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METHODS FOR DETERMINING THE SOLIDITY OF CABBAGE HEADS

O. H. PEARSON[1]

The terminal bud of a cabbage is the part of the plant that is put to commercial use. The inner leaves, pressed against the interlocked outer head leaves, vary at maturity in number and size, and so cause differences in solidity or tightness of head. A solid head of cabbage is desired by all who have to do with the vegetable—grower, shipper, wholesaler, retailer, and consumer. These people are not concerned with exact measurements of solidity, for only a few degrees are recognized by the trade in the range from slack to tight heads. But for accurate work, such as testing the effects of cultural practices on tightness of head, or for selection work in breeding, some exact measurement must be used which can be expressed numerically. Solidity can be expressed in exact terms of apparent specific gravity or density.

REVIEW OF LITERATURE

Others who work with cabbage have recognized the value of such a measure and have used several methods in determining the solidity of the cabbage under their observation. Kotowski (1923) determined specific gravity by measuring the heads and calculating their volume according to the formula for an oblate spheroid. Mack (1926) immersed the heads in water and measured their volume either by weighing the displaced water or by determining their buoyance. Kotowski had tried this method of immersion, but discarded it as inaccurate because of the penetration of water into the head during

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immersion. Mack likewise recognized this error. Unfortunately they had no way of checking the results of these methods against the actual volume of the head.

Geometrical calculations of volume from polar and lateral diameters are of questionable accuracy. The nature of the cabbage head, a mass of overlapping leaves, with heavy midribs and bulging areas, often one-sided, renders the application of a formula for a symmetrical geometrical figure such as an oblate spheroid open to considerable error. It is true, as Kotowski says, that in general cabbage heads of the Brunswick type approach an oblate spheroid in shape; but no one head can be expected to exactly fulfill the requirements of such a symmetrical figure.

Methods of determining volume which involve immersion in water would be accurate if errors arising from the penetration of water into the head could be eliminated. On immersion, water drives out the air from the spaces in the head, and what is really determined is the specific gravity of the leaf tissue and not a measure of the compactness of the head. Also, because of variations in the manner of bud growth, chiefly in the relative penetration of the stem into the head, the tightness of interlocking of the leaves over the terminal bud varies so that an unpredictable amount of air is retained.

DESCRIPTION OF EXPERIMENTAL METHODS

For the past four years at Davis, in breeding work with cabbage, a modification of the immersion method has been used to determine the volume. The head has been tightly covered with a cap of rubber cloth, like a heavy rubber bathing cap, so that the air within the head will be retained. In 1926–27 the volume was determined by weighing the water displaced; in 1928–29 the buoyancy of the head was used.

This paper presents the results of a study of the variations in the values for the volume, and indirectly the apparent specific gravity or density, secured by the methods described below.

Method A, Buoyancy.—The head, previously weighed in air, was tightly covered with a cap of rubber cloth held in place by heavy rubber bands. The head so protected was placed in the harness shown in figure 1 and the whole weighed under water. The volume of the head was found by subtracting the weight of the cabbage and harness (tare) under water from the weight of the harness under water and adding this value to the weight of the head in air. The specific

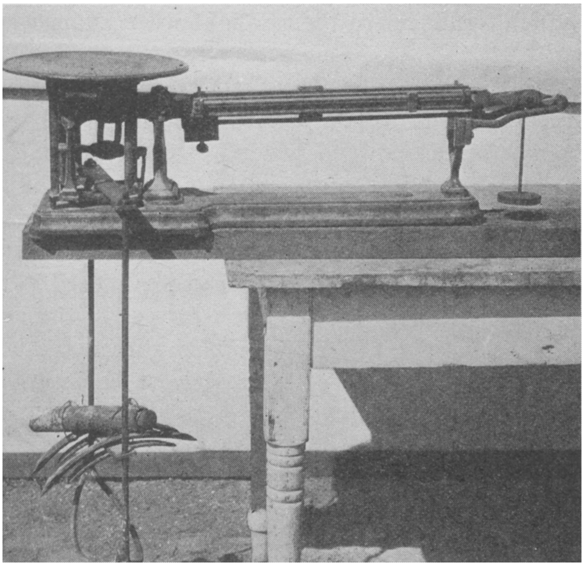

Fig. 1. Method A. Harness used in the determination of volume. The head, covered with the rubber cap (not shown), is placed in the loop, and the weighted tare is let down upon it.

