Original paper

A Modified American Association of Cereal Chemists Method for Compressive Force Value Determination of White Bread Crumb Firmness

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Received February 4, 2016 ; Accepted April 11, 2016

A modified American Association of Cereal Chemists (AACC) parameter for white bread crumb, \( CFV_{20} \), was established using a 20-mm-diameter plunger, and represents an interchangeable parameter to compression force values (\( CFV \)) used in the AACC method. The relationship between \( CFV \) and storage days was expressed by a 2nd order polynomial equation. Using this equation, the storage days at maximum \( CFV \) was around 4 days at \( 5^\circ C \). In addition, mouthfeel firmness was evaluated by 20-year-old participants, and also showed a maximum score at around 4 storage days. Moreover, \( CFV_{20} \) reflected not only mouthfeel firmness but also tactile sensory score, resulting in a good parameter describing sensory white bread crumb firmness, and is interchangeable with \( CFV \) of the AACC method, evidenced by the high correlation between \( CFV_{20} \) and \( CFV \) of the AACC method.

Keywords: bread, firmness, mouthfeel, compression test, texture

Introduction

Bread quality is mainly influenced by bread texture (Gámbaro et al. 2002; Curic et al. 2008), which is determined based on sensory evaluation (Stöllman and Lundgren 1987; Elia 2011). Consumer acceptance can decrease when the crumb firmness increases (Eckardt et al. 2013). Thus, firmness is an important sensory attribute of bread (Redlinger et al. 1985). The American Association of Cereal Chemists (AACC) has developed a standard method for evaluating bread firmness (AACC 2000). The force (N) of 25-mm-thick bread compressed at 25% bread thickness was proposed as the compression force value (\( CFV \); AACC 2000; Baker et al. 1986a, b; Baker and Ponte 1987; Baker et al. 1988). This AACC method was adopted using a 36-mm-diameter plunger (AACC, 2000; Angioloni and Collar, 2009; Carr et al. 2006; Dogàn et al. 2012), which can be difficult to use because its wide measurement area makes obtaining sufficient sample numbers challenging. Although \( CFV \) can be compared using a 21-mm-diameter plunger for pup loaves (AACC 2000), many different measurement conditions have been applied (Stöllman and Lundgren 1987; Sidhu et al. 1997; Gámbaro et al. 2002; Mohamed et al. 2006; Bosmans et al., 2014; Gerits et al., 2015), resulting in various parameter values that are not comparable to \( CFV \) (Baker and Ponte 1987; Baker et al. 1988).

Moreover, the plunger speed for \( CFV \) in the AACC method is 100 mm/min, which makes conversion to the international unit inconvenient. Thus, a new AACC modified \( CFV \) parameter is required that is comparable to \( CFV \) of the AACC method.

In the present study, a modified \( CFV \) was compared to the original \( CFV \) for use in the AACC method. In addition, the number of storage days showing maximum bread firmness was determined using different conditions for \( CFV \) and compared to that established using sensory evaluation of bread firmness.

Materials and Methods

Bread slice preparation  As shown in Table 1, 280 g of commercial wheat flour (Camellia; Nisshin Foods, Inc., Tokyo,
Japan), 11 g of butter (Snow Brand Hokkaido Butter, unsalted; Megmilk Snow Brand, Co., Ltd., Tokyo, Japan), 20 g of sugar (The Spoon Brand; Mitsui Sugar Co., Ltd., Tokyo, Japan), 5 g of salt (The Salt Industry Center of Japan, Tokyo, Japan), and 200 g of distilled water were poured into a cell in an automatic baking bread machine (SD-BM103; Panasonic, Osaka, Japan) to avoid differences in dough preparation. After kneading the dough, 3 g of dry yeast (Lesaffre Co., Ltd., Marcg-en-Baroeul, France) was added to the dough and baked. Bread slices (25 mm thickness) were prepared 30 min after baking. The weight of baked white bread (Length of the loaves (Average ± standard deviation), 130.32 ± 0.85 mm; Width, 106.88 ± 1.37 mm; Height, 188.79 ± 4.72 mm) was 446.61 ± 4.60 g (Average ± standard deviation) (n=84).

Bread samples were stored in ziploc bags (Asahikasei Home Products Co., Ltd., Tokyo, Japan) at 5°C to prevent water evaporation (rate of weight decrease was below 0.3% even if stored for 5 days at 5°C), and were kept at 20°C for at least 2 h prior to the instrumental measurement and sensory evaluation. Half of the sample bread was examined for tactility based on direct touch with a finger and the other half for mouthfeel firmness.

