng, Li, Liu, & Bian, 2015). First, full fermentation dough was prepared with 500 g wheat flour, 225 g water and 4 g yeast and mixed for 15 min. Then, the dough was fermented at 30 °C and 85% relative humidity. Second, after fermentation, the dough was sheeted 20 times on the surface pressure machine (MP800, Yechang food machinery Co., Ltd, Shanghai, China) and split into 100 g portions. The chunks were formed into rounded shapes by hand and fermented at 30 °C and 85% relative humidity for 35 min. Third, the proofed doughs were steamed for 25 min in a pot using a steam tray and boiling water. After cooling at room temperature for 1 h, the quality of steamed bread was evaluated.

**Evaluation of dough quality**

The Rapid Visco Analyser (RVA) parameters were determined using RVA-4 (Newport Scientific Pvt. Ltd., Australia) according to Zaidul et al. (Zaidul, Norulaini, Omar, Yamauchi, & Noda, 2007) with some modifications. Each sample was mixed with 25 mL of distilled water to obtain a 14% suspension (w/w). The suspension was kept at 50 °C for 10 min, then heated to 95 °C at a speed of 12.2 °C/min and held for 2.5 min. It was then cooled to 50 °C (cooling rate 11.8 °C/min) and kept for 2 min. The empirical rheological property of flour dough was studied using Mixolab (Chopin, Tripette & Renaud, Paris, France) according to Jia et al. (Jia, Huang, Abdel-Samie, Huang, & Huang, 2011).

**Texture profile analysis (TPA) of steamed breads**

The steamed bread was cut into pieces 20 mm in thickness. TPA of steamed bread was tested using the TA-XT2i texture analyzer (Stable Micro Systems, Surrey, UK) with its Pasta Firmness/ Stickiness Rig probe (P35). Instrument settings were compression mode, trigger type, auto-5 g; pretest speed, 2.0 mm/s; posttest speed, 1.0 mm/s; compression height, 50%; interval between consecutive compressions, 5 s; compression time, 2 s. Samples were measured twice and the final results were the average values (Liu et al., 2015).

**Sensory evaluation of steamed breads**

The steamed bread was cooled to room temperature and the weight and volume determined according to GB/T 17320-2013. The quality scoring system is based on LS/T 3204-1993. The scores (points) were assigned as follows: volume/weight, 15; height, 5; skin color, 10; skin structure, 10; external appearance, 10; internal structure, 15; elasticity, 10; toughness, 10; stickiness, 15; taste, 5; and quality score,
100. The panel consisted of 13 trained members (five males and eight females) from different provinces of northern China (Lijuan, Guiying, Guoan, & Zaigui, 2007).

Statistical analysis

Data from the three repeated experiments were analyzed to determine whether the variances were statistically homogeneous, and the results expressed as means ± SD. Statistical comparisons were made by one-way analysis of variance (ANOVA) followed by a Duncan’s multiple range tests using SPSS software (version 19.0, Statistical Package for the Social Sciences Inc., Chicago, USA). Differences are considered to be significant when the p-values are under 0.05.

Results and discussion

Composition analysis

Ozone treatment did not affect protein (11.4%) or fat (0.82%) contents in the wheat flour samples (data not presented). These results are similar to those previously reported by Sandhu et al. (Sandhu, Manthey, & Simsek, 2011).

Ozonization can damage the wheat endosperm starch granule, resulting in increasing degradation of wheat starch. Reduction of starch content did not show significant differences when the treatment time was 1 h or less (Figure 1a). Ozone treatment times between 1.5 h and 2.0 h showed a higher oxidation rate and further degradation of starch. Therefore, ozone treatment of wheat flour for 1.5 and 2.0 h had a significant effect on starch degradation (P < 0.05). Reduced starch levels are prejudicial to the quality of wheat products, promoting enzymatic degradation and the rate of water absorption during dough making. There are two possible explanations for this: (i) increasing starch degradation increases initial water absorption and prevents optimum gluten formation during mixing; or (ii) dough consistency decreases and loses its gas-retentive capacity after starch degradation (Barrera, Pérez, Ribotta, & León, 2007).

