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MEASUREMENTS RELATING TO PEA TENDEROMETER CALIBRATION

by

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ENGINEERING RESEARCH SERVICE

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MEASUREMENTS RELATING TO PEA TENDEROMETER CALIBRATION

Peter W. Voisey and M. Kloek

1.0 INTRODUCTION

The F.M.C. pea tenderometer estimates the maturity of peas by recording their tenderness. A set of blades is driven through a matching set to compress shear and extrude the peas. The force required to perform this operation is indicated by a pendulum attached to the matching set of blades which are able to pivot. Weights at the end of the pendulum provide an increasing force as the pendulum moves from the vertical position. The angle of the pendulum is indicated by a pointer and scale. The pointer is moved up scale by the pendulum and held in position by friction. It thus indicates the maximum force in each test which is used as the tenderness index. The scale is calibrated in tenderometer units (T.U.) which correspond to lb/in^2 of shearing blades.

The indicating system is calibrated by placing the pendulum in the horizontal position and attaching a specified counterbalancing weight at a specified distance from the pendulum pivot. The pendulum weights are then moved until the pendulum exactly balances the counterweight.

It is well known that the pea tenderometer is difficult to standardize (Voisey and Nonnecke 1971 a, b; 1972 a, b), and this instrument has been subjected to lengthy investigations. There are two aspects to calibration of this instrument a) to standardize the force indicating system; b) to verify the condition of the shearing blades.

The purpose of this work was to investigate the effect of moving the pendulum weights on the instruments calibration. The work forms part of a broader investigation (Voisey and Nonnecke 1972 c, d; 1973 a, b), and was directed to examining the use of wax as a standardizing material.

2.0 ANALYSIS OF SYSTEM

The geometry of the pendulum is shown diagramatically in Figure 1. When the blades compress and shear the product, a torque T_p is exerted about the center of rotation (O). This is resisted by the upper (W_1) and lower (W_2) weights, and the weight of the pendulum rod and other parts which move with it (W_3) at radius R_3. W_3 being a mass equivalent to all moving parts with the exception of W_1 and W_2.

The pendulum moves to some angle (A) to the horizontal so that the torque due to the weights equals the torque generated by the peas to resist shearing, compression and extrusion.

Thus $T_p = (W_1R_1 + W_2R_2 + W_3R_3)$ CosA

or $T_p = K$ CosA where K is a constant.

The scale is thus a cosine function where the length, representing one T.U., changes over the entire scale (Voisey and Nonnecke, 1971 a, b) being a maximum at the maximum reading, and

a) when $A = 0^\circ$, CosA = 1.0 and $T_p = W_1R_1 + W_2R_2 + W_3R_3$

b) when $A = 90^\circ$, CosA = 0 and $T_p = 0$

If W_1, W_2, W_3 and R_1, R_2, and R_3 are known, the torque can be calculated for all angles of the pendulum.

3.0 EXPERIMENTAL METHODS

A pea tenderometer, overhauled by Engineering Research Service and tested in previous work as a "master tenderometer" (Voisey and Nonnecke, 1972 d), was used for this experiment.

The tenderometer was first calibrated by the standard procedure, and the radii of the two weights (R_1 and R_2) recorded. The weights were then removed and the pendulum held horizontal. The apparent weight (W_3)

of the pendulum at a selected radius (R_3) was then measured. The two weights were also weighed. This showed that $W_1 = 20.25$ lb $R_1 = 23.5$ in

$W_2 = 62.75$ lb $R_2 = 30.5$ in

$W_3 = 5.1$ lb $R_3 = 30.5$ in

The pendulum angle to the horizontal (A) was then measured for tenderometer readings ranging from 0 to 200 T.U. in 10 T.U increments.

These data were used to calculate the torque in in/lb corresponding to each tenderometer reading (Table 1) where

$$\text{Torque} = (W_1R_1 + W_2R_2 + W_3R_3)\ \text{CosA}$$
$$= \underline{2545.4\ \text{CosA in lb}}$$

Thus at 200 T.U. Torque = 2545.4 in lb.

Calibration tests using wax wafers were then conducted using previously established techniques (Voisey and Nonnecke 1971 a, b; 1972 a) in a controlled environment chamber at 74°F.

Five single, double and triple wafers were tested with the pendulum weights in the correct calibrated position. This was repeated while moving the small weight in increments of 0.5 in over its total possible range of movement. From these data the mean tenderometer reading and torque were calculated for each position of the small weight (Table 2). This procedure was then repeated with the small weight at its calibrated position and moving the large weight in increments. Mean tenderometer readings and corresponding torques were then calculated (Table 3). The first test was then repeated using frozen and thawed peas (collected from one batch of fresh peas delivered to a processor) instead of wax (Table 4).

Three samples of various products were tested in the pea tenderometer (calibrated properly) and then in the Ottawa Pea Tenderometer (Voisey and Nonnecke, 1973 b) to determine the relationship between these two instruments over the bottom portion of the tenderometer scale. Mean values were calculated in each case (Table 5).

4.0 RESULTS

The relationship between tenderometer reading and pendulum angle was a cosine function (Fig. 2A), but did not pass through zero. The relationship between tenderometer reading and torque was not linear (Fig. 2B). It deviated from a straight line (Fig. 2C) by a maximum of about 3% of scale. The maximum deviation occurring over the mid portion of the scale. It was considered that this could be attributed to errors in measuring the angle of the pendulum which would have to be about 3° to account for the non linearity of the relationship. This source was eliminated because all the points on the tenderometer reading - pendulum angle curve fitted a smooth line within about 0.5°. It was, therefore, assumed that the errors could possibly be attributed to a) errors in marking the tenderometer scale; b) the fact that the geometric relationship between the circular scale and pendulum had to be manipulated in order to make it read correctly at zero and full scale.

Results from the wax wafers in moving the small weight (Table 2) indicated a linear relationship between torque and tenderometer reading (Fig. 3). In changing the radius of the weight from 19.5 to 25.5 in the pendulum, torque was theoretically changed as follows, if the angle A remained constant: $\text{Torque} = (W_1R_1 + W_2R_2 + W_3\ R_3)\ \text{CosA}$

$$= (20.25\ R_1 + 1914 + 156)\ \text{CosA}$$

$$\text{or Torque} = (20.25\ R_1 + 2070)\ \text{CosA}$$

$$\text{at 19.5 in. Torque} = 2465\ \text{CosA}$$

$$\text{at 25.5 in. Torque} = 2586\ \text{CosA}$$

$$\%\ \text{Change} = \frac{\text{Maximum - Minimum}}{\text{Full scale reading}}$$

$$= 4.8\%$$

The percentage change is calculated on the basis of the full scale reading in the calibrated condition in all cases.

