Comparison study of the effect of green tea extract (GTE) on the quality of bread by instrumental analysis and sensory evaluation

Rong Wang, Weibiao Zhou *, Mia Isabelle

Food Science and Technology Programme, Department of Chemistry, National University of Singapore, Science Drive 4, Singapore 117543, Singapore

Received 30 January 2006; accepted 4 July 2006

Abstract

Sensory evaluation techniques and instrumental analyses were used to investigate the changes in crumb appearance, texture properties and taste profile of bread containing tea antioxidants. Bread incorporating green tea extract (GTE) at the levels of 1.5 and 5.0 g/kg flour was analyzed concurrently with the control in a random order by panelists. Sensory analysis was carried out through a descriptive profiling test by both un-trained panelists and trained panelists. A total of six sensory attributes including brightness, porosity, hardness, stickiness, sweetness and astringency were evaluated. Instrumental analyses included image analysis for porosity, spectrophotometric measurement for brightness, and texture profile analysis for hardness and stickiness. Results showed that the sensory evaluation was generally correlated well with the instrumental analysis. With an increase in the level of GTE, the brightness and sweetness of the bread with GTE decreased, whereas the hardness, stickiness and astringency increased. No significant difference in the histogram of cell diameter (porosity) was found. The threshold level of GTE was at 5.0 g/kg flour for astringency and sweetness, and 1.5 g/kg flour for brightness, hardness and stickiness.

© 2006 Elsevier Ltd. All rights reserved.

Keywords: Bread; Sensory quality; Texture profile analysis; Porosity; Green tea extract

1. Introduction

As a traditional and important food in the daily diet, wheat bread was reported having increased consumption since 1995 (Kihlberg, Johansson, Kohler, & Risvik, 2004). Meanwhile, the demands for wheat-based products with value-added are growing rapidly in the past few decades (Bhattacharya, Langstaff, & Berzonsky, 2003) as consumers realized that eating foods with health benefits is better than taking supplements (Martin, 2005). This requires the research communities and manufacturers to rejuvenate wheat-based products such as bread with health benefits. Many nutrients are inherent or have been fortified in bread, such as minerals, fiber, vitamins, and even some essential oils containing natural antioxidants etc. (Magan, Arroyo, & Aldred, 2003). Blueberries and chocolate were examples in a report on the 2005 food trends, due to their containing of natural antioxidants (Martin, 2005).

Tea and tea products mainly contain tea polyphenols, which are natural antioxidants and have been demonstrated to show antioxidative, anti-carcinogenic and antimicrobial properties by many researchers (McKay & Blumberg, 2002; Rietveld & Wiseman, 2003). These health benefits of teas, in particular green tea, are gaining increased attention in recent years. Green tea contains the most abundant tea polyphenols, namely tea catechins. They are nowadays utilised in a wide range of applications, such as food, beverage, cosmetics toiletries etc. (Wang, Provan, & Helliwell, 2000). However, very little attention was focused on the addition of tea or tea products to bread which is consumed daily. Green tea extract (GTE) as an excellent source of tea polyphenols, especially tea catechins, was added to bread dough in a no-time breadmaking process in our previous reports (Wang & Zhou, 2004; Wang, Zhou, Yu, & Chow, 2006). It was found that tea...
catechins were relatively stable in breadmaking, having 84% of the total tea catechins remained after baking as well as during its shelf life (Wang & Zhou, 2004). On the other hand, instrumental results revealed some negative impacts on the quality of bread with GTE, giving smaller bread volume and harder crumb (Wang et al., 2006).

Although the instrumental measurements, for example, texture profile analysis (TPA) could provide valuable information to producers on the potential perception of consumers on a product in the first place, it was reported that consumers’ acceptance does not just simply rely on the texture characteristics of the product. Some important characteristics such as flavor and taste are difficult to be assessed instrumentally, and the taste profile of bread is considered very important to consumers (Kihlberg et al., 2004). How much of the green tea catechins responsible for most of the sensory characteristics associated with bread quality as well as consumers’ perception level is unknown at the present time. Hence, there is a need to carry out a sensory study on the quality of bread with addition of GTE.

