Volume Measurements Calculated by Several Methods Using Cross-Sectional Tracings of Cake[1]

J. D. CLOKE,[2] E. A. DAVIS, and J. GORDON, University of Minnesota, Department of Food Science and Nutrition, St. Paul 55108

ABSTRACT

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Volumes of cakes were calculated from tracings of cross-sectional areas. Formulas were based on assumptions of a cylindrical shape and of cylindrical shapes with spherical or symmetrical caps. General trends in treatment differences could be detected by any of the methods, but numerical values, specific differences, and variability depended on the method chosen.

Measurements of volume are important in evaluating cake quality because volume is one attribute of quality and is related to the underlying structural development. In most experiments, a single method of measurement is used to compare volumes. Often volume, per se, is not measured, but an index of volume based on the dimensions of the cake is used. In this article, several volume indices are compared, and two new formulas for estimating volume from cross-sectional measurements are presented. To illustrate the use of these indices, measurements made on a series of cakes in which saturated or unsaturated monoglyceride preparations replaced 0–10% of the shortening (corn oil) in a research model cake formulation (Cloke et al 1984) are presented.

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[2]Roehampton Institute, Digby Stuart College, London SW155PH, England.

MATERIALS AND METHODS

Details of the formulation, preparation, and baking conditions for cakes are given by Cloke et al (1984). Two types of emulsifiers and 10 levels of each emulsifier type were used. Four replications of each emulsifier type and level were prepared. The cakes were cut into two equal halves, and tracings of the cross section were made. The positions of the various measurements are shown in Fig. 1.

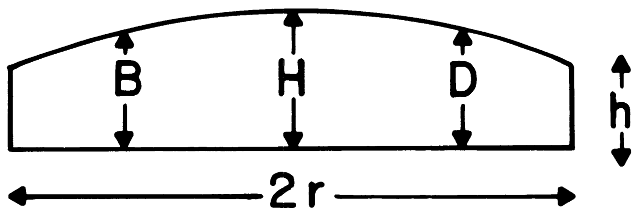

Fig. 1. Schematic cross-sectional tracing of a cake, where r = radius; h = height at edge; H = height at center (also labeled C in AACC terminology); and B and D = heights at three-fifths of distance from center to edge.

TABLE I
Average Contour and Volume Indices[a] for Cake Series

		Contour			Volume				
								Seed Displacement (cm^3)	
Emulsive System	Conc. (%)	Symmetry 2 H-B-D[b]	Uniformity B-D[b]	Cross-Sectional Area (cm^2)	Cylindrical (cm^3)	Spherical Cap (cm^3)	Symmetrical Cap (cm^3)	$\overline{X}$	n
Unemulsified	0	0.25	1.25	26.65	312	284	305	233	4
Saturated	0.5	0.50	1.00	26.65	313	290	298	265	3
	1.0	0.25	1.25	26.45	311	290	297	258	2
	1.5	0.25	1.25	27.80	318	286	308	287	3
	2.0	2.00	1.35	27.61	325	312	335	276	2
	2.5	3.00	1.00	29.67	342	317	347	276	2
	3.0	1.25	0.75	28.77	334	308	313	285	4
	4.0	0.75	0.75	29.16	339	310	335	289	3
	5.0	2.50	1.50	35.10	404	339	399	287	2
	7.5	1.00	2.00	35.74	412	340	393	333	2
	10.0	2.25	4.25	35.35	405	347	382	344	2
Unsaturated	0.5	0.50	1.50	24.45	283	265	275	257	3
	1.0	1.25	3.00	28.19	329	301	305	315	2
	1.5	3.50	2.50	34.45	403	360	372	332	2
	2.0	1.25	4.25	37.23	435	370	419	349	3
	2.5	0.75	2.75	35.87	413	350	392	335	3
	3.0	2.50	3.00	33.97	394	342	386	328	2
	4.0	1.75	2.85	36.52	423	364	386	299	1
	5.0	0.25	4.75	34.32	391	346	377	331	2
	7.5	1.75	2.00	33.42	384	357	396	270	2
	10.0	0.50	1.50	33.94	389	350	382	337	3
Standard deviation	···	···	···	2.07	23.9	20.3	36.4	35.8	···

[a]n for all measurements except seed displacement = 8 for unemulsified cakes, 3 for 2% saturated cakes, and 4 for all other emulsifier combinations.
[b]H = height at center, B and D = distance between center and each edge.

Uniformity and symmetry indices were calculated from the height at the center and at the distance between the center and each edge as suggested in AACC method 10-91 (AACC 1976) but adjusted for the smaller pan radius as shown in Fig. 1. Cross-sectional areas were determined from the tracings from triplicate measurements on a Hewlett-Packard Digitizer (model 9107A). Volume was calculated from measurements of the tracings as follows.

Volume, assuming a cylindrical shape, was calculated from equation 1:

$$V = \frac{\Pi r A}{2} \quad (1)$$

where V = volume, r = radius, and A = cross-sectional area.