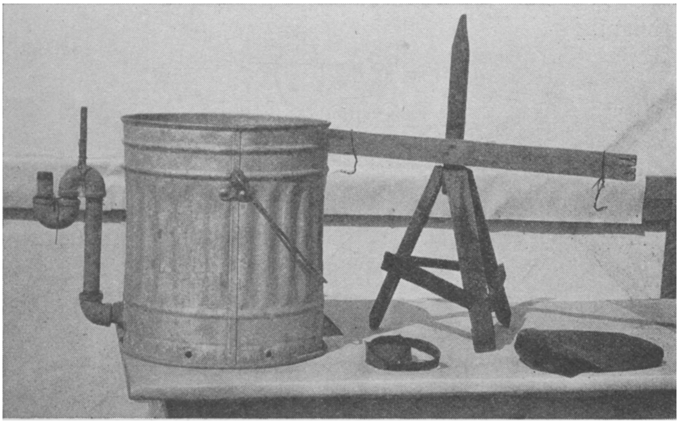

Fig. 2. Method B. Apparatus for determining the displaced water. The rubber cap and bands are also shown. The displaced water runs out of the nipple. The vent is necessary to prevent air from being caught and checking a full stream discharge. In making a determination, the tripod is hooked down, the can filled, and surplus water drained off. The tripod is removed, a tared bucket set under the outlet, the head placed in the container, and the tripod again hooked down over it. Perhaps ten minutes must pass before equilibrium is established.

gravity of the rubber cap and bands is very near to that of water (1.05 for this sample of rubber) so their weight when submerged has been neglected.

Method B, Displacement.—The head as prepared for method A was submerged in water (fig. 2); the water displaced was weighed. Since the volume of the cap and bands was 85 cubic centimeters, and the weight of the receiving container (not shown in the figure) was 2075 grams, the volume of the head in cubic centimeters was equal to the gross weight of this container and overflowed water, less 2160.

Method C, Calculated.—Before the head was placed in the cap, the diameters of the head were taken with a caliper to the nearest tenth of a centimeter, the polar (PD) being taken direct, the lateral (LD) as the average between the greatest and least horizontal diameters. The formula of Kotowski was used—

$$V=\frac{\pi}{6}\, d_1{}^2 \cdot d_2$$

where d_1 equals the lateral or rotating diameter, and d_2 equals the polar or fixed diameter.

Method D, Area.—After all direct volume determinations had been made, the head was split along the polar diameter, and the outline of the cross-section was traced on paper. The areas of these cross-sections were determined by a planimeter, and the volume calculated by the formula

$$V=12.327\left(\frac{A}{F}\right)^{\frac{3}{2}}$$

where V equals the volume in cubic centimeters, A equals the area in units of the planimeter, and F equals the factor which changes the planimeter reading to square inches. Although this method is geometrically incorrect, since an irregular spheroid cannot be resolved into a perfect sphere by any such simple means, the agreement with method A, taken as a standard, in table 2 is nearly as good as that of method C, which is correct geometrically. One very great source of error in method D (area) is, that in cutting the head it was exceedingly difficult to strike the average lateral diameter; usually the actual horizontal diameter of the longitudinal section of the head approached either the greater or the lesser diameter as determined by the calipers.