Quantitative descriptive analysis (QDA) and spectrum method are commonly used in sensory evaluation. QDA employs specific experimental design and statistical analysis such as analysis of variance (ANOVA) to ensure the validity of the results from independent panelists. Spectrum Method includes a high degree of calibration of panelists for intensity scale points to achieve reproducible and repeatable sensory results for specific characteristics of a product. In order to obtain a valid sensory test with good acuity, low error variance and statistical significance, hybrid approaches of the above two methods are commonly adopted by many users (Lawless & Heymann, 1999). In the present study, a hybrid design based on these two methods was also used.

This paper focuses on the sensory quality of bread containing GTE at different levels produced by a no-time breadmaking process to provide a correlation between the sensory evaluation and instrumental analysis on the product. Meanwhile an appropriate threshold level of GTE, which could be significantly detected by trained panelists, was also investigated.

2. Experimental

2.1. Materials

Bread flour (Clover brand, 14% moisture) was obtained from Prima Ltd. (Singapore). Fine sugar and shortening were purchased from Phoon Huat & Co Pte Ltd. (Singapore). Fine salt of 99.9% purity was purchased from Ng Nam Bee Pte Ltd. (Singapore). Instant dry yeast (Saccharomyces cerevisiae) was obtained from Algict Bruggeman N.V (Belgium). Food grade L-ascorbic acid was obtained from Sino Chemical & Co Pte Ltd. GTE was purchased from Pure Herbal Remedies Pte Ltd. (Singapore), originally from green tea leaves (Camellia sinensis) harvested in Guangxi, China. The GTE used in the study contained 60% total tea catechins (Wang & Zhou, 2004).

2.2. Preparation of bread

Bread samples were prepared using a no-time breadmaking process (Wang & Zhou, 2004) with slight modification. The materials used in control bread with 1 kg flour basis, contained 590 g water, 40 g fine sugar, 30 g shortening, 20 g fine salt, 10 g yeast, and 0.1 g L-ascorbic acid. GTE was added at the levels of 1.5 and 5.0 g/kg flour, respectively. Dough mixing was completed within 5.5–6 min in a mixer (Globe WAG-RN20, Denmark) using high speed with final dough temperature controlled at 24–24.5 °C. Three batches of bread with different formulation were randomized and made successively at this stage. The impact of batch sequence on the corresponding bread quality after baking was also examined by TPA. Dough was moulded and divided automatically by a bread-moulder (DR-ROBOT², Netherlands). Eight pieces of dough (57 g) were obtained from each batch. After a resting of 10 min at room temperature (22 °C), dough was proofed for 70 min at 40 °C with 95% relative humidity. They were then baked for 11 min at an oven temperature of 215 °C.

2.3. Instrumental analyses

After 1 h of cooling in ambience, bread was proceeded to instrumental measurements and sensory tests. One part of bread was cut into slices of 12.5 mm thickness mechanically by a bread slicer (Rhino CM-36, Taiwan). The central slice was used for the tests of color intensity, porosity and TPA. Porosity was analyzed by an image analysis software (Micro Image 4.5, USA). Using a CM-3500 d spectrophotometer (Minolta, Japan), color intensity was measured and expressed as the L*a*b* values, where L* represents whiteness (value 100) or blackness (value 0), a* represents red (+a) or green (−a), and b* represents yellow (+b) or blue (−b). TPA including hardness and stickiness was carried out on a TA-XT2i texture analyzer (Stable Micro System, UK) with a probe of 20 mm diameter (Wang et al., 2006). The other part of bread was manually cut into cubes of approximate 15 mm size and sealed in polyethylene (PE) plastic bags for immediate sensory evaluation.

2.4. Experimental design of sensory evaluation

Sensory evaluation of bread was conducted using a descriptive profiling test, which combined QDA and Spectrum methods with slight modifications (Lawless & Heymann, 1999; Meilgaard, Civile, & Carr, 1999). Six attributes of bread, i.e. porosity, brightness, hardness, stickiness, astringency and sweetness were selected according to a list of standardized lexicon of terms for bread evaluation (Meilgaard et al., 1999). Reference products for each attribute were agreed unanimously as the sensory intensity index by the panel. For the attribute of astrin-
gency, preparation of the reference and the training program were according to the method described in Drobná, Wismer, and Goonewardene (2004) with necessary modifications. Five intensity anchors for each of the attributes were evenly placed at 0, 2.5, 5, 7.5 and 10 of the scale line (0–10). Each attribute was assessed for three different samples at a time. Plain water was used to rinse mouth between samples, and plain bread purchased from local market was used to remove residual taste before reading the attributes “sweetness” and “astringency”. Astringency was also the last sensation to be detected. All sensory sessions were carried out in separate booths equipped with a computerized system and sensory software (FIZZ 2.01, France) where the sensory data were recorded directly. Samples were assigned 3-digit codes and their serving orders were randomized by the software.