Similarly, the results obtained in moving the large weight (Table 3) showed a linear relationship between torque and tenderometer reading (Fig. 4). In this case, at 30.5 in., Torque = 2546 CosA

at 33.5 in., Torque = 2734 CosA

% Change = 7.4

Also, for frozen and thawed peas (Table 4) the relationship between torque and tenderometer reading appeared linear (Fig. 5), and in this case at 25.5 in., Torque = 2586 CosA

at 20.5 in., Torque = 2485 CosA

% Change = 4.0%

In previous experiments on calibrated tenderometers, the variation of readings for wax wafers has been consistently at a low level. For example, the average coefficient of variation for 10 single, double or triple wafers has been less than 2.5% over a great number of tests. Thus, it was concluded that providing the temperature was constant, the wafers gave repeatable results. In other words, the torque generated by the wax wafers in resisting shearing should be constant at the three levels (single, double, triple) no matter what position the weights are in. If this is the case, as the radius of the weights is increased, then the angle of the pendulum to the horizontal should increase and the tenderometer reading decrease when testing the wafers. This trend was shown with double and triple wafers when moving the small weight, but a reversed trend was indicated for single wafers (Fig. 6). When moving the large weight, the trend was consistent for single, double and triple wafers (Fig. 7). The slopes of these lines were greater than the slope of the changes based on calculating the percentage change with respect to the full scale reading. However, it was obvious in both tests that the small differences in wafer properties introduced variation in the experimental data. The points were as far as ± 7 T.U from a straight line relationship (Fig. 6, 7 and 8).

The calculated torque generated by the wax changed by 2.0 to 11.0% as a percentage of the full scale torque during the test and gave coefficients of variation ranging from 2.2 to 5.0 (Table 5). Thus, the wax does not appear to generate a constant torque, but the changes and variation correspond approximately to that of frozen and thawed peas. Throughout the test the percent change in reading and variation of torque and reading corresponded except in moving the large weight and testing wax where the change and variation in reading was higher than that of the calculated torque. However, it should be noted that throughout the test the changes are relatively small and may be significantly affected by experimental error.

It can be concluded that the tenderometer responds to changes in torque generated by the test material, but that wax does not generate a constant torque.

The torque generated by the wax (T_W) will depend on the stresses (S) developed, the rate of change of stresses with time (t) and the geometry of the shearing blades (a) and any viscous effects of wax between the blades, i.e. $T_W = a\ f\ (x)\ t + aF\ \dot{A}$ where F is a coefficient of adhesion between the blades.

The torque developed by the pendulum (T_p) will depend on the displacement and acceleration of the pendulum and the friction within the system. Consider a simple pendulum consisting of a weight W at radius R displaced at some angle A from the horizontal (Fig. 1B). When measuring pea tenderness or testing wax the pendulum generally moves until it reaches the peak reading (Voisey and Nonnecke, 1972 d), but not at constant velocity.

Thus, inertia must be taken into account, i.e. $T_p = I\ddot{A} + WR\ \mathrm{Cos}A + MW$

where I is the moment of inertia of W about the center of rotation

$\ddot{A}$ is the acceleration

M is the coefficient of friction of the pendulum pivot

$I = WR^2$

or $T_p = W\ (R^2\ddot{A} + R\ \mathrm{Cos}A + M)$

At the peak the pendulum must be decelerating rapidly because it must stop and then reverse direction over a small portion of its angular displacement. Thus, the inertial effect may be significant since it is proportional to R^2.

For example, consider moving the large weight from a radius of 30.5 to 31.0 in and assuming the acceleration is unchanged.

Inertial torque = $WR^2\ddot{A}$

at 30.5 in this = $W\ 30.5^2\ A$

at 31.0 in this = $W\ 31.0^2\ A$

difference = $3.1\ W\ddot{A}$

or a 10% change in inertial torque.

This effect cannot be fully evaluated unless the acceleration is measured, but, in theory, moving the weight to achieve calibration under static conditions affects the calibration operating under dynamic conditions.

The results obtained in testing various food products in the pea tenderometer and an Ottawa Pea Tenderometer (Table 6) indicate that the instrument readings are related at the low end of the pea tenderometer scale (r = 0.81). The relationship also appeared to pass through zero (Figure 9). In previous comparisons using fresh peas (Voisey and Nonnecke, 1973 b) the relationship between the two instruments did not pass through zero. The data here suggests that either a) the zero setting of the tenderometers previously used was not correct; or b) the relationship between the instruments is affected in this respect by the type of product tested.

5.0 CONCLUSIONS

Wax wafers which on the average give repeatable tenderometer readings vary in results sufficiently that it is not possible to use them to establish the effect of calibration weight position on the instrument readings. This leads to the converse conclusion that wax wafers are not suitable for standardizing tenderometers accurately by testing wax and moving the weights to give a specific reading. Thus, wax wafers are only suitable for measuring differences between tenderometers to locate instruments that produce readings that differ by some significant amount from the mean (Voisey and Nonnecke, 1971 a).

The use of static calibration techniques may introduce errors in the dynamic performance of the instrument.

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Table 1. Tenderometer readings and torque calculated from Torque = 2545.4 CosA in lb.

Reading T.U.	Angle A Degrees	Torque in lb.
0	90	0
10	87	133
20	83	310
30	80	442
40	77	573
50	74	702
60	71	829
70	68	954
80	65	1076
90	61	1234
100	58	1349
110	55	1460
120	51	1602
130	47	1736
140	43	1862
150	39	1978
160	35	2085
170	30	2204
180	24	2325
190	16	2447
200	-2	2561

Table 2. Mean values of 5 tenderometer readings and the calculated torque obtained in testing wax wafers at 74°F with the large pendulum weight at its correct calibrated position for various positions of the small weight.