Method E, Index.—This was taken from Kotowski's paper as an original method proposed by J. Ryx (Kotowski page 6). His formula is

$$Z=\frac{C}{W} \cdot 100$$

TABLE 1

DENSITY OF 37 COPENHAGEN MARKET CABBAGE HEADS AND OF 18 HEADS OF OTHER TYPES DETERMINED BY VARIOUS METHODS

Head No.	Weight, grams	Shape index $\frac{LD}{PD}$	Density					Air easily replaceable (cc)
			Method A, buoyancy	Method B, displacement	Method C, calculated	Method D, area	Method E, index	
1	1625	1.14	.593	.608	.638	.700	98	720
2	2708	1.08	.540	.534	.563	.572	131	1600
3	1290	1.25	.537	.541	.595	.606	83	935
4	1527	1.17	.645	.643	.696	.800	97	430
5	1395	1.50	.586	.588	.653	.704	88	675
6	960	1.11	.491	.490	.537	.425	65	845
7	1690	1.08	.652	.673	.673	.683	102	535
8	1575	1.18	.675	.675	.640	.727	98	310
9	721	92	.486	.495	.453	.420	49	606
10	1292	1.18	.629	.624	.687	.700	86	....
11	867	1.08	.674	.673	.725	.776	67	....
12	809	.88	.481	.469	.486	.431	54	749
13	730	.92	.531	.525	.551	.443	53	540
14	1060	.98	.655	.652	.708	.622	74	425
15	1250	1.07	.458	.466	.438	.510	74	1260
16	1705	1.14	.644	.658	.640	.647	104	675
17	862	1.37	.491	.506	.510	.569	61	700
18	975	1.14	.516	.532	.519	.593	65	775
19	1157	1.04	.653	.678	.668	.687	78	385
20	1715	1.07	.626	.633	.663	.615	102	645
21	1380	1.12	.557	.576	.567	.613	84	835
22	1160	1.06	.649	.683	.693	.622	79	380
23	1615	1.07	.455	.454	.430	.477	85	1590
24	1390	1.05	.458	.453	.448	.487	77	1374
25	2155	1.28	.434	.408	.432	.413	100	2271
26	1470	.93	.711	.710	.741	.618	93	199
27	1562	1.07	.565	.557	.577	.559	91	822
28	1975	1.36	.604	.590	.671	.685	115	812
29	1524	1.17	.654	.642	.671	.628	96	409
30	1210	.94	.608	.602	.642	550	78	558
31	1211	1.05	.690	.687	.718	.694	83	300
32	1941	1.06	.686	.685	.795	.671	118	550
33	935	.99	.652	.639	.670	.650	67	300
34	1406	1.09	.447	.444	.427	.387	77	530
35	1335	1.37	.529	.515	.536	.587	83	899
36	1993	1.30	.598	.592	.603	.685	112	907
37	1828	1.22	.443	.440	.417	.475	93	1135
38	652	.71	.607	.602	.551	.487	46	358
39	642	1.06	.604	.579	.554	.626	50	339
40	962	.89	.552	.544	.480	.536	60	591
41	1257	1.44	.558	.550	.580	.637	82	760
42	1867	1.42	.528	.521	.564	.583	122	1283
43	1929	1.95	.578	.564	.585	.780	110	1100
44	896	1.48	.627	.615	.679	.747	69	396
45	1312	2.02	.472	.467	.503	.555	82	1218
46	832	1.64	.452	.458	.479	.566	59	832
47	850	.77	.604	.602	.610	.517	58	359
48	536	.98	.379	.377	.331	.400	37	729
49	1570	1.71	.463	.442	.468	.575	89	1518
50	664	.88	.334	.330	.309	.295	40	1145
51	1667	1.49	.568	.567	.543	.748	97	942
52	1100	.80	.363	.424	.326	.308	57	706
53	1000	1.68	.375	.379	.390	.453	62	446
54	760	2.00	.559	.551	.591	.765	60	452
55	538	.74	.364	.331	.323	.258	34	756

in which C is the weight of the head in kilograms, W is the average diameter of the head in centimeters (suggested by Kotowski to be the average of the lateral and polar diameters), and Z is an index of compactness. Obviously calculations based on this method would be rendered inaccurate by the shape of the head. The correlation value of $+.329 \pm .0498$ (table 3) indicates the low agreement with the direct determinations of volume (method A). If the "average diameter," W, were cubed, much better agreement would be secured with the other values (practically identical with method C) since the volume varies with the cube of the diameter. The lack of this exponent in the formula used by Kotowski may explain his dissatisfaction with the method.