There were three major stages in the sensory evaluation performed by the panelists, who were recruited from the staff and students of the National University of Singapore. At the first stage, the evaluation was performed by 30 untrained panelists without replicate. At the second stage, in order to identify the significant differences among the products, the panelists, and the sessions as well as to reduce the variability and bias from the panelists, a training program was conducted. During the training course, reference materials that showed gradient intensities for each of the attributes were given to the panelists for calibration. Eight qualified panelists, who were able to recognize specific characteristics of the attributes, were selected for descriptive profiling test to detect the changes in the sensory quality between the control and the GTE bread. Sensory evaluation in this stage was performed under normal condition. At the last stage, the same group of trained panelists conducted the sensory evaluation under colour masked condition, in which red-bulbs and opaque plastic were used in order to eliminate bias likely from the product appearance. As such, the brightness attribute was removed from the analysis in this stage. Triplicate sessions were performed at the last two stages by the trained panelists. The sensory evaluation results were then compared with the instrumental results.

2.5. Statistical analysis of the experimental results

All the mean values and standard deviations from at least triplicate tests were analyzed by several statistical methods. The instrumental results were tested by single-factor ANOVA. The sensory results obtained by untrained panelists was analysed by two-factor (panelist and product) ANOVA. Results of the descriptive analysis by the trained panelists were tested by three-factor (panelist, product and session) ANOVA. Multiple mean comparisons such as Duncan test was also carried out at the corresponding level of significance to determine whether the significant difference in a particular attribute was due to the product, the panelist, or the session variations. Meanwhile, Duncan test was also used for selecting qualified panelists.

3. Results and discussion

3.1. Impact of GTE on bread color

The GTE used in the present study was a fine and water soluble powder, which was brown color in appearance. Therefore, it is expected that bread with GTE had different color from the control. Comparison of bread color between the control and bread with two levels of GTE is listed in Table 1. From the results of the descriptive analysis performed by 30 untrained panelists and 8 trained panelists respectively, both evaluations showed similar result, i.e. with an increase of GTE in bread, a decrease in brightness was perceived significantly (\(P < 0.001\)) among the three variants. Statistical analysis of the variances proved that the change in brightness was due to the change in the GTE concentration. The difference in brightness could be significantly detected with GTE at 1.5 g/kg flour by both the untrained panelists and the trained panelists. Spectrophotometric measurement showed a consistent trend in bread color with the sensory test. For bread with more GTE added, the \(L^*\) value reduced but the \(a^*\) value increased. This means decreased brightness and increased red color. It is interesting to note that the \(b^*\) value i.e. yellow color did not show an increase or decrease trend as the other two values did. Nevertheless, the \(L^*, a^*\) and \(b^*\) values were all significantly different (\(P < 0.001\)) between the control and the bread with GTE at the two levels.

Based on our previous study (Wang & Zhou, 2004), the \(L^*\) value of the GTE bread in this research fell into the range of market products, such as whole meal bread and fiber enriched bread. Therefore, no consumer acceptability problem due to color is expected for bread containing GTE up to the level of 5 g/kg flour.

3.2. Effect of GTE on bread porosity

Porosity refers to the pore structure in the crumb (Baardseth, Kvaal, Lea, Ellekjaer, & Faergestad, 2000). The results on porosity from the 30 untrained panelists did not show any significant difference (\(P < 0.05\)) among the three variants of bread according to the ANOVA tests on the products and panelists, respectively (Section A of Table 2). Meanwhile, images of the bread crumb (Fig. 1) recorded by a digital camera (Olympus C-5060, UK) and processed by Micro Image software using Hi-Gauss enhancement filters. Results of the image analysis showed that the bread with GTE at the level of 5.0 g/kg flour was significantly different (\(P < 0.05\)) from the other two variants in the number of cells per mm\(^2\) and mean cell diameter (Section B of Table 2). However, the histogram results from the image analysis exhibited no apparent difference in the major range of cell diameter (0.1–0.2 mm) and cell distribution among the control and bread with GTE at the two levels (Fig. 2). The undifferentiable sensory results of porosity could be due to the fact that visual detection was difficult to discern the micro-variation in cell
Table 1
Comparison of the bread color intensity values between the sensory evaluation and spectrophotometric measurement