	Radius of small weight R_1 (in)	Single Wafer			Double Wafer			Triple Wafer		
		Reading (T.U.)	Angle A degrees	Torque (in lb)	Reading (T.U.)	Angle A degrees	Torque (in lb)	Reading (T.U.)	Angle A degrees	Torque (in lb)
	25.5	43	76.0	626	80	65.0	1093	115	52.8	1563
	25.0	43	76.0	623	81	64.5	1109	108	55.5	1459
	24.5	43	76.0	621	83	63.8	1133	117	52.0	1580
	24.0	44	76.7	632	80	65.0	1080	113	57.0	1392
	23.5	43	76.0	616	78	65.5	1056	110	55.0	1460
	23.0	44	75.7	627	82	64.0	1111	118	51.5	1579
	22.5	44	75.7	624	87	62.5	1166	126	48.5	1673
	22.0	44	75.7	622	86	63.0	1142	125	48.8	1657
	21.5	44	75.7	619	85	63.2	1129	126	48.5	1659
	21.0	44	75.7	617	86	63.0	1133	126	48.5	1653
	20.5	45	75.5	622	83	63.8	1097	119	51.5	1547
	20.0	43	76.0	599	83	63.8	1092	119	51.5	1540
	19.5	42	76.4	580	81	64.5	1061	120	51.0	1550
Mean		43.5		618	83		1108	119		1562
Maximum	25.5	45	76.4	632	87	65.5	1166	126	57.0	1673
Minimim	19.5	42	75.5	580	78	62.5	1056	108	48.5	1392
Change	6.0	3	1.2	52	9	3.0	110	18	8.5	281
% Change		1.5	1.3	2.0	4.5	3.3	4.3	9.0	9.4	11.0
C.V. %		1.8		2.2	3.3		2.9	5.1		5.6

$$\% \text{ Change} = \frac{\text{Max} - \text{Min}}{\text{Full scale reading}} \times 100\%$$

Table 3. Mean values of 5 tenderometer readings and the calculated torque obtained in testing wax wafers at 74°F with the small pendulum weight at its correct calibrated position for various positions of the large weight.

	Radius of large weight R_2	Single Wafer			Double Wafer			Triple Wafer		
	(in)	Reading (T.U.)	Angle A degress	Torque (in lb)	Reading (T.U.)	Angle A degress	Torque (in lb)	Reading (T.U.)	Angle A degrees	Torque (in lb)
	30.5	43	76.0	616	82	64.0	1116	118	51.6	1582
	31.0	43	76.0	624	80	65.0	1089	115	52.9	1554
	31.5	39	77.2	578	76	66.0	1061	107	55.7	1470
	32.0	36	78.0	548	72	67.3	1019	104	56.8	1444
	32.5	36	78.0	555	70	68.0	1000	107	55.7	1505
	33.0	35	78.5	539	70	68.0	1012	106	56.0	1511
	33.5	36	78.0	568	65	69.5	958	95	59.9	1371
Mean		38		575	74		1036	107		1491
Maximum	33.5	43	78.5	624	82	69.5	1116	118	59.9	1582
Minimum	30.5	35	76.0	539	65	64.0	958	95	51.6	1371
Change	3.0	8	2.5	85	17	5.5	158	23	8.3	211
% Change		4.0	2.8	3.3	8.5	6.1	6.2	11.5	9.2	8.3
C.V. %		9.0		5.7	8.2		5.3	7.0		4.7

$$\% \text{ Change} = \frac{\text{Max} - \text{Min}}{\text{Full scale reading}} \times 100\%$$

Table 4. Mean values of 3 tenderometer readings and the calculated torque obtained in testing frozen and thawed peas at 74°F with the large weight at its correct calibrated position for various positions of the small weight.

Radius of small weight R_1 (in)	Reading (T.U.)	Angle A degress	Torque (in lb)
25.5	105	56.3	1435
25.0	113	53.5	1532
24.5	118	51.6	1594
24.0	118	51.6	1590
23.5	109	55.0	1460
23.0	109	55.0	1454
22.5	109	55.0	1448
22.0	110	54.7	1453
21.5	110	54.7	1447
21.0	109	55.0	1431
20.5	108	55.4	1409
Mean	111		1478
Maximum	118	56.3	1594
Minimum	105	51.6	1409
Change	13	4.7	185
% Change	6.5	5.2	7.3
C.V.%	3.66		4.34

$$\%\ \text{Change} = \frac{\text{Max} - \text{Min}}{\text{Full scale reading}}$$

Table 5. Summary of wax and pea test data.

Table	Test		Single Wafer or peas		Double Wafer		Triple Wafer	
			Reading T.U.	Torque in lb	Reading T.U.	Torque in lb	Reading T.U.	Torque in lb
2	Moving small weight - wax (Change 4.8%)	Mean	43.5	618	83	1108	119	1562
		% Change	1.3	2.0	4.5	4.3	9.0	11.0
		C.V. %	1.8	2.2	3.3	2.9	5.1	5.6
4	Moving small weight - peas (Change 4.0%)	Mean	111	1478				
		% Change	6.5	7.3				
		C.V. %	3.7	4.3				
3	Moving large weight - wax (Change 7.4%)	Mean	38	573	74	1036	107	1491
		% Change	4.0	3.3	8.5	6.2	11.5	8.3
		C.V. %	9.0	5.7	8.2	5.3	7.0	4.7

Table 6. Mean of 3 readings obtained for various products tested in the Pea Tenderometer and Ottawa Pea Tenderometer.

	Product	Reading[*] P.T. (T.U.)	O.P.T. (Kg)
1	Jello	0	2.15
2	Canned sliced carrots	4	10.00
3	Canned tomatoes	6	11.60
4	Canned luncheon meat	7	11.60
5	Spaghetti (12 min. cooking)	8	6.50
6	Spaghetti (10 min. cooking)	8	8.20
7	Canned potatoes	16	33.50
8	Canned Beets	20	30.50
9	Baked beans (A)	22	51.50
10	Baked beans (B)	25	53.50
11	Canned cut green beans	30	29.00
12	Canned asparagus	71	60.00