PRESENTATION OF DATA

Data for Comparison of the Methods.—Table 1 presents the results of measuring the density of 37 heads of Copenhagen Market cabbage, and of 18 heads of various other types, ranging from Flat Dutch to Winningstadt, by the five different methods listed above. The shape index shows to which type the heads belong, the value increasing as the head becomes flatter.

TABLE 2

PER CENT DEVIATION IN VOLUME OBTAINED BY DIFFERENT METHODS FROM THE VOLUME OBTAINED BY METHOD A

Per cent deviation	Method B	Method C	Method D
16-18	0	0	1
14-16	0	1	1
12-14	0	1	5
10-12	0	2	4
8-10	0	3	1
6-8	0	4	2
4-6	1	4	5
2-4	7	10	0
−0-2	5	5	2
+0-2	20	2	3
2-4	3	1	1
4-6	0	3	3
6-8	1	4	1
8-10	0	0	0
10-12	0	0	2
12-14	0	0	0
14-16	0	0	3
16-18	0	0	0
18-20	0	0	1
20-22	0	0	1
22 24	0	0	0

Table 2 presents the data for volume given in table 1 for the 37 heads of Copenhagen Market in a slightly different way, showing the distribution of the per cent of deviation of volume from the value secured by method A. Evidently method B (displacement) shows but a slight deviation from method A, usually in the plus direction, possibly because of the water held on the surface of the rubber cap. Methods C (calculated) and D (area) deviate greatly and irregularly from the base volume.

Table 3 gives the correlations between the various methods. If method A (buoyancy) is used as the base, method B (displacement) gives nearly perfect correlation. Method C (calculated) gives a high

TABLE 3

Correlations of Density Determinations; Heads 1 to 37

Methods correlated	Coefficient of correlation	
Method A with method B	+.992	±.0000
Method A with method C	+.967	±.0001
Method A with method D	+.826	±.0033
Method A with method E	+.329	±.0498
Method C with method D	+.821	±.0036

correlation, while D (area of cross-section) gives one much lower, and E (index of solidity) gives a very low value of $+.329 \pm .0498$. The correlation between C and D was high, although not so high as expected. These correlation values were determined as described by Wallace and Snedecor (1925).

Inaccuracy of Calculated Volumes.—As can be seen from table 4 the deviations in volume for the conic and flat types as determined by the two geometrical methods are extreme. In general the two methods of direct determination, A and B, agree; Methods C and D give much too large values when the heads are conic. This deviation probably results from the shape of a conic head, ovoid, rather than symmetrically tapered at each end. Cabbage heads intergrade so gradually from the extreme conic head of Jersey Wakefield or Winningstadt to the Flat Dutch varieties that it is practically hopeless to attempt to find a geometrical formula which will apply equally well to all shapes. Some direct method must be used.

Necessity of Preventing Penetration of Water.—The volume cannot be accurately determined directly by either displacement or buoyance, unless penetration of water into the head can be prevented. Some heads were used to determine the rate at which water penetrated the head. The results are shown in table 5, and the internal structure of the heads appears in figure 3. The heads were immersed in water in the harness of method A and weighed every minute until equilibrium was reached. The heads were then cut deeply across the top, and weighings were taken at minute intervals until equilibrium was reached. Of course not all the air was replaced because of the

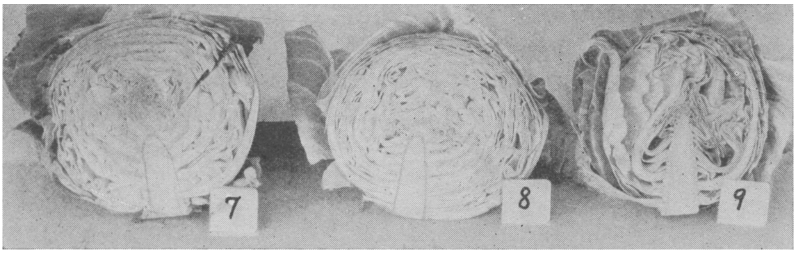

Fig. 3. Cabbage heads split vertically. Head No. 7, density .652; head No. 8, density .675; and head No. 9, density .486.