<table>
<thead>
<tr>
<th></th>
<th>Control bread</th>
<th>Bread with GTE 1.5 g/kg flour</th>
<th>Bread with GTE 5.0 g/kg flour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightness intensity (%)&lt;sub&gt;a&lt;/sub&gt;, by untrained panelists&lt;sub&gt;b&lt;/sub&gt;, n = 30</td>
<td>7.63 ± 0.70</td>
<td>4.24 ± 1.11</td>
<td>3.07 ± 0.91</td>
</tr>
<tr>
<td>Brightness intensity (%)&lt;sub&gt;c&lt;/sub&gt;, by trained panelists&lt;sub&gt;d&lt;/sub&gt;, n = 24&lt;sup&gt;e&lt;/sup&gt;</td>
<td>7.83 ± 0.78</td>
<td>4.64 ± 1.04</td>
<td>3.23 ± 0.68</td>
</tr>
<tr>
<td>Color values measured by spectrophotometer&lt;sub&gt;d&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( L^* )</td>
<td>77.41 ± 0.35</td>
<td>69.99 ± 0.94</td>
<td>63.99 ± 1.17</td>
</tr>
<tr>
<td>( a^* )</td>
<td>-0.81 ± 0.01</td>
<td>0.73 ± 0.12</td>
<td>2.18 ± 0.22</td>
</tr>
<tr>
<td>( b^* )</td>
<td>12.73 ± 0.52</td>
<td>10.54 ± 0.22</td>
<td>11.28 ± 0.39</td>
</tr>
</tbody>
</table>

<sup>a</sup> All data in the table are significantly different at \( P < 0.001 \) using ANOVA test.
<sup>b</sup> Higher value indicates brighter in color, obtained from sensory evaluation.
<sup>c</sup> Results were expressed as mean ± standard deviation, perceived by 8 trained panelists in triplicate sensory sessions.
<sup>d</sup> Results were expressed as mean ± standard deviation from at least triplicate measurements.

Table 2
Results of sensory evaluation and image analysis of the crumb porosity

<table>
<thead>
<tr>
<th></th>
<th>Control bread</th>
<th>Bread with GTE 1.5 g/kg flour</th>
<th>Bread with GTE 5.0 g/kg flour</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: results of sensory evaluation (n = 30)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porosity intensity</td>
<td>4.81 ± 2.37&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.53 ± 2.71&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.92 ± 2.01&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>B: results of image analysis (n = 10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of cells per mm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>4.6 ± 0.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.1 ± 0.6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.2 ± 0.4&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total cell area/total measured area, %&lt;sup&gt;e&lt;/sup&gt;</td>
<td>40.3 ± 3.5&lt;sup&gt;e&lt;/sup&gt;</td>
<td>35.1 ± 4.3&lt;sup&gt;f&lt;/sup&gt;</td>
<td>37.2 ± 2.3&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>Min. cell diameter, mm</td>
<td>0.01 ± 0.00&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.01 ± 0.00&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0.01 ± 0.00&lt;sup&gt;g&lt;/sup&gt;</td>
</tr>
<tr>
<td>Max. cell diameter, mm</td>
<td>4.48 ± 0.87&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.21 ± 0.67&lt;sup&gt;h&lt;/sup&gt;</td>
<td>3.47 ± 0.58&lt;sup&gt;i&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean diameter, mm</td>
<td>0.17 ± 0.01&lt;sup&gt;i&lt;/sup&gt;</td>
<td>0.18 ± 0.02&lt;sup&gt;j&lt;/sup&gt;</td>
<td>0.22 ± 0.01&lt;sup&gt;k&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>-<sup>k</sup>Means with the same superscript letters are not significantly different (\( P < 0.05 \)).

Fig. 1. Crumb image of the center slices of bread. (a) Control bread, (b) bread with GTE 1.5 g/kg flour and (c) bread with GTE 5.0 g/kg flour.