This equation assumes that the volume of the cake may be obtained by rotating the tracing through 180°. It assumes cake symmetry, and because it is derived from the formula for a cylinder, it does not take into account the peak shape of the cake.

Volume, assuming a spherical cap, was calculated according to equation 2:

$$V = \Pi r^2 h + \frac{\Pi}{6}(H-h)\,[3r^2 + (H-h)^2] \quad (2)$$

where V = volume, r = radius, h = height at edge, and H = height at center.

The assumption for equation 2 is that the cake is symmetrical and that the cake peak occurs at the center. The cake is considered to be a cylinder with a sphere on top.

TABLE II
Average[a] Edge and Center Heights and Radii for Cake Series

Emulsive System	Conc. (%)	Edge Height (cm)	Center Height (cm)	Radius (cm)
Unemulsified	0.0	1.36	1.89	7.46
Saturated	0.5	1.35	1.95	7.48
	1.0	1.43	1.88	7.50
	1.5	1.45	1.98	7.33
	2.0	1.50	2.00	7.50
	2.5	1.50	2.23	7.38
	3.0	1.53	2.05	7.43
	4.0	1.53	2.08	7.43
	5.0	1.45	2.55	7.35
	7.5	1.45	2.58	7.35
	10.0	1.60	2.55	7.30
Unsaturated	0.5	1.38	1.75	7.38
	1.0	1.55	2.05	7.45
	1.5	1.60	2.53	7.45
	2.0	1.58	2.68	7.45
	2.5	1.60	2.55	7.35
	3.0	1.50	2.48	7.40
	4.0	1.65	2.60	7.40
	5.0	1.73	2.38	7.35
	7.5	1.75	2.48	7.35
	10.0	1.73	2.45	7.33
Standard deviation	···	0.13	0.21	0.09

[a] n = 8 for unemulsified cakes, and 4 for all other combinations except for 2% saturated cakes, for which n = 3.

Volume, assuming a symmetrical cap, was calculated according to equation 3. For this calculation, the cap was divided into N divisions, each 2 mm apart as shown in Fig. 2. The length (X_i) of each chord was then measured.

$$V = \Pi r^2 h + \Pi \frac{(H-h)}{N} \sum_{i=1}^{N} X_i^2 \quad (3)$$

where V = volume, r = radius, h = height at edge, H = height at center, N = number of divisions in the cap, and X_i = length of chord.

The assumption for equation 3 is that the cake is a cylinder with a symmetrical, but not necessarily spherical, cap.

Volume by seed displacement was measured on the combined cake halves used for cross-sectional tracings. Cakes were frozen before displacement measurements were made. Fewer replications were analyzed by seed displacement, because for some replications the crumb was too fragile for the complete cake to be removed from the pan.

Two-way analyses of variance were calculated for each volume measurement.

RESULTS AND DISCUSSION

This series of cakes was characterized by a range in contour (Table I). Cakes varied from the relatively flat contour and small volume of cakes made with unemulsified shortening to the asymmetric shapes of some of the cakes made with unsaturated monoglycerides. Photographs of the center cross sections of the cakes (Cloke et al 1984) give additional information on the interior characteristics that resulted in asymmetrical shapes.

The AACC indices of symmetry, uniformity, and volume are all based on measurements of heights at specific locations in the center cross section of the cake. Positive values of the symmetry index indicate a peaked cake, whereas negative values indicate a collapsed center. High values of the symmetry index for this series of cakes were associated with large tunnels that terminated in the center of the cake. The uniformity index measures the difference in height at two points between the center and edge of the cake. For the optimum cake, this index should be zero because positive or negative values occur when one side of the cake is higher than the other. The measurement for this series of cakes illustrates the effects of tunnels terminating off-center (eg, cakes containing 2% unsaturated monoglycerides).

The volume index by the AACC method is based on the sum of the height at the three positions used in the symmetry and uniformity indices. As such, it would include the effects of large air cells and tunnels as discussed for the other indices, but it would not include the effects of changes in radius or edge heights. In this particular series of cakes, analysis of variance applied to the radius measurements showed highly significant differences ($P < 0.01$)

Fig. 2. Division of a symmetrical cap. Three divisions are shown. X_1, X_2, and X_3 are the lengths of the respective chords.

