AN APPARATUS FOR MEASURING THE TORSIONAL STRENGTH OF MACARONI[1]

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ABSTRACT

A device is described for measuring the torsional strength of macaroni and spaghetti. The standard error of the means of ten measurements was 1.79 kg. per cm.^{2} A highly significant correlation of $+0.85$ was found between torsional strength and bending strength of 25 samples of macaroni, but neither of these properties was significantly correlated with the "wet weight" of the macaroni after cooking. However, the smaller the value of the torsional or the bending strength, the more observable were such defects as inelasticity, splitting, checking, or tendency to become sticky upon cooking.

This device is particularly useful for detection of hidden failures in macaroni. In a macaroni specimen a fissure running in a straight line along the axis of the cylinder, or very fine irregular cracks or checks, can exist. Such a macaroni may show a rather high bending strength, but when twisted, just as during cooking, it disintegrates.

The quality of a macaroni sample is usually ascertained by determining its cooking and mechanical characteristics. However, the majority of the methods currently in use are subjective. Such cooking characteristics as color, smell, and taste can only be evaluated by organoleptical means. The elasticity and ease of mastication of the cooked product are ascertained by subjective test. The only mechanical test which has been studied extensively is the bending or breaking strength (1–6).

A routine test known for a long time is to twist a macaroni specimen with both hands in opposite directions. This otherwise simple and practical method is deficient in two respects: 1) it is subjective, so that the result of the test depends to a large extent on expert and skillful handling by the operator; and 2) the result cannot be expressed either by a number or a diagram.

The present study was undertaken to design and construct an apparatus, as simple as possible, which would ensure that the twisting can always be performed under identical conditions and that the test results can be expressed by a single number.

The torsional strengths of 25 samples of macaroni were determined and the data compared with the bending strength and cooking characteristics of the samples.

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Description and Use of the Torsionmeter

The main features of the torsionmeter are shown in Figs. 1 and 2. It consists of a phonograph motor *1* with a coupled reducing gear connected through a clutch *2* to a clamping head which is rotated at 3 r.p.m. After the specimen has been clamped, the clutch, *2*, is displaced to the left and the motor rotates the sleeve *4* placed on shaft *3*. The torque is transmitted by the crosspin *5*. A longitudinal slot is provided in sleeve *4* so that the pin may have free axial movement. This is necessary for clamping the specimen and also for balancing axial stresses. The two clamping heads are identical and are illustrated in Figs. 2 and 3. Two small pins join the forked piece *6* to sleeve *4* (Figs. 1 and 2). Two tapered pins *7* which are adjustable by means of screws, retain the clamping head *8* in fork *6*; in this way, the clamping heads *8* may adjust themselves freely in a similar manner to ball joints. Sleeve *4* of the clamping head (Figs. 1 and 2) is short in length and is keyed to shaft *9* (Fig. 3), which supports the loading arm *10* (Figs. 1 and 2) producing the torque. The loading weight is about 150 g. and in Fig. 2 it is shown suspended at the shorter arm length used for testing specimens of very thin alimentary pastes.

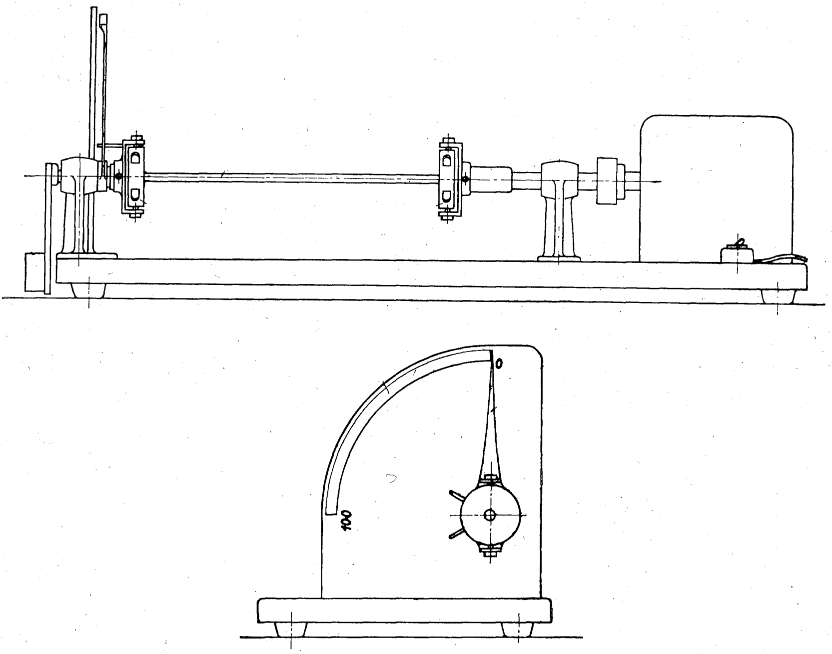

Fig. 1. Diagram of torsionmeter.