Fig. 2. Histogram of crumb cell diameter (mean, n = 10).

Please cite this article as: Rong Wang et al., Comparison study of the effect of green tea extract (GTE) on the quality of bread by instrumental analysis and sensory evaluation, Food Research International (2006), doi:10.1016/j.foodres.2006.07.007.
diameter among the three variants. The high percentage (26–33%) of cell diameter in the range of 0.1–0.2 mm could play an important role in the sensory evaluation, responsible for the non-significantly-different ratings perceived by the 30 untrained panelists.

In addition, results of the image analysis in Table 2 revealed that the cell number per mm² and total cell area in the GTE bread was decreased compared to the control. In other words, the density of the bread was increased and the bread volume was reduced when GTE was added. These results were consistent with our previous study that the bread specific volume was significantly reduced at the level of 1.5 g GTE/kg flour (Wang et al., 2006).

Porosity of bread is affected significantly by mixing and proofing processes (Baardseth et al., 2000). During mixing, the involved air form gas cells as nucleation sites for the following CO₂ gas generated by yeast activity during proofing. Meanwhile the involved oxygen aids the oxidation of ascorbic acid to dehydroascorbic acid, which helps the formation of gluten network. The three-dimension protein network traps gases and the embedded gases expend the dough, leading to a porous structure after baking (Campbell, 2003). The image analysis results of porosity may indicate that the formation of bubble cells in dough was affected by the addition of GTE during mixing at the current levels of 1.5 and 5.0 g/kg flour.

3.3. Changes in taste profile: sweetness and astringency in bread with added GTE

Sweetness is one of the important taste characteristics in food acceptance (Lawless & Heymann, 1999). Meanwhile, astringency is the characteristic taste of green tea products. As it is difficult to determine a taste profile such as sweetness and astringency by instrumental measurements, an investigation of the impact of GTE on bread taste profile by sensory evaluation is necessary. The attributes of sweetness and astringency were tested in three separate sensory sessions involving untrained and trained panelists. Significant difference in the sweetness of bread between the control and the GTE bread was detected in all sessions. It can be seen from Table 3 that GTE at the level of 5.0 g/kg flour significantly reduced the sweetness and gave the strongest astringency perceived by both the untrained and the trained panelists (P < 0.01). The sweetness and astringency of bread with GTE at the level of 1.5 g/kg flour were in between the control and the bread with 5.0 g GTE/kg flour. The sweetness in the GTE bread decreased with the arising of astringency. Mean comparison by Duncan test revealed that the more GTE added in bread, the more intensive astringency was detected. Astringency was perceived significantly by the untrained panelists at P < 0.1, whereas the trained panelists detected the astringency more sensitively at P < 0.01.

It has been reported that tea catechins are responsible for the tastes of astringency, especially epigallocatechin gallate (EGCG) (Scharbert & Hofmann, 2005). Among the four major epicatechins and their epimers, EGCG exhibits the lowest threshold concentrations for the astringency in liquids at 190 μmol/L. The rest of catechins are also responsible for the astringency but at relatively higher threshold concentrations. In the GTE used in the present study, EGCG is the most abundant catechin (24%). According to our previous study (Wang & Zhou, 2004), there was ≈83% of EGCG remained in bread crumb after baking. In other words, there were about 437 and 1457 μmol EGCG/kg in the crumb of the bread with GTE at the levels of 1.5 and 5.0 g/kg flour, respectively. Hence, the adequate amount of EGCG as well as other catechins in GTE would likely enable the panelists to detect the astringency, although bread is a solid product.

The decreased ratings of sweetness with large variation in GTE bread could be due to the small intensity of sweetness because there was 4% sugar (flour basis) in the bread formula. The other taste sensations such as astringency and

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Mean comparison of bread sweetness and astringency intensity, analyzed by Duncan test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensory sessions</td>
<td>Level of significance, P</td>
</tr>
<tr>
<td><strong>A: Sweetness intensity</strong></td>
<td></td>
</tr>
<tr>
<td>Untrained panelists, n = 30</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Trained panelists under normal condition, n = 24^a</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Trained panelists under color masked condition, n = 24^a</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td><strong>B: Astringency intensity</strong></td>
<td></td>
</tr>
<tr>
<td>Untrained panelists, n = 30</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Trained panelists under normal condition, n = 24^a</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Trained panelists under color masked condition, n = 24^a</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

^a**Means with the same superscript letters are not significantly different.

