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Variation in Determinations of Shear Force by Means of the "Bratzler-Warner Shear"[a]

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The investigation of variation in shear force measurements by means of the Warner-Bratzler Shear was made using parowax and beeswax as homogeneous standards to display a minimum of variation in the test material. The variation observed in the experimental results could be thus ascribed primarily to the apparatus used for testing. Three criteria of tenderness were investigated for use in connection with the Warner-Bratzler apparatus: (1) maximum shear force (commonly used at the present time), (2) total time necessary for failure in shear and (3) the slope of the shear force vs. time curve. This last criterion was found to be best as it displayed the smallest coefficient of variation and highest discriminative ability between treatments which were in fact different.

Objective evaluation of tenderness of meat by generally accepted practice in food research is expressed in terms of maximum shear force obtained by means of Bratzler-Warner Shear apparatus. Such determinations display very wide variations. Ramsbottom and Strandine *(2)*, Bard and Tischer *(1)*, and Tischer, Hurwicz and Zoellner have demonstrated the occurrence of extreme experimental variations in the determination of shear force in beef subjected to various processing conditions.

Similar difficulties are encountered in the evaluation of thermal and other physical characteristics of beef because of large variations in individual determinations. The variation of the means, however, is considerably smaller when a sufficient number of determinations is available and the mean experimental values lend themselves to a mathematical treatment resulting in rather well behaved functional relationships.

In shear force determinations, extremely large variations persisted in means of eight to ten determinations per sample and through several replicates *(3)*. The relationship of shear force to processing time discussed in *(3)* displayed characteristics of a roughly sigmoid curve and did not lend itself easily to mathematical interpretation. Only approximate prediction equations could be derived because of the large variations in the measurements.

Either an inherent variation of the shear force apparatus, or of the criterion of the maximum shear force itself as determined by Bratzler-Warner Shear may be responsible to a great extent for the experimental variations encountered in attempts at objective evaluation of the tenderness of meat.

The determination of either the error of the machine (its calibration) or the development of a new criterion of tenderness would allow an improved and more critical interpretation of the results of shear tests on meat and facilitate a separation of the errors due to the lack of homogeneity of meat from those inherent in the apparatus. An improvement of the design of the apparatus could be made to eliminate its lack of precision or perhaps the development of a new criterion of tenderness would result in experimental values with smaller experimental error. If the new criterion (such as the slope of the shear force vs. time curve) displayed smaller variation, the present Bratzler-Warner apparatus could be retained without modification to yield more precise results than those afforded by the maximum shear force criterion used at the present time.

In view of these considerations the Bratzler-Warner shear apparatus was tested to evaluate three criteria of tenderness:

a. Maximum shear force
b. Total time for failure in shear
c. Slope of the shear force vs. time curve.

To avoid the bias and variability attached to the material tested, waxes were chosen as testing standards because of their chemical homogeneity. It was assumed that variation displayed while testing waxes could be ascribed primarily to the Bratzler-Warner apparatus. The experimental errors determined in this manner could then be attributed to the measurements performed by the apparatus and separated from the variations observed in testing other materials. In effect, the shear force apparatus would be calibrated.

The assumption of the homogeneity of waxes chosen as the standards for calibration may be justified as relative to a definite lack of homogeneity of biological ma-

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terials such as meat and by the fact that they were used by Bratzler *(4)* in designing the apparatus.

This experiment was undertaken to determine the magnitude of variations associated with "Bratzler-Warner Shear" and to compare the three proposed criteria of tenderness.

EXPERIMENTAL PROCEDURE

Parowax and beeswax were chosen as standard materials in testing the variability of the machine. Other waxes originally considered were found to be too hard and too brittle, and their shear strength did not fall in the range occupied by beef.

The shear force tests were made for these 2 waxes at 4 temperatures (32, 45, 60, and 80° F.) to obtain a varying range of hardness represented by varying melting points and to demonstrate whether the machine would yield results correspondingly dependent in terms of variance (or experimental error) on the hardness of the sample.

A 2 x 4 factorial design in completely randomized blocks was used (4 reps). One half inch diameter cylinders of wax were cut with a cork borer, brought up to the required temperature, and tested immediately upon removal from conditions of controlled temperature.

A moving picture was made of every test using a camera mounted above the apparatus to record the movement of the scale hand on the dial and the passage of time as recorded on an electric timer installed close to the dial. The film was projected using a still projector and the data (shear force values and time) were transcribed and tabulated frame by frame. In this manner shear force values were obtained at approximately one-second intervals throughout the duration of the total shearing process.

RESULTS AND DISCUSSION

Parowax and beeswax appeared to substantiate the assumption of their homogeneity, as they showed no evidence of fractures and other damage during handling; no cleavage surfaces were apparent in the sample cylinders cut out with the cork borer.

