Volume is an important measure of the quality of fermented bread products (5,7). Bread volume most commonly is determined by long-established seed displacement methods (9,12, 14). Despite their widespread use these methods have a number of drawbacks. They are cumbersome, require frequent calibration, and are poorly suited to samples that are compressible, sticky, or creased. Their precision also is limited by differing designs, seed packing densities, operator effects, loaf sizes, and other factors (4,6,13). Alternative methods, including measuring water displacement after coating (10) and extrapolation from single or two-dimensional measurements (8,11), present challenges as well and have not been widely adopted. To date, there is no internationally recognized standard method to measure bread volume, only a guideline (1).

The bread volume meter (BVM) shown in Figure 1 was introduced in 2000 to provide a simple, objective, and contact-free method for measuring bread volume. Ultrasound detection originally was used but was replaced in 2004 by laser topography (2). Using a laser volumeter, a sample is placed centrally in the instrument, rotated on its vertical axis, and scanned from base to apex by a low-intensity, high-precision laser range-finding (triangulation) system rotated through a semicircular arc. The scanning process produces a spiral “cloud” of surface coordinate data that is reconstructed into a three-dimensional mesh representation of the sample and from which volume and other parameters are derived (Fig. 2).

Collaborative Study

Collaborators. Eleven collaborators were selected to represent typical users and included commercial baking companies, raw material (flour, wheat) suppliers, a government regulatory agency, and an R&D facility. Collaborators were based in the United States, France, and Sweden; provided the necessary BVM instrumentation; and received no compensation.

Samples. Due to the unstable nature of baked products, the collaborative study was conducted using polyurethane bread replicas. Replica shapes, colors, and opacity were modeled on typical bread types to ensure equivalence of measurement (2). A Y ouden matched-pair study design was used, with each pair of samples differing in volume by <5%. Six pairs of samples with round, elongated, and rectangular shapes were selected.

In 2005 the AACC International (AACCI) Physical Testing Methods Technical Committee conducted a collaborative study to assess the precision of a proposed method to measure leavened bread volume using the BVM.

**Fig. 1. Bread volume meter (BVM) instrument.**
Reference volumes were determined by water displacement (6) prior to circulating the samples. Volumes ranged from approximately 200 to 2,800 mL (Table I). A set of samples was forwarded successively to each collaborator for analysis within a five week period commencing June 20, 2005.

**Instruments.** Samples were analyzed using BVM series bread volume meters (Perten Instruments), model BVM-L370 or BVM-L450, with standard sample mounts and control software. Collaborators were asked to calibrate their instrument laser systems following the manufacturer’s instructions and report their results to help identify the source of any potential irregularities; however, no irregularities were reported.

**Method.** Collaborators were asked to zero (tare) the laser and then perform a single volume analysis on each sample. For each test, the sample was mounted on a suitable support platform and placed centrally in the instrument. Information about the sample and test was then entered in the control software as required, and the test was initiated. After completing the scans, the volumes, measured in milliliters (cm$^3$), were collated and forwarded to the study director.

**Statistical Analysis.** Data were analyzed according to the AOAC guidelines for collaborative study procedures (3,15) using templates provided by AACCI (Microsoft Excel worksheet). The following analyses were performed:

1) **Laboratory Ranking Test**—To remove laboratories whose sum of ranked sample results significantly differed from the bulk of the laboratories

2) **Single and Double Grubbs Tests**—To remove laboratories with a mean value substantially different from the bulk of the laboratories

3) **Precision Statistics**—Analysis of variance (ANOVA) on the remaining data to obtain precision values, including mean, repeatability standard deviation ($S_r$), within-laboratory repeatability relative standard deviation ($RSD_r$), reproducibility standard deviation ($S_r$), and between-laboratory reproducibility relative standard deviation ($RSD_R$)

4) **Comparison to Reference**—Ratio of the average laser volume from the laboratories and the corresponding reference water displacement volume for each sample

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**Results and Discussion**

Bread volume data are given in Table I. Laboratory ranking (15) showed significant bias ($P < 0.05$) in the data from laboratory 2. It was found that this laboratory was operating with a significantly older version of the software, which could explain the bias, and the data were removed from further analysis. Grubbs analysis on the remaining data showed that the results for samples LT5, OB5, LT3, and ST5 from laboratory 6 and sample OSB4 from laboratory 9 were outliers; these data also were removed with their laboratory pair. No further data were removed, confirming to the limit of 2 of 9 labs specified by the AOAC procedure (3).

Precision statistics are given in Table II. Within-laboratory repeatability standard deviation ($S_r$) results were ≤20.7 mL and between-laboratory reproducibility standard deviation ($S_R$) results were ≤28.0 mL for all samples. Corresponding relative standard deviations within and between the laboratories ($RSD_r$ and $RSD_R$, respectively) were ≤1.5% and ≤3.0%, respectively. The relative precision of the method improved slightly with increasing sample volume. Averaged laboratory laser volume results ranged from 98.7 to 100.3% of the corresponding reference water displacement volume for each sample (Table II). These results indicate satisfactory accuracy and precision of the method.

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![Fig. 2. Laser topography image of a typical bread loaf. Inset shows surface mesh reconstructed from scanned point “cloud” surface coordinate data.](image-url)
Conclusions

A new method for determining bread volume using laser topography was assessed by a collaborative study conducted by the AACCI Physical Testing Methods Technical Committee. The proposed method showed acceptable precision for samples with volumes ranging from 200 to 2,800 mL. Results were similar to volumes determined by reference water displacement analysis. The BVM method is objective, contact-free, rapid, and simple to perform, making it well suited to the requirements of the milling and baking industries. The method has been approved as AACCI Approved Method 10-14.01.

Acknowledgments

We thank Johan Bjurenvall (TexVol Instruments), Elaine Sopiwnyk (AACCI Physical Testing Methods Technical Committee chair), Terry Nelsen (AACC International), and the participants for their assistance in this study: Dan Ayd and Stacy Moore (General Mills), Bon Lee and Greg Lind (Wheat Marketing Center), Scott Frazer and Matt Gennrich (Horizon Milling), Brian Williams (Foss North America), Johan Bjurenvall (TexVol Instruments), Arnaud Dubat and Christian Serry (Tripette & Renaud Chopin), Robert Townsend and Terrance McGovern (Rich Products), and Syed Rizvi and Normell Jhoe de Mesa (Cornell University).

References


Table II. Precision statistics for bread volume as determined by a bread volume meter (BVM)

<table>
<thead>
<tr>
<th>Sample</th>
<th>No. of Labs</th>
<th>Mean (mL)</th>
<th>BVM/WD (%)</th>
<th>S_m (mL)</th>
<th>RSD (%)</th>
<th>S_r (mL)</th>
<th>RSD (%)</th>
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<tr>
<td>LTB1</td>
<td>9</td>
<td>2,684</td>
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<td>LTB5</td>
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<td>STB1</td>
<td>10</td>
<td>1,523</td>
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<td>4.7</td>
<td>0.3</td>
<td>27.5</td>
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<tr>
<td>STB2</td>
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<td></td>
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<td>20.7</td>
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</tr>
</tbody>
</table>

S_m = repeatability standard deviation, RSD = repeatability relative standard deviation. S_r = reproducibility standard deviation, and RSD_r = reproducibility relative standard deviation.

LT = long and thin; ST = short and thin; OL = other large; and OS = other small, where long and large are >16 cm on the longest axis.

Mean BVM volume divided by water displacement (WD) volume.