^bResults were expressed as mean ± standard deviation, perceived by eight trained panelists in triplicate sensory sessions.

Please cite this article as: Rong Wang et al., Comparison study of the effect of green tea extract (GTE) on the quality of bread by instrumental analysis and sensory evaluation, Food Research International (2006), doi:10.1016/j.foodres.2006.07.007.
bitterness, which are the intrinsic tastes of tea products although bitterness was not evaluated by the panelists in this study, could significantly suppress the sense of sweetness. In other words, the sense of sweetness became insensitive to be detected with the company of astringency and bitterness.

Meanwhile, large standard deviations in the astringency perceived by the panelists were found concurrently, whereas session replicates did not significantly ($P < 0.05$) contribute to the variations. In Table 3, it is noted that surprisingly the astringency was also detected in the control sample that contained no GTE. Astringency is a chemically induced complex of tactile sensations (Lawless & Heymann, 1999), which occurs when praline-rich proteins such as salivary proteins are precipitated in the mouth, causing lubricating effect lost (Kallithraka, Bakker, Clifford, & Valvis, 2001). It was reported that EGCG was able to precipitate protein (Hagerman, Dean, & Davies, 2003). Variation in the astringency ratings could be due to the different salivary flow produced in individual panelists. Panelists who generate greater amount of saliva are expected to rate lower level of astringency intensity (Drobna et al., 2004). The ratings of the control bread could be due to the different perception to astringency by the panelists. However, the possibility of minute residual taste from the previous test sample of bread with added GTE could not be completely ruled out.

3.4. Changes in textural characteristics: hardness and stickiness in bread with added GTE

Hardness, an important characteristic, is commonly used as an index to determine bread quality, as change in hardness is frequently accompanied with loss of resilience during storage (Spices, 1990). In this study, hardness was selected as one of the quality indices in both sensory evaluation and instrumental analysis.

The hardness of bread was found to increase with increased GTE concentration in both investigations, i.e. the sensory evaluation and texture profile analysis (Fig. 3). Results from the sensory session by the untrained panelists showed that there was no significant difference ($P < 0.05$) among the products, due to the large standard deviations in the mean values as shown in Fig. 3a. ANOVA tests revealed that the variations were significantly ($P < 0.001$) attributed to the varied perception of the untrained panelists. Meanwhile, results from the sessions involving 8 trained panelists under both normal and color masked conditions showed significant differences ($P < 0.01$) among the three variants. Compared to the untrained panelists, the trained panelists produced slightly lower average hardness which remained in the same trend. The variations from the trained panelists were smaller than those from the untrained panelists. The narrowest variation was found in the session with color masked condition. ANOVA tests showed that the variations were significantly ($P < 0.001$) attributed to the varied perception of the trained panelists, while Duncan tests showed that the session replicates did not contribute significantly ($P < 0.01$) to the variations. Varied hardness ratings were found among the trained panelists, whereas all individual panelists rated hardness consistently. This is reasonable because among the trained panelists, the ratings could be varied according to the individual perception to hardness.

Comparing the mean values of the sensory tests by the trained panelists in both normal and color masked conditions using Duncan test revealed that the bread with GTE was significantly ($P < 0.01$) harder than the control at the level of 5.0 g GTE/kg flour. TPA tests showed similar results, in which the bread hardness increased signifi-
Significantly \((P < 0.05)\) at the level of 5.0 g GTE/kg flour, and insignificantly at 1.5 g GTE/kg flour (Fig. 3b). The TPA results are in agreement with the findings of our previous study on the effect of GTE on unfrozen dough breadmaking process (Wang et al., 2006), which reported that there was an increase in bread hardness with the increase of GTE, significantly at 5.0 g/kg flour.