Table 1. Formulation of white pan bread baked using a commercial automatic bread-baking machine

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Product company</th>
<th>Formula (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat flour</td>
<td>Camellia, Nisshin Foods, Japan</td>
<td>280</td>
</tr>
<tr>
<td>Butter</td>
<td>Snow Brand Hokkaido Butter, unsalted, Megmilk Snow Brand, Japan</td>
<td>11</td>
</tr>
<tr>
<td>Sugar</td>
<td>The Spoon Brand, Mitsui Sugar, Japan</td>
<td>20</td>
</tr>
<tr>
<td>Salt</td>
<td>The Salt Industry Center of Japan</td>
<td>5</td>
</tr>
<tr>
<td>Distilled water</td>
<td>–</td>
<td>200</td>
</tr>
<tr>
<td>Dried yeast</td>
<td>Lesaffre, France</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2. Description of the AACC Method 79-09 for white bread, and the modified AACC method

<table>
<thead>
<tr>
<th>Shape of plunger</th>
<th>Diameter of plunger (mm)</th>
<th>Speed of plunger (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified AACC method</td>
<td>20</td>
<td>300</td>
</tr>
<tr>
<td>AACC method 79-09</td>
<td>36, 21</td>
<td>100</td>
</tr>
<tr>
<td>(mm/s)</td>
<td>5</td>
<td>5/3*</td>
</tr>
</tbody>
</table>

* Not shown in AACC method 79-09.

A modified compression force value, $CFV_{20}$, was applied to analyze physical properties on force-deformation curves generated by a texturometer (RE2-3300SS; Yamaden Co., Ltd., Tokyo, Japan or Rheometer RT-2010D D-CW; Rheotech Co., Ltd., Tokyo, Japan), in which a single compression was applied using a 20-mm-diameter cylinder-type plunger according to the AACC method (AACC 2000; Baker et al. 1988) at 20°C (Table 2). $CFV$ was estimated based on force-deformation curves, and represents the force (N) at 25% deformation ($L = 6.25$ mm) at measurement points chosen to avoid the end effect of the loaf edge at several plunger speeds, in both the original and modified AACC methods. $CFV_{20}$ was measured at a total of n=25 with 5 as the number of repetitions (n=5 per bread). $CFV$ estimated using the AACC method was performed using the CT3-4500 Texture Analyzer (Brookfield Engineering Laboratories, Inc., Middleboro, MA) with 36-mm-diameter ($CFV_{36}$) or 21-mm-diameter plunger ($CFV_{21}$) at a 100 mm/min plunger speed at 20°C.

Sensory evaluation Two different sensory evaluations (mouthfeel firmness and tactility) were performed for bread stored for 2 h after baking, and then for 1–5 days at 5°C. The attribute of mouthfeel firmness is based on the force necessary to bite through a piece of bread (near the center). Bread tactility represents the firmness perceived by touching the bread crumb with one finger, and is very similar to manual hardness as described by Gámbaro et al. 2002. However, the use of tactility here is not synonymous with manual hardness found in the literature, since samples were not completely compressed for tactility assessment. The parameters were evaluated using a 5-point scale: from +2 for “very much firmer” to –2 for “very much softer” compared with the control score 0 of the bread stored for 3 days at 5°C. To ensure random selection for statistical analysis, participants were not trained to perform these sensory evaluations. Participants were 20 ± 1 (Average ± standard deviation)-year-old students at the Prefectural University of Hiroshima, which included 17 men and 33 women (total of 50 participants). Sensory evaluation scores for mouthfeel firmness were estimated by 9 randomly selected participants.

Determination of storage days showing maximum $CFV$ and mouthfeel firmness score The relationship between storage days and $CFV$ was described using the following 2nd order polynomial

$$y = ax^2 + bx + c$$

where $y$ is the $CFV$ value at each storage day, and $x$ is the storage day. The parameters $a$, $b$, and $c$ are determined by regression analysis. The maximum $CFV$ and mouthfeel firmness score were then determined by finding the peak point of the polynomial curve.
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equation:

\[ CFV = m_0 + m_1 \times D + m_2 \times D^2 \]  

Eq. 1

where \( m_0, m_1, \) and \( m_2 \) are empirical coefficients, and \( D \) is the storage days of bread.