TABLE 4

PER CENT DEVIATION IN VOLUME FROM THAT OBTAINED BY METHOD A, OF HEADS OF SEVERAL VARIETIES ARRANGED IN ORDER OF SHAPE

Shape index	Head No.	Method A, volume in cc	Deviation		
			Method B	Method C	Method D
.71 (Conic)	38	1072	+ .93	+10.3	+24.8
.74	55	1477	+10.1	+12.9	+41.2
.77	47	1409	+ .3	− 1.14	+16.8
.80	52	3026	−14.1	+11.3	+18.2
.88	50	1989	+ 1.16	+ 7.85	+13.0
.89	40	1744	+ 1.2	+14.85	+ 2.9
.98	48	1415	+ .5	+14.35	− 5.4
1.06	39	1061	+ 4.3	+ .91	− .37
1.42	42	3538	+ 1.2	− 6.53	− 9.5
1.44	41	2257	+ 1.5	− 3.9	−12.5
1.48	44	1430	+ 1.9	− 7.6	−16.1
1.49	51	2935	+ .17	+ 4.46	−24.2
1.64	46	1842	− 1.35	− 5.8	−20.3
1.68	53	2666	− 1.0	− 3.67	−17.1
1.71	49	3397	+ 4.5	− 1.24	−19.6
1.95	43	3329	+ 2.7	− .96	−25.8
2.00	54	1360	+ 1.54	− 5.4	+26.9
2.02 (Flat)	45	2778	+ 1.0	− 5.9	−15.0

waxy covering of the leaves, to which air clings so as to prevent wetting. A glance at the figures in table 1 for "Air easily replaceable" shows why displacement values without the use of a cap are worth but little.

TABLE 5

RATE OF PENETRATION OF WATER INTO HEADS; CUBIC CENTIMETERS OF WATER PER MINUTE

	Head No. 7	Head No. 8	Head No. 9
First minute	344	172	446
Second minute	39	23	48
Third minute	2	14	1
Fourth minute	....	7	....
Fifth minute	....	5	....
		Heads Cut	
First minute	43	41	89
Second minute	67	14	22
Third minute	13	9	....
Fourth minute	15	12	....
Fifth minute	6	4	....
Sixth minute	3	5	....
Seventh minute	2	2	....
Eighth minute	1	2	....
Weight	1690	1575	721
Density (A)	.652	.675	.486

Duplication of Results.—In methods A and B, however, the errors arising from not including all the air-space, in measuring the volume of the heads, are eliminated. Table 6 gives the duplicate determinations by methods A and B for nine heads in per cent of change from

TABLE 6

DUPLICATE DETERMINATIONS OF VOLUME

Head No.	Method A		Method B		Weight grams
	Original volume, cc	Per cent deviations from original	Original volume, cc	Per cent deviations from original	
1	2725	(0), (−1.1), (−2.6), (−2.9)	2730	(−2.2)	1625
3	2418	(−.75), (−.3)	2360	(−1.0), (−5.7), (−1.0)	1290
4	2367	(−1.7), (−1.7)	2368	(−.6)	1527
5	2380	(−1.9), (−3.6)	....		1395
7	2595	(−.4), (−.4)	....		1960 (−.6), (−.9), (−.9)
8	2347	(−.3), (−.3)	....		1575 (−1.1), (−2.1)
9	1487	(−.5), (−5.9)	....		721 (−.6), (−1.7)
10	2055	(0)	2099	(−2.6), (−1.4), (−1.0)	1292 (−.6)
11	1285	(−2.6)	1289	(−.3)	867

the original for each duplication. In every case the error is small, the greatest being 5.9 per cent, and is probably the result of variations in tension of the rubber cap because of handling and of the attempt at each determination to have the cap tightly stretched.