Stickiness is another important attribute for bread quality. In a typical TPA graph, stickiness is the negative force area between the first and second bite (Bourne, 1982). Three products including Fuji apple, muffin and Mars chocolate were measured by the texture analyzer and selected as the references for stickiness intensity in the sensory evaluation, rated as “not sticky”, “moderately sticky”, and “very sticky”, respectively. Results obtained instrumentally showed that the stickiness of the control and the GTE bread was well within the range of the three references (data not shown). Results perceived by the untrained panelists showed no significant difference in stickiness among the three bread variants (Fig. 4a). Significant difference \((P < 0.01)\) in the bread with 5.0 g GTE/kg flour from the other two bread variants was perceived by the trained panelists under both normal and color masked conditions. TPA results showed that there was an increase in the stickiness with increased level of GTE. The stickiness of the bread with 5.0 g GTE/kg flour significantly differed from that of the control at \(P < 0.01\), whereas the bread with 1.5 g GTE/kg flour was similar to the control (Fig. 4b). Large variation of stickiness was found significantly attributed to the varied perception of the trained panelists \((P < 0.001)\). ANOVA tests on the TPA and sensory results showed that there was no significant difference in bread stickiness in replicate sessions. Similar to the results on hardness, the stickiness was rated consistently by the individual trained panelists in different sessions, but varied largely among the trained panelists. The varied results were subjected to different perception to stickiness by individual trained panelists.

As bread matrix is a complex system, the mechanism responsible for the increment of bread hardness with elevated GTE still remains unknown. The varied hardness in GTE bread might be explained by the affected enzyme activity and yeast activity. Zhang and Kashket (1998) reported that green tea polyphenols depressed the activity of the amylase in human saliva, producing less maltose which is commonly adopted as an indicator for the activity of amylases. Therefore, it is likely that the activities of amylases in wheat dough might be restricted, leading to insufficient maltose for yeast activity during proofing. As a result, the yeasts’ gassing power was confined; subsequently a smaller volume of bread with relatively harder and denser texture was obtained. The denser texture would give a stickier perception to the panelists. In addition, Turchetti et al. (2005) reported that GTE was able to inhibit the activity of yeast *Saccharomyces cerevisiae* (Strain DBVPG 6173), with its minimum inhibitory concentration (MIC) at 1006 μg/mL of total green tea polyphenols. The concentration levels of total tea catechins were approximately 533 and 1775 μg/g (wet basis) in the dough with GTE at 1.5 and 5.0 g/kg flour, respectively. Therefore, it is possible that the bakers’ yeast activity in bread dough could be partially depressed by GTE at an effective level around 1.5 g/kg flour, which also caused a poorer gassing power. Subsequently, bread with smaller volume was produced that had relatively harder and denser texture, by which a relatively stickier texture would be perceived by the panelists when compared to the control. However, the model used in the study of Turchetti et al. (2005) contained bio-medium that was much different from the bread dough model which is a multiphase system. Hence, further
Table 4
Comparison of the attributes perceived by the trained panelists under normal condition and color masked condition using Duncan test, \( P < 0.01 \)

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Control bread 1.5 g/kg flour</th>
<th>Bread with GTE 1.5 g/kg flour</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Trained panelists under normal condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stickiness</td>
<td>2.02 ± 0.77 ( ^a )</td>
<td>2.48 ± 0.77 ( ^b )</td>
</tr>
<tr>
<td>Hardness</td>
<td>2.40 ± 0.66 ( ^a )</td>
<td>2.88 ± 0.76 ( ^a )</td>
</tr>
<tr>
<td>Astringency</td>
<td>0.24 ± 0.46 ( ^a )</td>
<td>0.65 ± 0.72 ( ^b )</td>
</tr>
<tr>
<td>Sweetness</td>
<td>1.65 ± 1.00 ( ^a )</td>
<td>1.26 ± 1.01 ( ^a )</td>
</tr>
<tr>
<td>B: Trained panelists under color masked condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stickiness</td>
<td>2.00 ± 0.57 ( ^a )</td>
<td>2.25 ± 0.52 ( ^m )</td>
</tr>
<tr>
<td>Hardness</td>
<td>2.08 ± 0.70 ( ^a )</td>
<td>2.52 ± 0.51 ( ^a )</td>
</tr>
<tr>
<td>Astringency</td>
<td>0.94 ± 1.36 ( ^a )</td>
<td>1.27 ± 1.26 ( ^m )</td>
</tr>
<tr>
<td>Sweetness</td>
<td>2.06 ± 0.75 ( ^a )</td>
<td>1.93 ± 0.77 ( ^m )</td>
</tr>
</tbody>
</table>

\* Means with the same superscript letters are not significantly different.