The transcribed shear force data were plotted against time for each determination, and the maximum shear force attained and total time necessary for failure were recorded. The slopes of the curves were determined by linear regression since the plot of shear force vs. time suggested linearity. An analysis of variance of the 3 criteria considered (Table 1) indicated largest variation

TABLE 1
Partial analysis of variance for three criteria of tenderness

	Max. shear force			Total time		Slope	
Source	*df*	*M.S.*	*"F"*	*M.S.*	*"F"*	*M.S.*	*"F"*
Among Treatments	7	48.58	......	4.025	......	0.3058	......
Waxes	1	44.18	29.26[1]	0.3628	0.67	0.4351	60.43[1]
Temperatures	3	96.03	63.60[1]	8.5287	14.95[1]	0.5658	78.58[1]
W X T	3	2.60	1.72	0.7370	1.29	0.0028	0.38
Units Treated Alike	24	1.51	......	0.5703	......	0.0072	......

[1] Significant at 1% probability level.

for the maximum shear force and smallest for the slope of the shear force vs. time curve. The variation of the total time criterion was intermediate in magnitude. Small variance of measurements of slope may be explained by the large number of observations necessary for its determination while the other 2 criteria are determined from one observation only. Also the smaller order of magnitude of the slope compared to the other criteria may be responsible for the small variance.

In view of these occurrences, small variance in the slope determinations may be considered as evidence that the slope is the best criterion of tenderness only if the coefficient of variation (C.V. = Standard deviation/mean) of the slope is smaller than for the other 2 criteria. A high capacity for distinguishing among groups actually different should also be an attribute of the criterion considered best.

Table 2 was set up to evaluate the merits of each of the 3 criteria and shows the coefficients of variation (C.V.) associated with the measurement of each of the characteristics. The Chi-square values for 4 temperatures resulting from Bartlett's test of homogeneity of variance indicated that the variances were homogeneous and thus could be pooled to facilitate the comparison of the 3 criteria presented in Table 2. Slope showed the smallest C. V. for the pooled data of both waxes and all temperatures and therefore may be considered as the best criterion. A plot of the C. V. and s (Figure 1) for

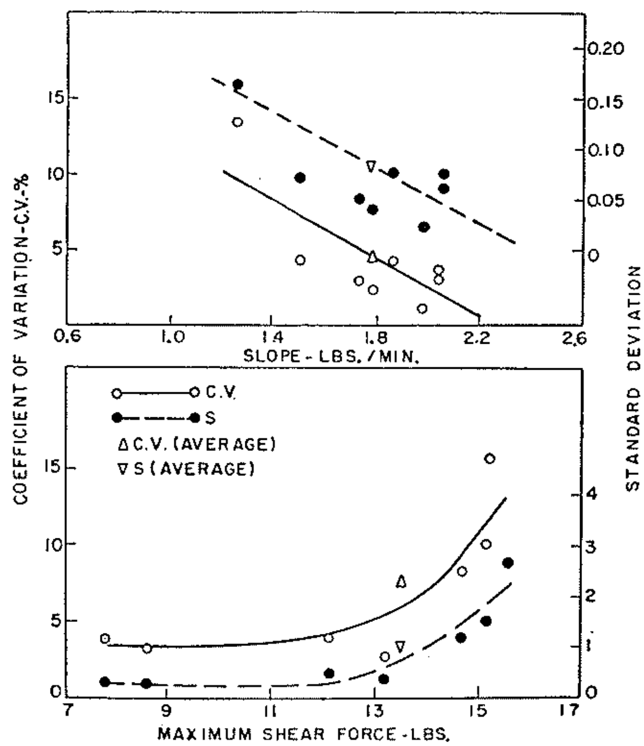

Figure 1. Variation of two criteria of tenderness.

the average of 4 determinations of each characteristic is in effect a calibration curve of the "Bratzler-Warner Shear" for each of the 3 criteria tested, which could be used in further tests of tenderness of meat. Figure 1 indicates also that the standard deviation s and coefficient of variation (C. V.) for the slope determination decrease with the increase in absolute value of the slope. This occurrence is desirable since the actual slope values for beef are found in the range where both s and C. V. are small. The opposite phenomenon is observed for the maximum shear force standard deviation and coefficient of variation. No definite trend was observed for the same statistics of total time necessary for failure. This evidence also supports the contention that slope is the best criterion of tenderness.