When wheat flour dough is washed to remove starch granules and water-soluble constituents, the wet gluten can be kept and defined as the gluten. In practice, the term ‘gluten’ refers to proteins and plays an important role in determining the unique baking quality of wheat flour by conferring water absorptive capacity, cohesion, viscosity and elasticity on dough (Torbica, Antov, Mastilović, & Knežević, 2007). As can be seen from Figure 1b, the wet gluten content of the oxidized wheat flour samples was higher than the control. Furthermore, the wet gluten content showed a significant increase (P < 0.05) and then a significant reduction in sample O-2.0. An appropriate ozone treatment time thus improved the insoluble gluten macropolymer and thereby increased the wet gluten content. However, further increasing ozone treatment time destroyed the gluten structure and the water-holding capacity decreased rapidly, which decreased the level of wet gluten. Traditionally, gluten proteins are divided into gliadins and glutenins. The glutenin fraction comprises aggregated proteins linked by interchain disulphide bonds. Both glutenins and gliadins are major contributors to the rheological properties of dough during mixing (Kieffer, Schurer, Köhler, & Wieser, 2007).

Flour whiteness

An important quality of wheat flour is its appearance, primarily color, which affects marketing of the product and the acceptability of products derived from it (Van Hal, 2000). Flour whiteness increased significantly (P < 0.05) from O-0.5 to O-2.0 (Figure 1c). Sandhu et al. also reported that ozone treatment increased wheat flour brightness (Sandhu, Manthey, Simsek, & Ohm, 2011). The color of flour is primarily based on a variety of complex biochemical factors including enzymatic and non-enzymatic browning reactions and

Figure 1. A. Effect of ozone treatment on the damaged starch content of wheat flour; B. Effect of ozone treatment on the wet gluten content of wheat flour; C. Effect of ozone treatment on the level of whiteness of wheat flour; D. Effect of ozone treatment on the falling number of wheat flour.

Figura 1. A. Efecto del tratamiento de ozono en el contenido de almidón dañado de harina de trigo; B. Efecto del tratamiento de ozono en el contenido de gluten mojado de harina de trigo; C. Efecto del tratamiento de ozono en el grado de blancura de la harina de trigo; D. Efecto del tratamiento de ozono en la reducción de la cantidad de harina de trigo.
also the presence of natural pigments (Collado, Mabesa, & Corke, 1997). Carotenoid pigments are found in flour at low concentrations and result in a pale yellow appearance in freshly milled flour. The conjugated double bonds in carotenoid pigments are susceptible to oxidation by ozone treatment, which is conducive to flour whiteness.

**α-Amylase activity**

The falling number method was developed by Hagberg and Perten to determine α-amylase activity and has become the international standard in grain classification, quality control and marketing (Mares & Mrva, 2008). Ozone treatment can have an effect on enzymatic inactivation in newly harvested wheat, resulting in a marked decrease of α-amylase activity. The time (in seconds) was recorded in the research for a plunger to drop through a gelatinized wholemeal paste in hot water after a standard mixing time. Ozone significantly increased the falling number of wheat flour with treatment time \((P < 0.05)\) (Figure 1d). Damaged starch content with 1.5 h ozone treatment time shows a significant difference with control in Figure 1d. After 2.0 h ozone treatment, the falling number rose almost to 400. Generally, higher falling number means lower α-amylase activity in wheat flour samples and it has a negative curvilinear relationship with α-amylase activity. In this experiment, ozone treatment had a passivating effect on the wheat enzymes and resulted in decreased α-amylase activity (the falling number rose from 250 in the control to 400 in O-2.0). Excess α-amylase activity can impair wheat flour quality as enzymatic hydrolysis of starch in food production results in processing problems and unsatisfactory end-products (Xing, Symons, Hatcher, & Shahin, 2011). Damaged starch is more sensitive to α-amylase and its content increased with treatment time, which is more likely to lead to hydrolyzation of the wheat flour by α-amylase. Damaged starch was hydrolyzed to polysaccharides, maltose, glucose, etc. by α-amylase and resulted in a decrease in the viscosity of wheat dough during mixing (Figure 2).

**Flour microstructure**

Micrographs of native and ozonized wheat flour granules are shown in Figure 3. The native wheat flour granules had irregular shapes with diameter ranging from 10 to 100 mm (Figure 3 C × 500, C × 1000), which are consistent with the results of Ma et al. (Ma, Yu, & Ma, 2005). Starch polymers clumped together to form these granules and protein was tightly adherent to them. Following ozone treatment, the hydroxyl groups were gradually replaced by carboxyl groups that affected the bonds between starch granules or between starch granules and protein (Tharanathan, 2005). Starch
granules progressively reduced in size (Figure 3; O-0.5 × 1000, O-1.0 × 1000, O-1.5 × 1000 and O-2.0 × 1000). At the same time, protein separated from the starch granules. After 2 h oxidation, the starch granules became single and small (Figure 3; O-2.0 × 1000), which led to an increase in low-molecular weight starch granules. When *Fusarium graminearum* was treated with ozone and applied to whole wheat grains, the starch granules well dispersed. However, the external and internal surfaces of grain pericarp, brush pericarp and isolated starch remained intact (Savi, Piacentini, Bittencourt, & Scussel, 2014). Wheat flours with a high content of low-molecular weight starch polymers showed a higher tendency to retrograde or setback (Sandhu et al., 2011).