Investigation of the effects of GTE on baker's yeast activity as well as amylase activity is necessary.

3.5. Role and effectiveness of color masked condition

Trained panelists are commonly endorsed in research communities and industries. However, problems can arise due to the apparent similarity of some sensory tests conducted even by trained panelists (Lawless & Heymann, 1999). From the sensory analysis results performed by the trained panelists under normal condition, the panelists seemed to be very discriminative as they could detect the differences among the control and the GTE bread in almost all attributes (Section A of Table 4), while the standard deviations were relatively large. ANOVA tests indicated that the large variations in the attributes were due to the panelist perceptions (\( P < 0.001 \)). There could be biases induced by the psychological effect on similar bread products which were just distinctive in brightness. In order to improve the reliability of the information obtained from the trained panelists, a sensory protocol with color masked condition was employed.

In the color masked sensory sessions, potential biasing factors from the product appearance were eliminated. Bread was kept in opaque PE bags with randomly blind-labeled. Lighting in the sensory booths used red-bulbs. It can be seen that the average stickiness and hardness among the three bread variants under the color masked condition were smaller than those under normal condition while their standard deviations were mostly reduced concurrently in the color masked sessions (Section B of Table 4). The average sweetness and astringency were higher than those under normal condition, resulting in their standard deviations became smaller in relative to the mean values. In general, the sensory analysis conducted by the trained panelists under the color masked condition was effective.

The overall bread quality perceived under color masked condition is showed in Fig. 5, where the attribute of brightness was obtained from the sensory tests under the normal condition. It is clearly showed that brightness of the crumb was the attribute with the most significant difference whereas sweetness was the one with the least difference among the three bread variants. The attributes of astringency, hardness and stickiness also showed evident differences, with their ranges much smaller than that of brightness.

3.6. Correlation between the sensory evaluation and instrumental analysis

Sensory evaluation is a quantitative technique in which numerical data are collected to establish lawful and specific relationships between product characteristics and human perception (Lawless & Heymann, 1999). It is desirable to correlate the sensory results with instrumental analysis. The use of instrumental measurements is usually to substitute sensory panels due to cost and/or efficiency. Correlation results for three of the bread attributes, i.e. brightness, stickiness and hardness are listed in Table 5. It can be seen that the sensory results of the bread brightness were highly correlated to those from the instrumental analysis, for both untrained and trained panelists with correlation coefficient \( r^2 > 0.95 \). Furthermore, the correlation was higher for the trained panelists. It was found that the \( r^2 \) values of exponential regression was higher than those of linear regression, especially for the trained panelists (\( r^2 = 0.9982 \)). This indicates that the exponential correlation would be more appropriate to describe the relationship between bread brightness by the sensory evaluation and that by the instrumental analysis. Meanwhile, the sensory results of bread stickiness conducted by the 30 untrained panelists were found not well correlated either linearly or exponentially with the instrumental results (\( r^2 \approx 0.56 \)). The lower \( r^2 \) values could be due to the large variation perceived by the untrained panelists. Nevertheless, the correlation was significantly improved by the trained panelists (\( r^2 > 0.95 \)). The sensory evaluations con-
Conducted by the trained panelists under both normal and color masked conditions showed similar results for the stickiness. However, the correlation coefficients for the hardness were relatively low \((r^2: 0.79–0.89)\) for the trained panelists, and the correlation was high for the untrained panelists. This may be due to the different mechanisms in the description of hardness between the instrumental analysis and sensory evaluation. TPA results have revealed that there was no significant difference in hardness between the instrumental analysis and sensory evaluation. TPA results have revealed that the sensory evaluation was generally correlated well with the instrumental analysis in the present research. Using the presented scheme, relatively low random errors and good sensory acuity were obtained.

The results in this paper, together with those from our earlier studies (Wang & Zhou, 2004; Wang et al., 2006), provide useful information on the threshold value of GTE fortification in bread. Below the threshold value, both the product quality and sensory quality of GTE-fortified bread are not significantly compromised. Meanwhile the GTE-fortified bread is a functional food product with additional health benefits. This provides a good guide for those bread manufacturers who are to pursue the production of GTE-fortified bread.

### References