The ability to distinguish among treatments which are in fact different was tested by the "F"-test which indicates, by the values associated with waxes and tem-

TABLE 2

Variations and mean values of three criteria of tenderness for beeswax and parowax

Temp. (° F.)	Parowax				Beeswax			
	Average	(s^2 x 10^3)[1]	(s x 10^3)[2]	C. V. (%)[3]	Average	s^2 x 10^3	s x 10^3	C. V. (%)
Slope of the Shear Force vs. Time Curves (lbs./min.)								
32	2.0310	4.108	63.25	3.11	1.0536	6.010	77.45	4.18
45	2.0318	5.619	3.58	3.58	1.7817	1.602	40.00	2.24
60	1.9803	5.185	22.76	1.15	1.7284	2.573	50.99	2.95
80	1.5009	3.965	62.44	4.16	1.2475	28.301	168.22	13.48
Pooled	1.8860	4.719	68.55	3.63	1.6528	9.622	97.98	5.93
Maximum Shear Force (lbs.)								
32	17.92	442.5	663.3	3.70	14.70	1460.0	1208.3	8.22
45	15.62	7282.5	2698.0	17.27	13.23	129.2	360.5	2.73
60	15.17	2349.2	1532.0	10.10	12.13	209.2	455.2	3.78
80	8.60	80.0	282.8	3.29	7.83	89.2	298.7	3.82
Pooled	14.33	2838.6	1593.7	11.12	11.97	471.9	685.5	3.73
Total Time for Failure (secs.)								
32	9.87	229.2	479.3	4.86	6.87	229.2	479.5	5.40
45	8.37	1729.2	1315.2	15.70	8.76	260.0	500.0	5.71
60	8.62	1062.5	1029.6	11.94	6.78	416.7	647.9	7.40
80	7.12	229.2	479.5	6.73	6.75	415.7	647.9	9.80
Pooled	8.50	812.5	900.1	10.59	6.28	328.2	574.3	6.93

Pooled means for both waxes

	Mean	s^2 x 10^3	s x 10^3	C. V. (%)
Slope	1.7694	7.175	84.80	4.79
Max. Sh. F.	13.50	1005.00	1002.0	7.41
Total time	8.39	570.35	754.9	9.00

[1] Variance. [2] Standard deviation. [3] Coefficient of variation.

peratures, that the total time criterion has the least capacity to distinguish (Table 1). The slope and maximum shear force both have high ability of distinguishing. The slope seems to be the better criterion because of the highest "F"-values resulting from the tests.

The highest ability to distinguish among different treatments connected with the lowest coefficient of variation substantiate the contention that slope is the best criterion to be used in connection with determination of tenderness by means of "Bratzler-Warner Shear."

Further evidence in favor of the slope as the "best" criterion of tenderness is given in Table 3 in which are data on the coefficients of variation for 21 mixtures of parowax and beeswax tested at room temperature. The

TABLE 3

Mean values and variation of the three criteria of tenderness for 21 mixtures of parowax and beeswax

% beeswax in parowax	Criterion: Slope lb./sec.	C. V.	Total time Sec.	Total time C. V.	Max. shear force lb.	Max. shear force C. V.
0	1.53	2.69	6.2	17.22	11.2	22.30
5	1.63	2.81	7.3	19.80	13.2	26.24
10	1.54	2.68	7.9	19.89	13.5	24.58
15	1.63	2.67	8.3	24.34	14.0	25.75
20	1.49	2.85	8.5	22.35	13.9	22.36
25	1.44	2.70	9.0	26.43	13.6	24.39
30	1.50	2.91	8.5	26.43	14.0	26.73
35	1.46	2.82	9.0	22.33	12.7	22.30
40	1.43	2.62	8.5	26.43	12.3	24.47
45	1.37	2.31	8.5	24.45	12.0	24.55
50	1.33	2.81	8.3	24.34	12.0	24.45
55	1.28	2.71	8.4	22.27	11.7	24.55
60	1.32	2.40	7.3	24.58	11.0	22.40
65	1.38	2.61	7.0	22.32	11.1	22.27
70	1.43	2.60	7.0	22.32	10.6	26.57
75	1.51	2.65	6.3	24.59	10.4	24.57
80	1.42	2.82	7.1	24.35	10.3	22.31
85	1.50	2.67	6.5	22.35	10.6	24.38
90	1.61	2.64	6.8	19.83	11.3	22.41
95	1.57	2.85	6.9	19.87	11.1	24.49
100	1.69	2.84	6.8	24.30	11.7	24.56
Average	1.48	2.71	7.6	22.89	12.0	24.13

average coefficient of variation for the slope was 2.71% as compared with 22.89% for the total time and 24.13% for the maximum shear force.

CONCLUSIONS

The maximum shear force as used at the present time as the criterion of tenderness by means of Bratzler-Warner shear displayed a pooled C. V. = 7.41% and is not the best criterion of tenderness to be used in connection with this machine.

The shear machine should be redesigned in an attempt to lower the experimental error inherent to it (shown in Figure 1 for the average of four determinations). This experimental error may be ascribed, on the assumption of homogeneity of the standard tested (waxes), to the machine only.

The slope of the shear force vs. time curve has been found to be the best criterion of tenderness with "Bratzler-Warner Shear" because of the smallest pooled C. V. = 4.79% and because of its ability to distinguish among treatments which are in fact different.

These conclusions were substantiated by experiment with mixtures of beeswax and parowax.

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