Correlation coefficient r = 0.813

Regressions O.P.T. (Kg) = 0.8687 P.T. (T.U.) + 9.9616

P.T. (T.U.) = 0.7602 O.P.T. (Kg) - 1.4321

[*] Mean of 3 tests

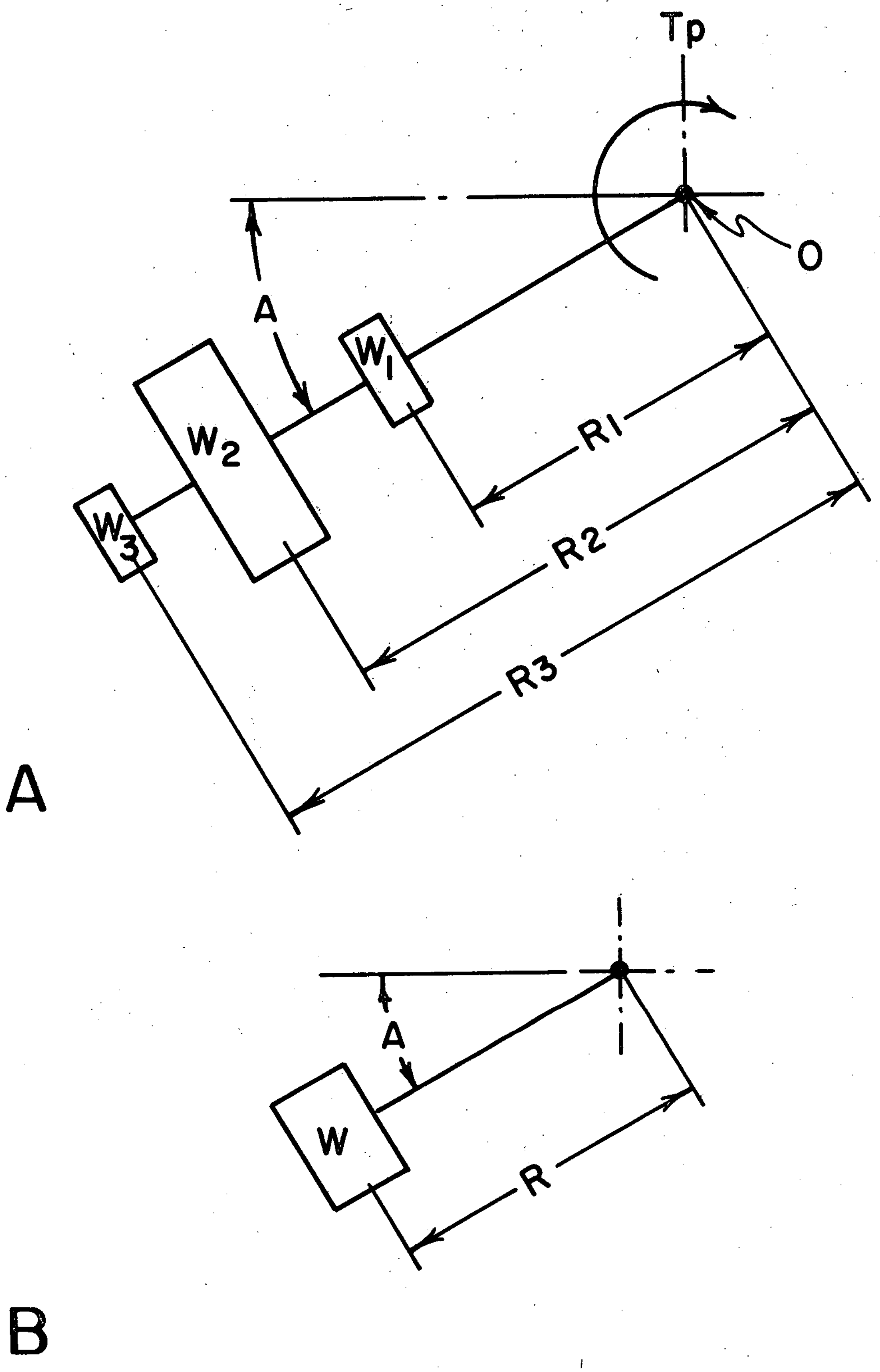

Figure 1A. Geometry of pendulum system W_1 and W_2 calibration weights at R_1 and R_2 respectively from the center of rotation O. W_3 is equivalent to the weight of the pendulum rod and other parts that move with it at some arbitrarily selected radius R_3; B. a simple pendulum.

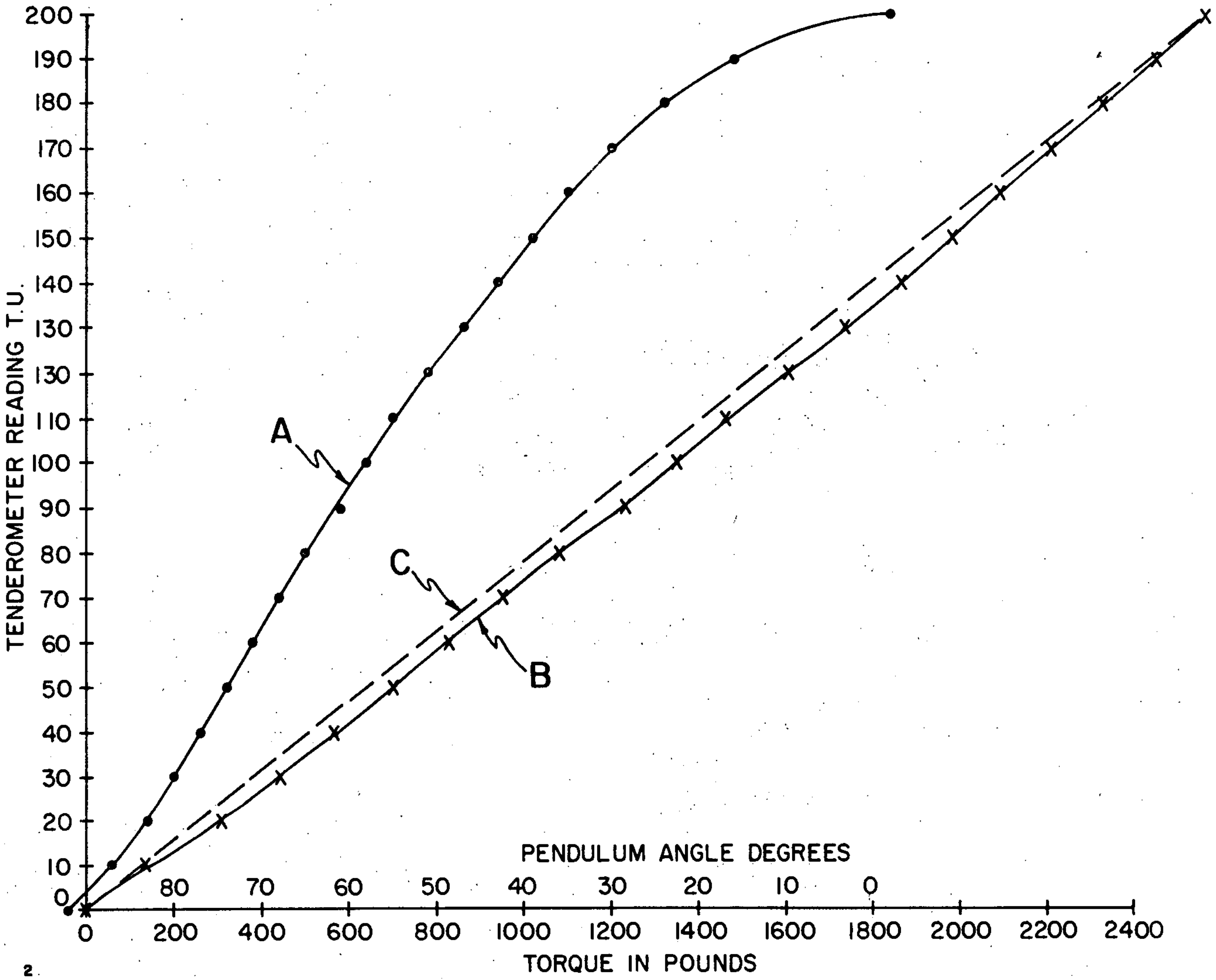

Figure 2A. Relationship between tenderometer readings and pendulum angle-based on measured values; B. relationship between tenderometer reading and torque - based on calculated torque values; C. straight line between origin and maximum reading on curve B.