TABLE III
Summary of Analysis of Variance for Edge Height, Center Height, and Radii of Cakes Made with Saturated and Unsaturated Monoglycerides

Source of Variation	df	Edge Height Mean Square	Edge Height F	Edge Height Significance of F	Center Height Mean Square	Center Height F	Center Height Significance of F	Radii Mean Square	Radii F	Radii Significance of F
Within cells (error)	65	0.0168	···	···	0.0448	···	···	0.0075	···	···
Emulsifier	1	0.3321	19.80	0.00003	0.8593	19.17	0.00004	0.0029	0.38	0.538
Percentage	10	0.0699	4.17	0.00018	0.4775	10.65	0.00001	0.0234	3.10	0.003
Emulsifier by percentage	10	0.0183	1.09	0.38214	0.1949	4.34	0.00011	0.0063	0.84	0.596

TABLE IV
Summary of Analysis of Variance for Cross-Sectional Areas for Cakes Made with Saturated and Unsaturated Monoglycerides

Source of Variation	df	Mean Square	F	Significance of F
Within cells (error)	65	4.2747	...	...
Emulsifier	1	169.4643	39.6	0.00001
Percentage	10	88.9319	20.8	0.00001
Emulsifier by percentage	10	35.7168	8.4	0.00001

TABLE V
Summary of Analysis of Variance for Volumes Calculated as Cylinder, Cylinder with Spherical Cap, and Cylinder with Symmetrical Cap

		Cylinder			Spherical Cap			Symmetrical Cap		
Source of Variation	df	Mean Square	F	Significance of F	Mean Square	F	Significance of F	Mean Square	F	Significance of F
Within cells (error)	65	571	...	...	411	...	...	1328	...	...
Emulsifier	1	27151	38.1	0.00001	14209	34.5	0.00001	17760	13.4	0.00051
Percentage	10	10609	18.6	0.00001	5358	13.0	0.00001	11509	8.7	0.00001
Emulsifier by percentage	10	5027	8.8	0.00001	1603	3.9	0.00036	2740	2.1	0.04050

among cakes made with different percentages of emulsifiers, but no significant differences among cakes made with different monoglyceride types (Tables II and III). Emulsifier type and percentage both significantly affected edge and center heights of the cakes ($P < 0.01$). The interaction between emulsifier type and percentages was highly significant for the center but not for the edge heights. Therefore, it is useful for this series of cakes to consider indices based on cross-sectional tracings that include evaluations of radius as well as of height.

The group of indices based on the cross-sectional tracings consisted of the center cross-sectional area and volumes calculated on the assumption of either a cylinder or a cylinder with a spherical cap or a symmetrical, but not necessarily spherical, cap (Table I). Analysis of variance for the cross-sectional areas and volumes (Tables IV and V) showed highly significant differences ($P < 0.01$) between the cross-sectional areas or volumes of cakes made with different emulsifier types and percentages of emulsifiers. The interaction between emulsifier type and percentage of emulsifier was highly significant ($P < 0.01$) for measurements of cross-sectional area and for volumes when either a cylindrical shape or a spherical cap was assumed, and significant ($P < 0.05$) when the assumption of a symmetrical cap was used. The error (within cells) term for the symmetrical cap was larger than for the cylindrical or spherical cap assumptions. This is not surprising because the series of measurements of X_i (Fig. 2) included in the symmetrical cap calculations can increase variability.

Ideally, the standard against which the indices are compared would be a direct measurement of volume. In initial studies of this series of cakes, the weight of the rapeseeds appeared to compact the cakes. To decrease this effect, measurements were made on frozen cakes. The crumb structure for some cakes was so fragile that it was difficult to remove the complete cake from the pan. As a result, fewer measurements of seed displacement were possible. Analysis of variance of volumes of cakes for which displacement measurements were possible showed that both emulsifier type and percentage of emulsifier affected volume (Table V). This is the same trend demonstrated in the other measurements. The interaction between emulsifier type and percentage was not significant. This

TABLE VI
Summary of Analysis of Variance for Volume Determined by Seed Displacement

Source of Variation	df	Mean Square	F	Significance of F
Within cells (error)	30	1278	...	...
Emulsifier	1	12423	9.72	0.004
Percentage	10	3343	2.62	0.020
Emulsifier by percentage	10	1770	1.39	0.234

apparent insensitivity may reflect the experimental problems in use of seed-displacement measurements for this series of cakes, which resulted in fewer replications.

Volumes by seed displacement were lower than those calculated from cross-sectional tracings. The latter may tend to overestimate volume if the symmetry or spherical assumptions are not met, but the seed displacement method would underestimate volume if compression of cake occurred.

Any of the methods used in this study will give information on general trends, but the numerical values and specific differences may vary with the method chosen. The suitability of methods based on cross-sectional measurements depends on an accurate assessment of cake shape. Photography and AACC contour and uniformity indices can aid in this assessment. Any of the methods will give consistent data if all of the cakes in a given series have similar shapes. If shapes vary, none of the methods is entirely satisfactory. If, in addition, wide variations in the crumb fragility are present, seed-displacement methods are not consistent either.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1976. Approved Methods of the AACC. Method 10-91, approved April 1968, reviewed October 1982. The Association, St. Paul, MN.

CLOKE, J. D., DAVIS, E. A., and GORDON, J. 1984. Relationship of heat transfer and water-loss rates to crumb-structure development as influenced by monoglycerides. Cereal Chem. 61:363.

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