Furthermore, using mouthfeel firmness score, the relationship between the sensory evaluation value and storage days was also expressed by a 2\(^{nd}\) order polynomial equation.

\[ S_{MF} = m_0 + m_1 \times D + m_2 \times D^2 \]  

Eq. 2

where \( S_{MF} \) is mouthfeel firmness score.

To estimate the number of storage days showing maximum bread firmness, both Eq. 1 and Eq. 2 were differentiated as follows:

\[ m_0 + 2m_1 \times D \]  

Eq. 3

Finally, the storage days with maximum firmness can be estimated for both cases according to Eq. 4.

\[ D = -m_0 / 2m_1 \]  

Eq. 4

**Statistical analysis** KaleidaGraph software (Synergy Software, Co., Ltd., PA, USA) was used for analysis of linear regression with standard deviation and \( R^2 \) coefficients. All coefficients in the 2\(^{nd}\) order polynomial equation were also calculated using this software. Average values were used in calculating the \( R^2 \) coefficients. An analysis of variance (one way-ANOVA) was conducted to determine statistical significance (\( p < 0.05 \)) with Tukey’s post-hoc test using the same software.

**Results and Discussion**

**Force-deformation curves using the modified AACC method**

All force-deformation curves for fresh-white bread, with different plunger diameters and/or plunger speeds, showed typical sigmoid force-deformation curves. The force values of the force-deformation curves generated using the 21-mm-diameter plunger at 100 mm/min plunger speed according to the AACC method were almost the same as those of the 20-mm-diameter plunger. In any case, the shape of force-deformation curves for bread crumbs corresponded to curves produced using the Instron Universal Testing Machine (Baker and Ponte 1987; Baker et al. 1988). These curves are characteristic of all bread firmness curves and are representative of the curves obtained using the AACC approved method 74-09 (AACC 2000; Baker et al. 1987; Baker et al. 1988).

The new modified AACC method adopted a 20-mm-diameter plunger with a compression speed of 5 mm/s; however, similar variation (0.63 ± 0.03 N for fresh-white bread, Average ± standard error, \( n = 45 \)) was observed as for a 1 mm/s plunger speed (0.49 ± 0.03 N, \( n = 20 \)). The faster rate represents greater measurement efficiency. Moreover, 1 mm/s may be too slow if \( CFV \) were used to mimic human mastication or tactility.

**Bread firmness at 5°C storage** As shown in Fig. 1, there was a very strong correlation, \( R^2 = 0.925 \), between \( CFV \) with a 21 mm-diameter plunger and with a 36-mm-diameter plunger, indicating that both \( CFV \) are very similar and valuable for determining bread firmness at 5°C storage, although the crosshead speed slightly affects the Instron force (Baker et al., 1986b). Of the two \( CFV \), \( CFV_{20} \) is recommended due to the larger area necessary for evaluation by \( CFV_{36} \) compared to that of \( CFV_{20} \). However, the plunger speed for both \( CFV \) was 100 mm/min, which is not easily converted to the international unit of 5/3 mm/s. Here, a modified compression force value for use in the AACC method was assessed, using a 20-mm-diameter plunger at a plunger speed of 5 mm/s.

In Fig. 2, \( CFV_{20} \) of the modified AACC method was compared to \( CFV_{21} \) of the AACC method. Results showed a close correlation between \( CFV_{20} \) and \( CFV_{21} \) despite the small difference in plunger diameter and plunger speed. Thus, this convenient AACC derived method using a 20-mm-diameter plunger produced a \( CFV \) parameter interchangeable with the original \( CFV \) of the AACC method, with \( R^2 = 0.975 \):

\[ CFV_{20} = -0.192 + 1.312 CFV_{21} \]  

Eq. 5

In this figure, \( CFV_{21} \) at 5 days was slightly lower than that at 4 days but the difference was not statistically significant.