**RVA results**

It has been reported that the wheat flour pasting properties measured by RVA simulated the actual production process (Ravi, Manohar, & Rao, 1999). In recent years, RVA has been widely used to determine pasting properties. Values for peak viscosities, hot paste viscosity, breakdown, cold paste viscosity, total setback, peak time and gelatinization temperature of wheat flour samples exposed to ozone for different treatment times are presented in Table 1. The peak viscosity was 2072.5 mPa·s with 0.5 h ozone treatment, decreasing to 1299.0 mPa·s with 2.0 h treatment. Hot paste viscosity, breakdown, cold paste viscosity and total setback showed similar tendencies to peak viscosity, decreasing significantly (*P < 0.05*) as a function of ozone treatment time. However, peak time and gelatinization temperature changed little following oxidation.

Slightly oxidized wheat flour (O-0.5, 2072.5 mPa·s) showed a significant (*P < 0.05*) increase compared with the control sample (C, 2002.5 mPa·s) in regard to peak viscosity, which may be attributed to the poor protein crosslinking effect. Peak viscosity had a negative correlation with protein. Peak viscosity indicates the maximum swelling of the starch granules, which were adversely affected by the presence of higher protein which competes for water with starch granules (Barak, Mudgil, & Khatkar, 2013). After 1.0 h treatment time or longer, peak viscosity showed a significant decrease. This result agrees with that of Jyothi et al., who observed that the peak viscosity of the cassava starch with crosslinking increased compared with that of native starch at a low level of crosslinking (Jyothi, Moorthy, & Rajasekharan, 2006). The decrease in peak viscosity may be due to partial cleavage of glycosidic bonds after ozone treatment, leading to a decrease in the molecular weight of starch and protein molecules. Therefore, a partially degraded wheat flour network has no resistance to shear and the integrity of the starch granules cannot be maintained, resulting in lower

![Figure 3](https://example.com/fig3.png)

**Figure 3.** Effect of ozone treatment time on the hardness, elasticity, chewiness and resilience of steamed breads.

**Tabla 1.** Las propiedades pastosas RVA de la harina de trigo con oxidación de ozono.

|                          | C   | O-0.5 | O-1.0 | O-1.5 | O-2.0 |
|--------------------------|-----|-------|-------|-------|-------|
| Peak viscosity (mPa·s)   | 2002.5 ± 3.5<sup>a</sup> | 2072.5 ± 1.5<sup>b</sup> | 1872.0 ± 6.0<sup>c</sup> | 1827.0 ± 4.0<sup>d</sup> | 1299.0 ± 16.0<sup>e</sup> |
| Hot paste viscosity (mPa·s) | 1130.5 ± 1.5<sup>a</sup> | 1217.5 ± 1.5<sup>b</sup> | 1037.5 ± 6.5<sup>c</sup> | 1068.5 ± 6.5<sup>d</sup> | 657.0 ± 9.0<sup>e</sup> |
| Breakdown (mPa·s)       | 872.0 ± 2.0<sup>a</sup> | 855.0 ± 3.0<sup>b</sup> | 834.5 ± 9.5<sup>c</sup> | 758.5 ± 7.5<sup>d</sup> | 642.0 ± 7.0<sup>e</sup> |
| Cold paste viscosity (mPa·s) | 2078.5 ± 3.5<sup>a</sup> | 2192.0 ± 8.0<sup>b</sup> | 1968.0 ± 1.0<sup>c</sup> | 1931.5 ± 0.5<sup>d</sup> | 1332.0 ± 16.0<sup>e</sup> |
| Total setback (mPa·s)   | 948.0 ± 2.0<sup>a</sup> | 9845 ± 9.5<sup>b</sup> | 910.5 ± 12.5<sup>c</sup> | 883.0 ± 14.0<sup>d</sup> | 675.0 ± 7.0<sup>e</sup> |
| Peak time (min)         | 6.0 ± 0.0<sup>a</sup> | 6.0 ± 0.0<sup>b</sup> | 6.0 ± 0.0<sup>c</sup> | 6.0 ± 0.0<sup>d</sup> | 6.1 ± 0.0<sup>e</sup> |
| Gelatinization temperature (°C) | 68.8 ± 0.5<sup>a</sup> | 69.4 ± 0.1<sup>b</sup> | 68.6 ± 0.1<sup>c</sup> | 69.4 ± 0.1<sup>d</sup> | 69.3 ± 0.2<sup>e</sup> |

Data shown as mean ± standard deviation.