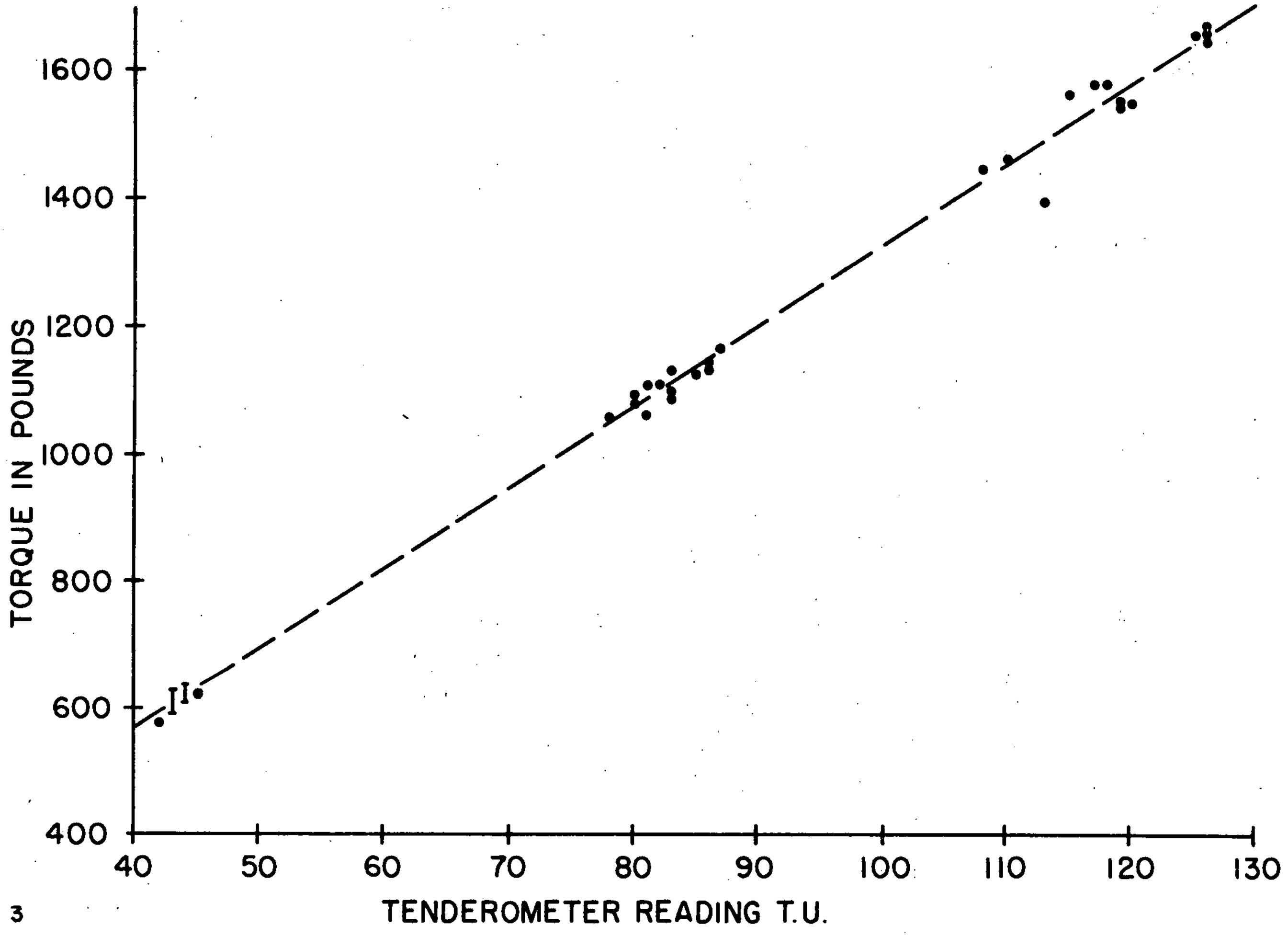

Figure 3. Relationship between torque and tenderometer reading established using wax at 74°F for moving the small calibration weight.