**Relationship between storage days and \( CFV_{20} \) at various temperatures** The relationship between storage days and \( CFV_{20} \) of stored bread crumb was described in the 2\(^{nd}\) order polynomial equation with a high \( R^2 \) coefficient, as shown in Fig. 3. A close
relationship was also obtained for \( CFV_{t_0} \) of the white bread crumb stored at 20°C (\( R^2 = 0.992 \)) and the crumb stored at 40°C (\( R^2 = 0.990 \)), respectively. Thus, the coefficients of the 2nd order polynomial equation are listed in Table 3. Regardless of the plunger diameter and speed, the storage days with maximum \( CFV \) were clustered around 4 days with storage at 5°C. The storage day determined by \( CFV_{t_0} \) was compared with a different apparatus. As a result, the number of storage days with maximum \( CFV_{t_0} \) was estimated to be 3.7 – 4.5 days due to the coefficients in the adapted 2nd order polynomial equation being 0.551 – 0.772, 0.948 – 1.245, -0.106 - -0.170 for \( m_0 \), \( m_1 \), and \( m_2 \) respectively. In the case of bread stored at 20°C, the number of storage days with maximum \( CFV_{t_0} \) was also estimated to be around 4 days, whereas this was prolonged at 40°C. In fact, the maximum \( CFV_{t_0} \) at 40°C was ambiguous and was lower than the values at 5 and 20°C, as seen in Fig. 3. Bosmans et al. (2014) concluded the highest firming rate was obtained at 23°C, in a comparison of rates at -25, 4, and 23°C. However, the highest firming rate is generally accepted to be at 4°C, even in reference to their data.

In the case of \( CFV_{t_0} \), each coefficient was almost identical despite differences in plunger speed, representing 3.6 – 4.3 days for maximum \( CFV \). Additionally, the relationship between storage days and the mouthfeel firmness score could also be described by the 2nd order polynomial equation. Moreover, the estimated storage days with maximum mouthfeel firmness was 4.5 days, which fits closely with the days estimated by \( CFV \).

Gámbaro et al. (2002) compared the instrumental data and sensory measurement data, and showed a high correlation between values. However, the number of storage days showing maximum bread firmness has not been determined. Stöllman and Lundgren (1987) evaluated the softness of bread crumbs according to 20°C storage time, and revealed a significant decrease over the first 2 days, after which values fluctuated. This can be shown as a 2nd order polynomial curve with a high \( R^2 \) value. Angioloni and Collar (2009) showed the relationship between storage days and bread crumb firmness but did not describe the maximum firmness and associated storage days.

Staling of bread is a highly complex phenomenon (Baruch and Atkins 1989; Sidhu et al. 1997); however, the staling effect on bread crumb is dependent on storage days and can be qualitatively defined (Baruch and Atkin, 1989). Gerits et al. (2015) described the mechanism of crumb firmness due to amylase gelation and crystallization in initial stages and amylopectin retrogradation in later stages with water migration from gluten to starch. Bosmans et al. (2014) also concluded that the amylase network and thermostet gluten were involved in initial bread firmness and subsequent amylopectin retrogradation. Due to the intimate involvement of starch retrogradation in bread firmness, crumb firmness is usually fitted to a first kinetic model or the Avrami equation (Armero and Collar, 1998; Licciardello et al., 2014):

\[
(F_s - F_\infty) = (F_s - F_0) \exp (-kt^n) \]  \hspace{1cm} \text{Eq. 6}
\]

where \( F_s \), \( F_0 \), and \( F_\infty \) are crumb firmness at zero time, \( \infty \), and \( t \) time; \( k \) is a rate constant, and \( n \) is the Avrami exponent.

Eq. 6 is described below.

\[
F_t = F_s (1 - \exp (-kt^n)) + F_\infty \exp (-kt^n) \]  \hspace{1cm} \text{Eq. 7}
\]

Although the Avrami exponents were shown to be clearly different from one due to several effects on crumb firmness, \( n \) may conventionally equal one.

In fact, the relationship between \( CFV_{t_0} \) and storage days can be fitted to Eq. 7, with \( n \) being 1.098. In this case, \( F_s \) was estimated as 2.6 N, while 2.7 N was estimated using Eq.(1).

In addition, the relationship between the sensory evaluation values, \( S_{MFs} \), which indicates mouthfeel firmness score and storage days could be fitted to Eq. 8.

\[
S_{MFs} = S_{MFs}(1 - \exp (-kt^n)) + S_{MF0} \exp (-kt) \]  \hspace{1cm} \text{Eq. 8}
\]

where \( S_{MFs}, S_{MF0}, \) and \( S_{MF\infty} \) are mouthfeel firmness score at zero time, \( \infty \), and \( t \) time; \( k \) is a rate constant. This type of equation can be seen elsewhere but the usage of sensory evaluation values is supposed to be unique.