Los datos muestran promedio ± desviación estándar.

Los valores a-e entre los diferentes tiempos de tratamiento seguidos por la misma letra no son significativamente diferentes (*P > 0.05*).
viscosity. This scenario is supported by results reported by Sandhu et al. (Sandhu et al., 2012).

Breakdown viscosity is different from peak viscosity and hot paste viscosity. Higher breakdown viscosity indicates either disruption of starch granules or a reduced capability of starch to resist shear forces during heating (Chan, Bhat, & Karim, 2009). In regard to breakdown viscosity, the control (C sample) was 872.0 mPa·s and showed an increase to 855.0 mPa·s after 0.5 h ozone treatment (O-0.5). Breakdown viscosity consequently decreased with ozone treatment time (from 834.5 mPa·s at O-1.0 to 642.0 mPa·s at O-2.0). Higher breakdown viscosity may be attributed to the weakened structure of the flour starch after ozone treatment, which facilitated breakdown of the granular structure. However, reduction in breakdown viscosity with higher ozone treatment time may be due to novel constituents in the oxidized starches and depolymerization at a higher level (Adebowale & Lawal, 2003). Setback viscosity shows the degree of retrogradation of starch (mainly amylose). Higher setback values indicate greater starch retrogradation (Karim, Norziah, & Seow, 2000). Table 1 shows that setback viscosity decreased progressively and significantly with ozone treatment time, similar to peak viscosity and breakdown viscosity. Increase in viscosity is governed by the reassociation tendency of starch polymers when hot pastes are cooled. This phenomenon is largely dependent on the affinity of hydroxyl groups of one starch granule for another. Oxidized wheat flour is less prone to such reassociation as it is subjected to the introduction of carboxyl groups, which replace the hydroxyl groups that limit the formation of such binding forces in starch granules, which accounts for the reduction in setback viscosity of wheat flour paste. These results are in accord with the study of Kuakpetoon and Wang showing that amylose was likely excessively degraded in oxidized corn starches, resulting in lower final and setback viscosities (Kuakpetoon & Wang, 2006).

**Mixolab properties**

Wheat flour formed viscoelastic dough due to the ability of wheat storage protein that has unique breadmaking properties (Stauffer, 2007). The obtained Mixolab parameters of wheat flour with ozone treatment are summarized in Table 2. The first part of the Mixolab curve denotes the protein characteristics of the dough: water absorption, dough development time, dough stability and C2 values that include protein weakening due to mechanical and thermal constraints. As can be seen from Table 2, development time varied significantly with different treatment times (P < 0.05).

Dough development time is dependent on the protein characteristics of the dough. Sample O-1.0 showed increased development time, which indicated that ozone treatment will not decrease the quality of wheat for end-users and will have the advantage of improving the flour quality. The presence of ozone led to a decrease in C2 values. It can be assumed that ozone treatment resulted in markedly inferior protein quality and thus decreased C2 values.

The second part of the Mixolab curve shows the wheat flour properties of the systems tested. More attention was paid to the first peak at C3, which was the measurement of properties during starch gelatinization and the difference between the C5 and C4 values represented the level of starch retrogradation. It will be seen (Table 2) that O-0.5 wheat flour is characterized by the highest gelling ability as shown by the value of C3. The torque values at C3 and the value of C5–C4 both decreased, the latter being correlated to the level of wheat flour retrogradation.

Water absorption by wheat flour can be influenced by many factors, such as gluten quality, starch properties (damaged starch content and enzymatically treated starch), flour particle size and so on (Dabčević, Hadnadev, & Pojić, 2009). The increase of protein content is in good agreement with the increase of water absorption and stability time in our research. Dough development time is strongly influenced by gluten and starch properties and the flour particle size of wheat flour. Good gluten quality has longer dough development time than poor gluten quality when wetted and kneaded. The variation of wet gluten contents also showed a similar trend to dough development time. However, oxidized starch exhibited similar pasting properties to those from oxidized starches treated with low concentrations of chemical oxidizing agents and did not significantly influence dough development time as in the case of gluten properties. Dough stability time is mainly influenced by gluten quality and its resistance to kneading forces. The calculated results showed the same tendency to ozone treatment time, which may be attributed to changes in gluten properties, which are governed by different factors such as wheat variety, agroecological conditions during wheat growing, protease activity and milling conditions.