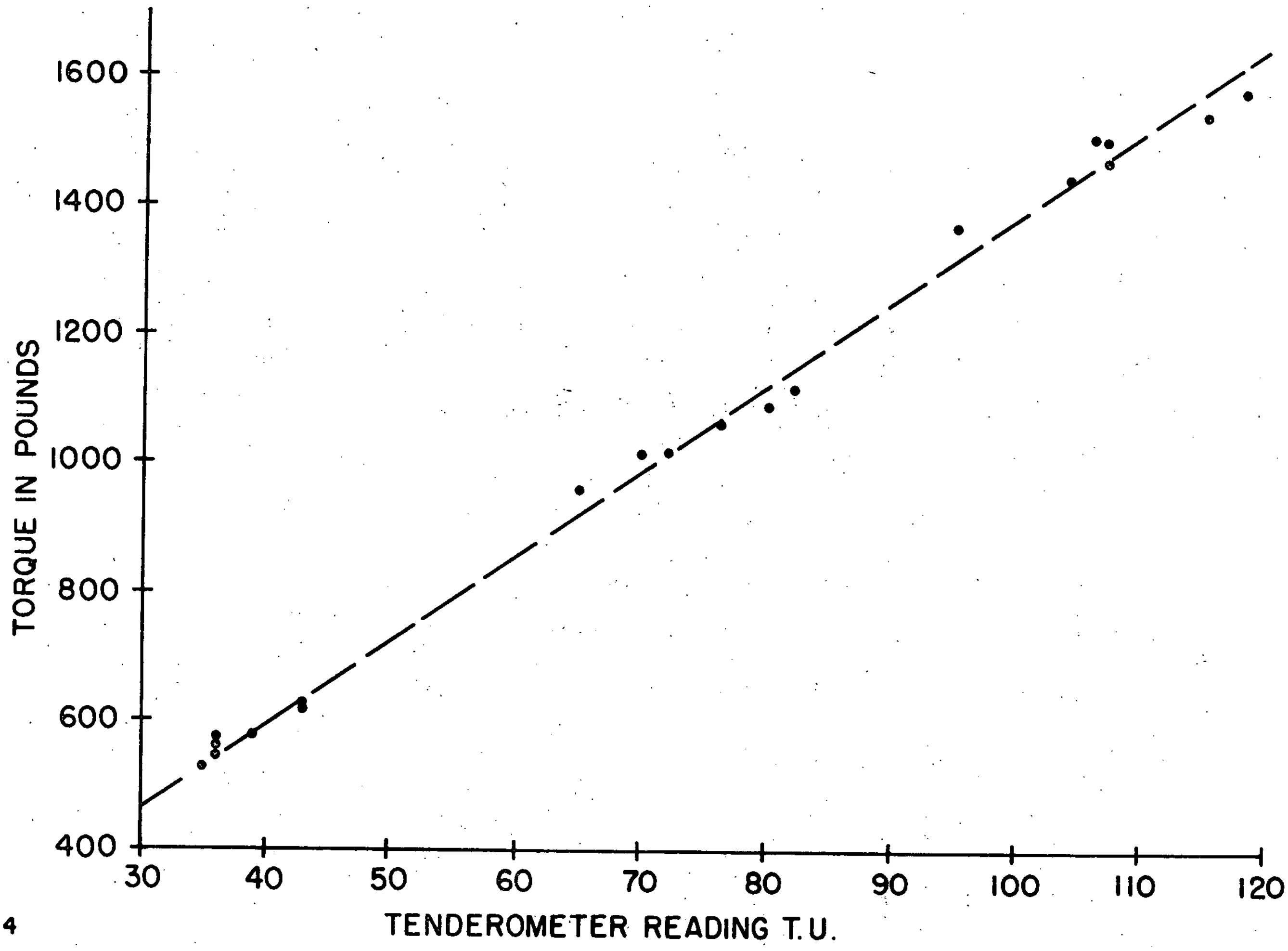

Figure 4. Relationship between torque and tenderometer reading established using wax at 74°F for moving the large calibration weight.

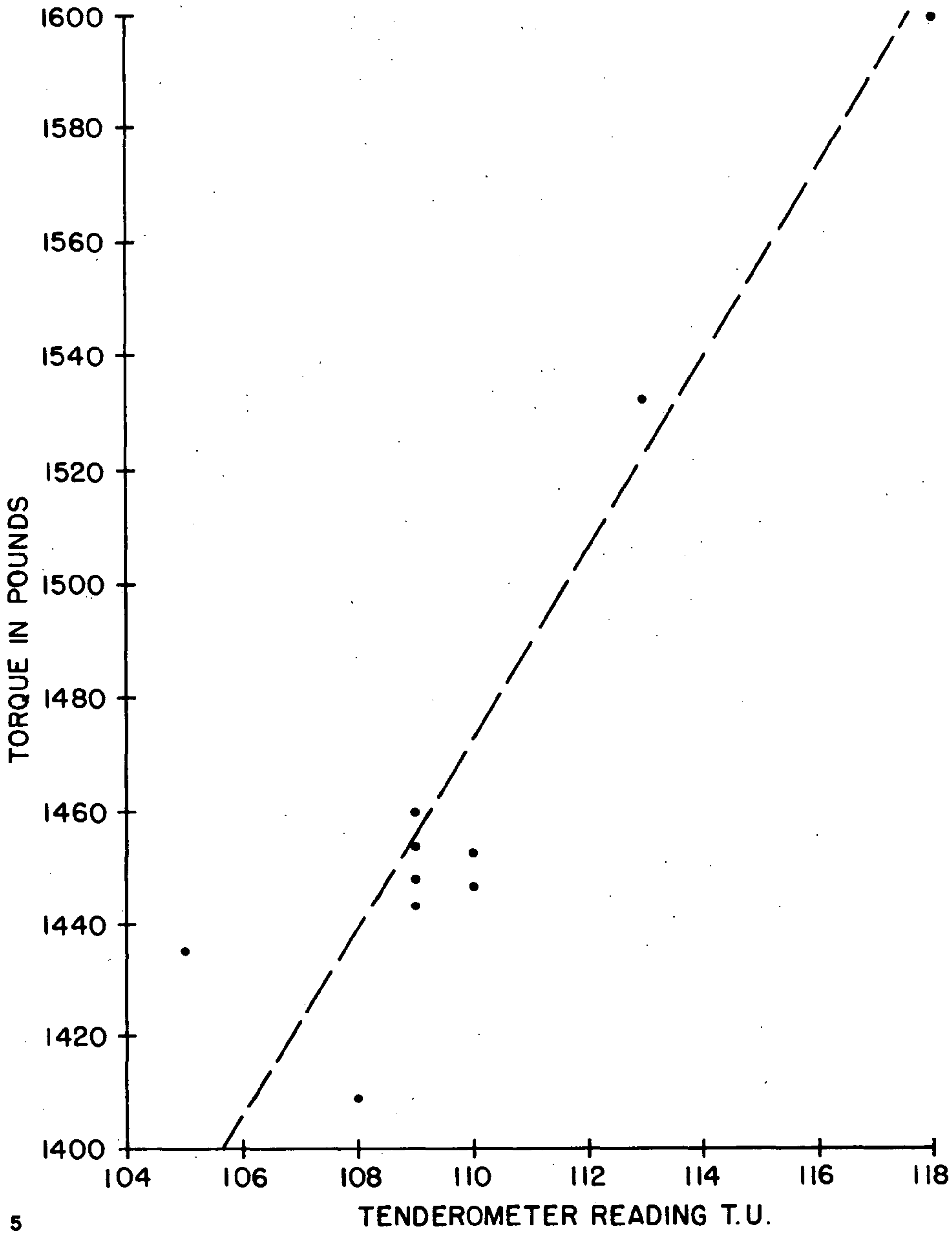

Figure 5. Relationship between torque and tenderometer reading established using frozen and thawed peas for moving the small weight. Each point is the mean of 3 samples.