The Time Factor.—Since time is an important factor in any series of determinations, the rate at which equilibrium is approached should be determined in any method. In methods A, C, and D the time involved is not an important factor. In method B, however, the time factor is of considerable importance. As seen from figure 2, the displaced water must run over the edge of a one-inch nipple. When the pressure is great, as at the first immersion of the head, the water runs out rapidly; but as equilibrium is approached, the rate becomes much slower. The last water passes over drop by drop. Table 7 shows

TABLE 7

VOLUME IN CUBIC CENTIMETERS CALCULATED AT ONE-MINUTE INTERVALS BY METHOD B

	Head No. 15	Head No. 16	Head No. 17	Head No. 18	Head No. 19	Head No. 20	Head No. 21
First minute	2620	2510	1655	1789	1662	2633	2323
Second minute	2663	2570	1692	1822	1692	2689	2367
Third minute	2672	2582	1698	1828	1698	2698	2377
Fourth minute	2677	2586	1702	1833	1703	2699	2380
Fifth minute	2679	2587	1703	1833	1704	2701	2385
Sixth minute	2680	2589	1703	1833	1705	2702	2386
Seventh minute	....	....	....	....	....	2703	2388
Eighth minute	2691	2591	1704	1833	1706	2706	2390
Ninth minute	....	....	....	....	....	....	....
Tenth minute	2682	2593	1704	1833	1706	2707	2393

the rate at which seven heads approached equilibrium. Each increment was collected and weighed separately. Some error was undoubtedly caused by evaporation, for the dishes were open, and by incomplete drainage of the receiving vessel.

The table shows that it is unsafe to weigh the displaced water before dripping has entirely ceased, and that dripping may continue for as much as ten minutes. Since the apparatus must be brought to equilibrium before each determination, another five or six minutes must be added to the time required for each determination. If but four or five determinations can be made per hour, the determination of volume becomes expensive. Contrast this to the volume determinations by method A, by which, in the cabbage breeding work of the Division of Truck Crops, an unskilled helper maintained an average speed of 3.5 minutes per head to do the following: weigh in air, measure the diameters, put on the rubber cap, weigh in water, split the head and measure the length and diameter of the core—recording the data himself.

Method A, for all the needs of a plant physiologist or plant breeder, is accurate within experimental error, is rapid enough to be practical, and requires no complicated or expensive equipment.

SUMMARY

The volume and density of 37 heads of the Copenhagen Market type of cabbage, approximately a slightly flattened sphere in shape, and of 18 heads of other types of cabbage, have been determined by five different methods. Densities based upon calculated volumes showed a general agreement with those determined directly by water displacement, but a variation of as much as 25 per cent of the direct determination was sometimes found when geometrical methods were employed.

An immersion method making use of a rubber cap and heavy rubber bands to retain all the air in the head was shown to permit of duplicating results on a given individual head with an extreme experimental error of about 6 per cent.

With the apparatus used for determining volume by displacing water, not more than six determinations could be made an hour, while the buoyancy method was much more rapid.

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The titles of the Technical Papers of the California Agricultural Experiment Station, Nos. 1 to 20, which HILGARDIA replaces, and copies of which may be had on application to the Publication Secretary, Agricultural Experiment Station, Berkeley, are as follows:

4. Effect of Sodium Chlorid and Calcium Chlorid upon the Growth and Composition of Young Orange Trees, by H. S. Reed and A. R. C. Haas. April, 1923.
5. Citrus Blast and Black Pit, by H. S. Fawcett, W. T. Horne, and A. F. Camp. May, 1923.
6. A Study of Deciduous Fruit Tree Rootstocks with Special Reference to Their Identification, by Myer J. Heppner. June, 1923.
7. A Study of the Darkening of Apple Tissue, by E. L. Overholser and W. V. Cruess. June, 1923.
8. Effect of Salts on the Intake of Inorganic Elements and on the Buffer System of the Plant, by D. R. Hoagland and J. C. Martin. July, 1923.
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10. The Seasonal Variation of the Soil Moisture in a Walnut Grove in Relation to Hygroscopic Coefficient, by L. D. Batchelor and H. S. Reed. September, 1923.
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