**Texture of steamed breads**

The effect of ozone treatment on steamed bread quality is shown in Figure 3. Ozone treatment had an effect on
α-amylase activity and gluten content of wheat flour. Reduced α-amylase activity prevented transfer of insoluble starch to soluble starch and the increased gluten content promoted the strength of wheat dough. Thus ozone treatment had a positive impact on the hardness of steamed breads. However, excessive ozone treatment time resulted in excessive damage to the gluten structure of wheat flour dough, which led to a decrease in the hardness of steamed breads. The elasticity, chewiness and resilience of steamed breads showed a similar tendency to hardness due to changes in α-amylase activity and gluten content in the wheat flour during ozone treatment.

### Sensory evaluation of steamed breads

The quality scores and sensory evaluations of the steamed breads are shown in Table 3. The quality scores of sample O-1.0 were higher than the other samples. At the same time, this samples showed improvement in volume/weight, height, skin color, skin structure, external appearance and internal structure. However, the elasticity and toughness of sample O-0 were better than the other samples. Sample O-2.0 scored lowest in almost evaluation indices, which may as a result of the lowest α-amylase activity and gluten content among the wheat flour samples.

### Conclusions

Our results indicate that medium hard wheat flour can be oxidized by ozone gas. Wet gluten content, flour whiteness, falling number and carboxyl contents of wheat flour increased significantly. In regard to dough characteristics, peak viscosity, hot paste viscosity, breakdown, cold paste viscosity and total setback decreased while peak time and gelatinization temperature altered little. Carboxyl groups increased the swelling of starch granules during heating in water, which has a positive correlation with setback values. Ozone can be used as an oxidizing agent and added to flours to accelerate their natural maturing. As a result, the flour gradually becomes whiter and has improved dough properties. Ozone treatment for 1.0 h showed positive effects on quality scores, volume, volume/weight height and structure of steamed breads, and significantly influenced the texture of steamed bread.

### Disclosure statement

No potential conflict of interest was reported by the authors.

### Table 3. Effect of ozone treatment time on quality scores and sensory evaluation of steamed breads.

| Samples | Volume/weight | Height | Skin color | Skin structure | External appearance | Internal structure | Elasticity | Toughness | Stickiness | Taste | Quality score |
|---------|---------------|--------|------------|---------------|---------------------|-------------------|-------------|-----------|------------|-------|---------------|
| O-0     | 11.5 ± 0.8ab  | 3.6 ± 0.6ab | 7.5 ± 0.6a | 7.3 ± 0.6ab   | 7.3 ± 0.7a          | 11.0 ± 1.1ab      | 7.5 ± 0.6b | 7.5 ± 0.5d | 11.5 ± 0.9b | 3.9 ± 0.5bc | 78.6 ± 3.0b   |
| O-0.5   | 11.6 ± 0.9ab  | 3.8 ± 0.5b  | 7.5 ± 0.5a  | 7.3 ± 0.5ab   | 7.2 ± 0.7a          | 11.6 ± 0.6b       | 7.3 ± 0.5b | 7.3 ± 0.4 cd| 12.2 ± 1.0c | 4.1 ± 0.5c  | 79.9 ± 3.4b   |
| O-1.0   | 12.1 ± 1.0b  | 4.1 ± 0.6b  | 8.0 ± 0.7b  | 7.5 ± 0.5b    | 7.9 ± 0.9a          | 12.5 ± 0.7c       | 7.4 ± 0.6b | 7.0 ± 0.4c | 12.5 ± 0.5c | 4.3 ± 0.4c  | 82.8 ± 3.3c   |
| O-1.5   | 11.5 ± 0.8ab  | 3.8 ± 0.5b  | 7.5 ± 0.5a  | 7.2 ± 0.7ab   | 7.2 ± 0.7a          | 11.4 ± 0.6b       | 7.0 ± 0.5b | 6.8 ± 0.4b | 11.5 ± 0.6b | 3.5 ± 0.5b  | 77.6 ± 2.8b   |
| O-2.0   | 11.1 ± 0.8a  | 3.2 ± 0.4a  | 7.2 ± 0.6a  | 6.9 ± 0.6a    | 6.8 ± 0.9a          | 10.5 ± 0.6a       | 6.5 ± 0.5a | 6.0 ± 0.5a | 10.1 ± 0.6a | 3.1 ± 0.5a  | 71.5 ± 3.0a   |

Data shown as mean ± standard deviation.

α-d Values for different treatment times followed by the same letter are not significantly different (P > 0.05).

Los datos muestran promedio ± desviación estándar.

Los valores a-d entre los diferentes tiempos de tratamiento seguidos por la misma letra no son significativamente diferentes (P > 0.05).

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