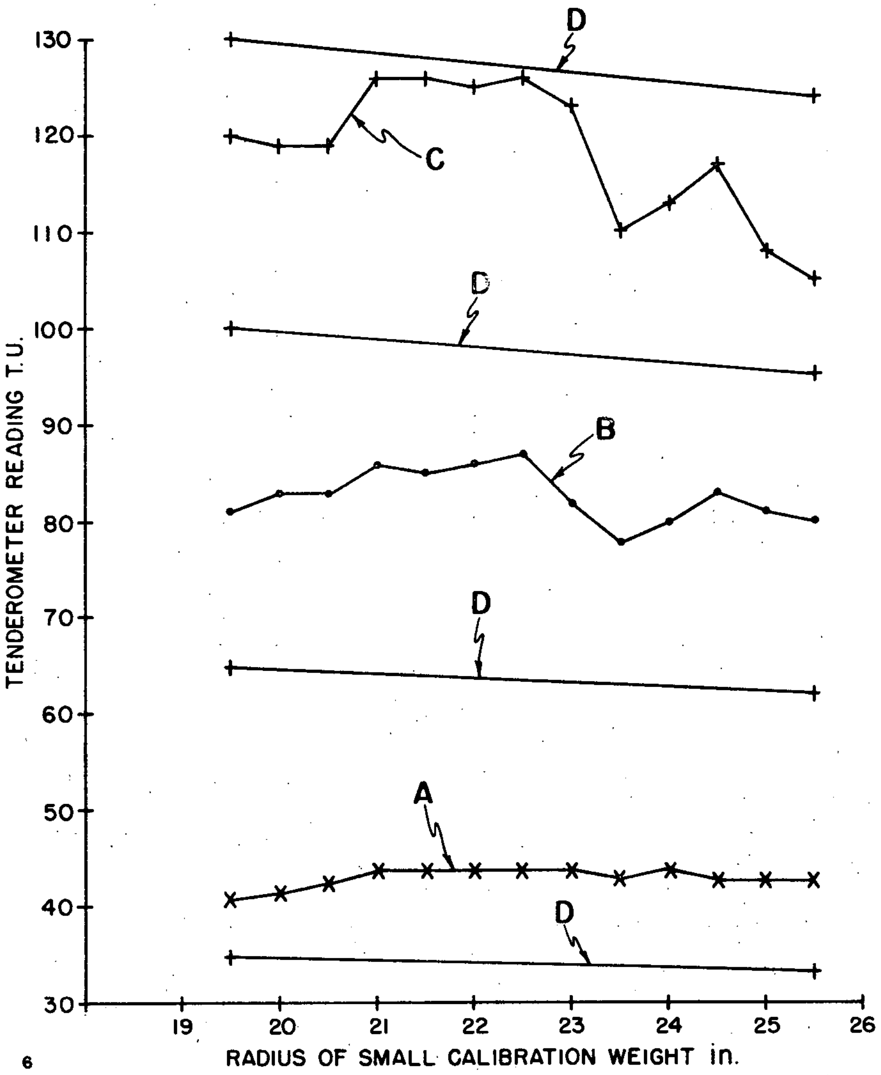

Figure 6. Tenderometer reading Vs radius of small calibration weight for wax wafers. A. single; B. double; C. triple; D. straight lines representing the calculated 4.7% change introduced by moving the weight at various points on the tenderometer scale.

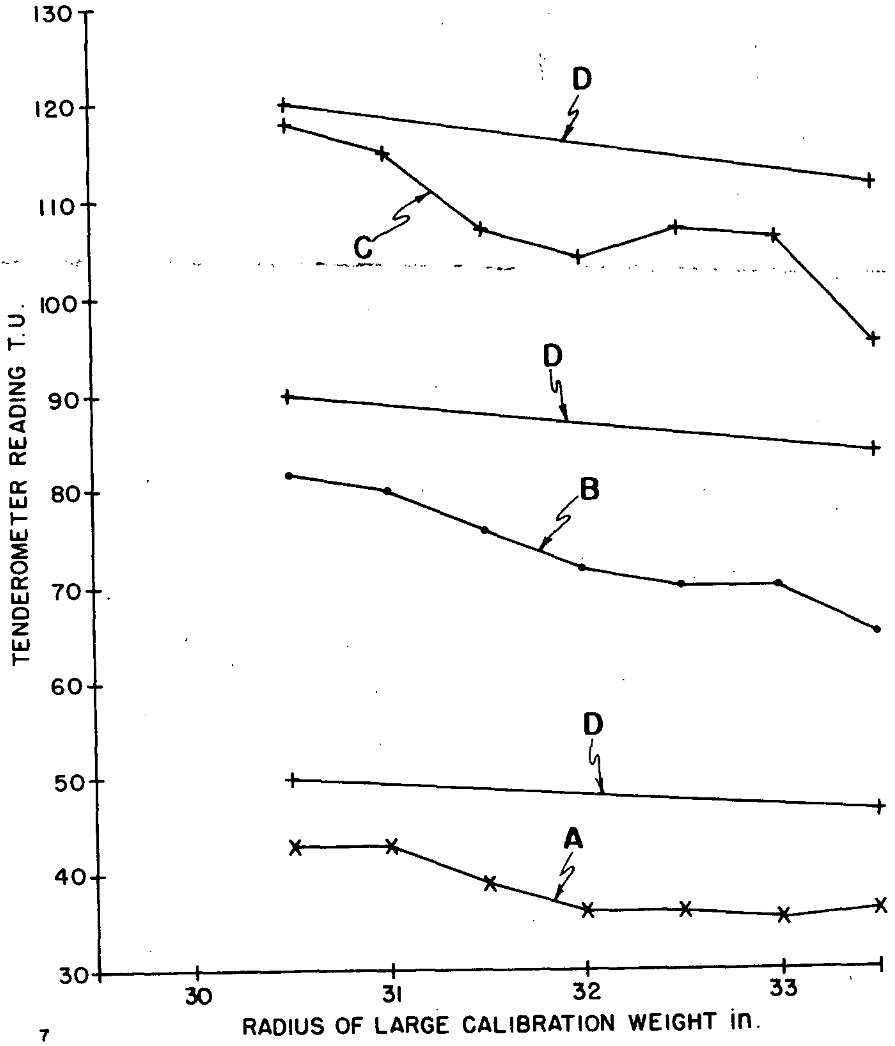

Figure 7. Tenderometer reading Vs radius of large calibration weight for wax wafers. A. single; B. double; C. triple; D. straight lines representing the calculated 6.9% change introduced by moving the weight at various points on the tenderometer scale.