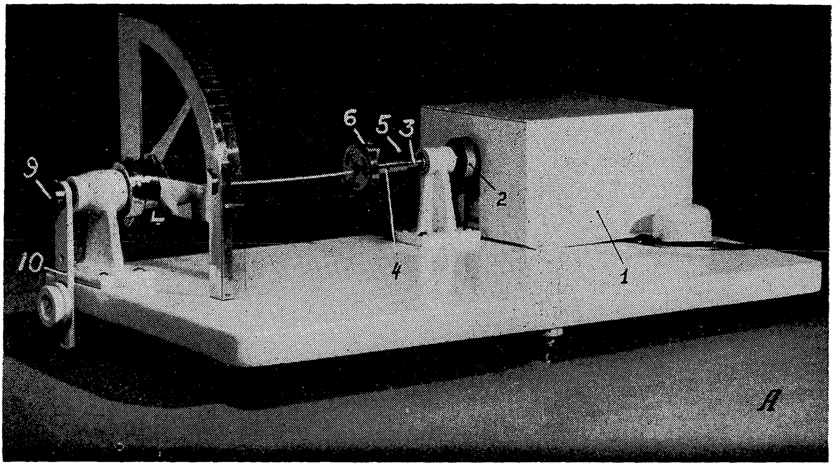

Fig. 2. Torsionmeter.

With thick samples of high strength, the weight should be placed at the greatest arm length; in some cases arm extensions should be used. As shown in Fig. 3 the index pointer *11* is dragged along by pin *12* by means of the small plate, *13,* mounted to the index. The index pointer can only be displaced by pin *12* in one direction. The balanced index pointer moves very easily and remains in the position attained until the sample is broken by the torsion to which it has been subjected.

It is advisable to make an auxiliary calibrating disk for scale recording. This is a light disk of some 150-mm. diameter, built onto the loading arm. A flexible thread is run on the disk perimeter, fixing one end to the disk and suspending a light load pan on the other. Progressively increased loads are placed in the pan and the relevant index position is recorded on the scale. The product of disk radius and loading weight specifies loading torque in units of cm. per kg. Two scales are plotted according to the two possible load positions.

Three jaws grip the sample. The clamping effect is self-locking, i.e., increased friction of the clamping jaws — as a consequence of specimen twist — increases the clamping force of the springs. Knurled jaw surfaces will enhance this action.

The bearing on the scale side should be of extremely low friction in order to minimize friction effects which would influence the test results.

Measurement of Torsional Strength. The specimen of macaroni (20 cm. long) is clamped between the two clamping heads in such a way that the heads can rotate freely in either direction. The pointer

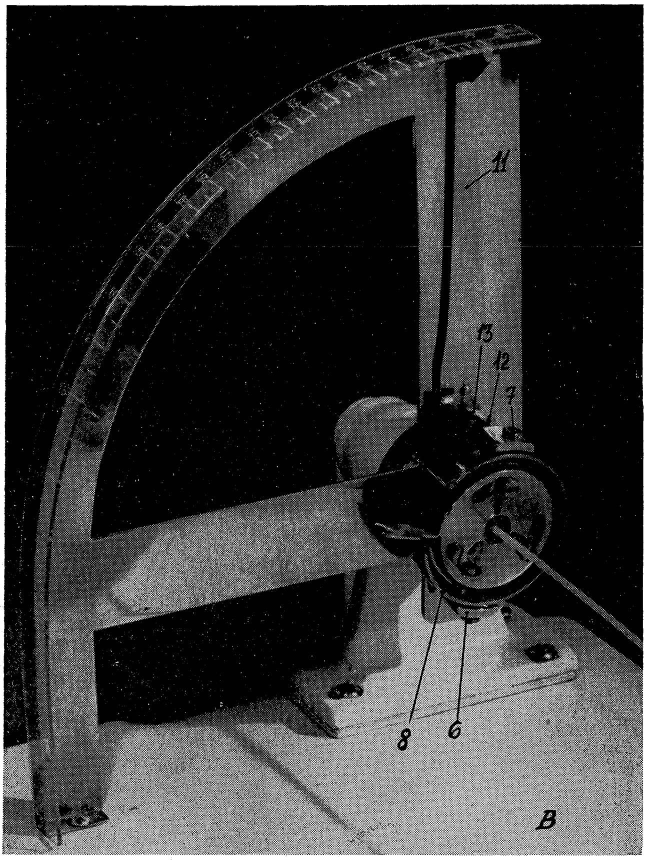

Fig. 3. Clamping head and index.

is set to the zero mark of the dial plate, and the motor is started and allowed to run until the macaroni breaks. After having broken the specimen, the pendulum returns to the vertical position, and the pointer remains in the position reached at the moment of the break. The measurement is repeated ten times with different specimens of the macaroni, and the mean torsional strength in kg. per cm.^{2} is calculated from the following formula:

$$\tau = \frac{D}{D^4 - d^4} \cdot \frac{16\,M_t}{\pi}\ \sin\alpha$$

where D = the outer diameter of the macaroni, in cm.;
d = the inner diameter of the macaroni, in cm.;
M_t = the product of the weight of the loading pendulum by the

length of the moment arm, in cm. per kg.;
α = angular deflection of the pointer.