Finally, \( S_{MFs} \), can be estimated as 1.00 by the polynomial Eq. 2, while it is 1.10 by Eq. 8. Then, both Eq. 1 and Eq. 2 may be useful equations for predicting \( CFV \) or the sensory evaluation value vs. storage days. Though both Eq. 1 and Eq. 2 are empirical equations,
these equations have also been used as an empirical model for the relationship between concentration and viscosity (Marcotte et al., 2001). Therefore, viscosity reflects the consistency of a liquid. In addition, Eq. 7 could not be adopted, probably due to the number of samples, but all cases could be adopted in Eq. 1 and Eq. 2.

Among a number of direct or indirect indices of staling (Sidhu et al., 1997), bread firmness has been considered a potent macroscopic index that directly reflects consumer acceptance and is related to starch retrogradation during bread storage (Persaud et al. 1990; Giovanelli et al. 1997). Though the staling mechanism of white bread could not be revealed even when using $CFV_{20}$, $CFV_{20}$ represents a potent firmness parameter and a convenient indicator that is interchangeable with $CFV$ in the AACC method of white bread firmness. Moreover, the relationship between sensory evaluation and $CFV_{20}$ was investigated as follows.

**Relationship between mouthfeel firmness score and $CFV_{20}$ of white bread crumb** As shown in Fig. 4, there was a correlation between the sensory evaluation of mouthfeel firmness of white bread and $CFV_{20}$ using mechanical measurements ($R^2 = 0.977$). Gámbaro et al. (2002) compared values obtained by sensory evaluation with instrumental measurements, resulting in a positive correlation between instrumental hardness and oral hardness.
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measurement. However, a different instrumental condition from the AACC method was performed, using a 35-mm compression cylinder at 3 mm/s speed. These results suggested that several modified AACC methods can be applied to determine mouthfeel firmness.

In previous sensory evaluations, panel training was conducted to analyze bread texture (Gámbaro et al. 2002; Angioloni and Collar 2009; Tong et al. 2010; Elia 2011; Ho et al. 2013; Starr et al. 2012).

Table 3. Determination of storage days by maximum compression force value \( (CFV) \) using 2nd order polynomial equations for fresh white bread crumb stored at 5°C

<table>
<thead>
<tr>
<th>Diameter of plunger (mm)</th>
<th>Plunger speed</th>
<th>( m_0 )</th>
<th>( m_1 )</th>
<th>( m_2 )</th>
<th>( R^2 )</th>
<th>Day at Max ( CFV )</th>
<th>No. of points</th>
</tr>
</thead>
<tbody>
<tr>
<td>20*</td>
<td>5 mm/s</td>
<td>0.551</td>
<td>1.245</td>
<td>-0.170</td>
<td>0.970</td>
<td>3.7</td>
<td>6</td>
</tr>
<tr>
<td>20*₂</td>
<td>5 mm/s</td>
<td>0.722</td>
<td>0.948</td>
<td>-0.106</td>
<td>0.943</td>
<td>4.5</td>
<td>6</td>
</tr>
<tr>
<td>21*</td>
<td>5 mm/s</td>
<td>0.646</td>
<td>0.789</td>
<td>-0.071</td>
<td>0.998</td>
<td>4.1</td>
<td>4</td>
</tr>
<tr>
<td>21*</td>
<td>1 mm/s</td>
<td>0.581</td>
<td>0.857</td>
<td>-0.096</td>
<td>0.999</td>
<td>4.5</td>
<td>4</td>
</tr>
<tr>
<td>36*</td>
<td>1 mm/s</td>
<td>0.941</td>
<td>2.662</td>
<td>-0.371</td>
<td>0.992</td>
<td>3.6</td>
<td>4</td>
</tr>
<tr>
<td>36*₃</td>
<td>1 mm/s</td>
<td>1.216</td>
<td>2.621</td>
<td>-0.364</td>
<td>0.999</td>
<td>4.3</td>
<td>4</td>
</tr>
<tr>
<td>36*₃</td>
<td>100 mm/min</td>
<td>1.302</td>
<td>1.832</td>
<td>-0.216</td>
<td>0.998</td>
<td>4.2</td>
<td>4</td>
</tr>
<tr>
<td>21*₃</td>
<td>100 mm/min</td>
<td>0.720</td>
<td>0.694</td>
<td>-0.070</td>
<td>0.938</td>
<td>5.0</td>
<td>6</td>
</tr>
<tr>
<td>36</td>
<td>5 mm/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36*₃</td>
<td>100 mm/min</td>
<td>1.155</td>
<td>1.010</td>
<td>-0.113</td>
<td>0.876</td>
<td>4.5</td>
<td>6</td>
</tr>
</tbody>
</table>

\[ CFV = m_0 + m_1 \times D + m_2 \times D^2 \]

\[ S_{MF} = m_0 + m_1 \times D + m_2 \times D^2 \]

where \( S_{MF} \) means mouthfeel firmness score.