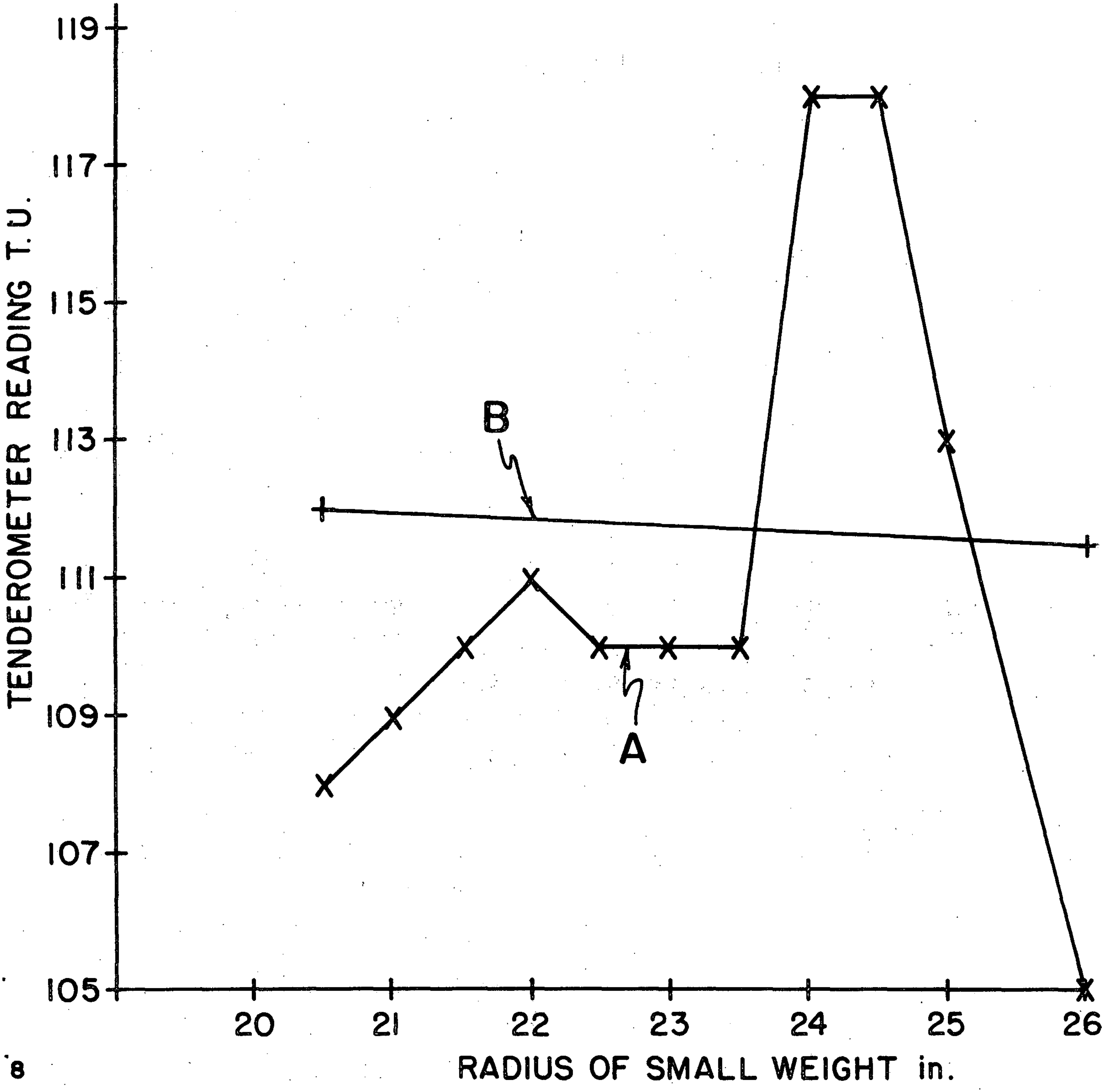

Figure 8A. Tenderometer reading Vs radius of small weight for frozen and thawed peas; B. straight line representing the calculated 3.9% change introduced by moving the weight at one point on the tenderometer scale.

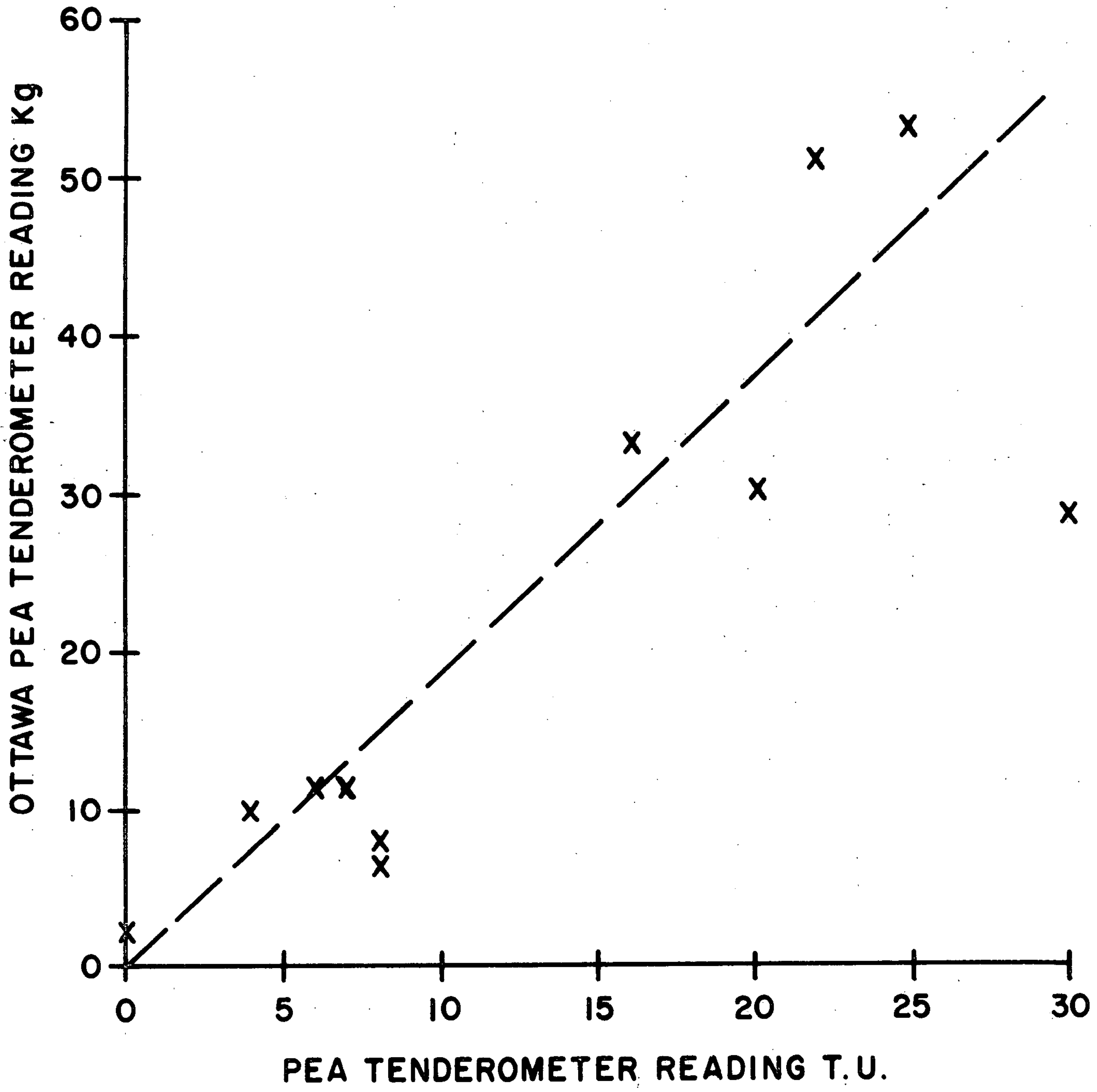

Figure 9. Relationship between readings from the Ottawa Pea Tenderometer and Pea Tenderometer readings in testing a range of products (see Table 6). Each point is the mean of 3 samples.