The abbreviation \( D \) means storage day.

The signs of \( m_0, m_1, \) and \( m_2 \) are empirical coefficients.

* RE-23005S (Yamaden)
*² Rheometer RT-2010D D-CW (Rheotech)
*³ CT3-4500 Texture Analyzer (Brookfield)

Fig. 4. Relationship between \( CFV_{20} \) of the modified AACC method and mouthfeel firmness scores for white bread crumb stored at 5°C. \( CFV \) means compressive force value, and the suffix represents the cylinder-type-plunger-diameter (mm). The \( CFV \) test conditions are shown in Table 2. The attribute of mouthfeel firmness is based on the force necessary to bite through a piece of bread. Each point represents the average value ± standard deviation (n=9 for each day). Suffix a and b, values with different letters in the same figure are significantly different (p < 0.05) by one way-ANOVA with Tukey’s test.

Fig. 5. Relationship between mouthfeel firmness scores and tactility scores for white bread crumb stored at 5°C. The attribute of mouthfeel firmness is based on the force necessary to bite through a piece of bread. Bread tactility represents the firmness perceived by touching the bread crumb with one finger. Each point represents the average value ± standard deviation (n=25 with 5 as the number of repeats (n=5 per bread) for each day). Suffix a–c, values with different letters are significantly different (p < 0.05) by one way-ANOVA with Tukey’s test.
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al. 2013). This training is typically done to reduce the variability in sensory evaluation. However, based on statistical concepts, random sampling must be adopted; thus, sensory evaluation was performed without training of the participants.

Using the average mouthfeel firmness scores, the relationship between storage days and mouthfeel firmness score was also described in a 2nd order polynomial equation (Table 3), and storage days at the maximum mouthfeel firmness score was estimated. Overall, the number of storage days with maximum firmness was closely clustered around 4 days, even when the mouthfeel firmness score was applied.

Relationship between mouthfeel firmness score and tactility of white bread The mouthfeel firmness score is closely associated with tactility ($R^2$ value of 0.910) as shown in Fig. 5. Therefore, tactility scores can reflect mouthfeel firmness scores. Thus, a simple and international unit applicable parameter, CFV$_{20}$, is proposed as a new AACC parameter capable of estimating the storage days showing maximum firmness of white bread crumb. In addition, tactility assessment can be a potent sensory evaluation tool for bread firmness.

Conclusion

The firmness of white bread was investigated using several modified AACC methods and sensory evaluation. Firmness parameters were established using the compression force value, CFV at several different plunger diameters. The shapes of force–deformation curves using this modified AACC method were similar, suggesting that plunger diameter had almost no effect on the shape of the force–deformation curves of white bread.

All CFV could be expressed by 2nd order polynomial curves as a function of bread storage days at 5°C, with $R^2$ greater than 0.938. Using these 2nd order polynomial curves, storage days at maximum CFV was estimated to be around 4 days. In addition, the relationship between mouthfeel firmness score and storage days could also be expressed by a 2nd order polynomial curve, and the estimated days showing maximum firmness closely approximated the results of various CFV and storage days. The AACC modified method using the 20-mm-diameter plunger is also a convenient method for detecting bread firmness. In addition, CFV$_{20}$ reflects tactile sensory scores, resulting in good firmness parameters; both CFV$_{20}$ and tactility score are proposed as convenient indicators interchangeable with CFV of the AACC method for determining white bread firmness.

Acknowledgements The author wishes to thank Ms. Chika Imura and Ms. Miyuki Iguchi for their technical assistance. In addition, the author thanks associate professor Tomoyuki Yoshino, Prefectural University of Hiroshima for his assistance in comparing CFV$_{20}$ data obtained at a different institution. This study was partly supported by the Tojuro Iijima Foundation for Food Science and Technology (No. 17, 2013: No. 8, 2015; No. 34, 2016).

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