The scale is calibrated in terms of $M_t \sin \alpha$; thus the scale values multipled by $(16/\pi) = 5{,}093$ give the actual torque in cm. per kg. The torsional strength of macaroni is equal to the product of the quotient $D/(D^4 - d^4)$ by 5,093 and the number read on the scale.

With the clamping heads provided, specimens of macaroni or spaghetti having a diameter of 2 to 7 mm. can be fixed. In testing spaghetti the loading pendulum should be set, by means of an adjusting knob, to the position of low torque, and the scale showing the smaller values should be used for test evaluation. In this case the quotient is $1/D^3$ instead of $D/(D^4 - d^4)$.

Materials and Methods

Materials. All macaroni samples under investigation were made from Ogg flours of more or less hard aestivum wheats, with an average particle size of 240 μ and an ash content between 0.50 and 0.55%. With the exception of No. 21, most macaroni samples were manufactured on a commercial scale by using two eggs per kg. of flour. Particulars regarding other individual samples are given in Table I.

Methods: Bending strength. The bending strength was determined according to the principle of Lukianov (3) on a Gruzl laborograph modified for this purpose by Szalai (6).

Lukianov places the macaroni specimen on a channel-shaped holder fixed to a pedestal, with supporting points 150 mm. apart. A pan of known weight is suspended on the specimen, against an index along the center line of the specimen holder. Weights of 10 g. each are placed on the pan until the specimen breaks. A measure of bending strength is given by the sum of the pan weight and the maximum break-free weights added to the pan. The test is repeated ten times and the arithmetic mean computed.

In the modification proposed by Szalai (6), the specimen is broken by the motor of the Gruzl-system laborograph. The height of the diagram recorded by the apparatus gives specimen break load in g.

The formula follows:

$$\sigma = \frac{D}{(D^4 - d^4)} \cdot \frac{8\ 1\ P}{\pi}$$

or in a simplified form,

$$\sigma = \frac{D}{(D^4 - d^4)} 39\ P$$

TABLE I

MECHANICAL AND COOKING CHARACTERISTICS OF MACARONI SAMPLES

NUMBER[a] AND TYPE	TORSIONAL STRENGTH	BENDING STRENGTH	COOKING TIME	WET WEIGHT	REMARKS
	kg/cm²	*kg/cm²*	*minutes*	*g.*	
1 Partly gelatinized flour	73.3	247	11.0	26.1	Slightly sticky
2 Liquid yeast	63.9	290	11.5	25.4	
3 Partly gelatinized flour	56.2	263	10.5	29.1	10% split in two, sticky
4 Straight-grade flour	52.8	228	9.5	24.7	Slightly sticky
5 Contains eggs	46.3	175	8.0	28.6	
6 75% Farina + 25% flour	43.3	146	12.0	29.5	Sticky
7 Contains eggs	35.2	129	10.5	28.2	
8 Contains eggs	33.9	147	10.5	24.7	A few specimens split in two
9 Contains eggs	31.7	139	9.5	24.7	
10 Contains eggs	28.9	156	11.0	22.0	Slightly sticky
11 Contains eggs	25.0	144	12.0	22.5	Sticky. A few specimens split in two
12 Contains eggs	23.6	129	18.0	27.2	
13 Contains eggs	23.4	124	18.0	27.4	
14 Contains eggs	23.2	138	20.0	27.8	
15 Contains eggs	21.9	151	21.0	28.2	
16 Contains eggs	20.5	155	20.0	27.9	
17 Contains eggs	19.9	136	19.0	27.6	
18 Contains eggs	19.4	108	10.0	21.8	Sticky
19 Contains eggs	16.0	144	18.0	25.7	A few specimens split in two
20 Contains eggs	15.8	142	17.0	26.4	Pulpy
21 Plain	14.8	143	15.0	24.4	Checked, inelastic
22 Contains eggs	14.6	151	18.0	25.1	Inelastic
23 Contains eggs	12.7	137	21.0	26.6	Somewhat pulpy
24 Contains eggs	10.8	120	20.0	27.0	Checked, inelastic
25 Contains eggs	8.8	134	16.0	22.3	Pulpy, inelastic

[a] Samples 1 through 7, 20, 21, and 25: o.d. 0.51 cm.; i.d. 0.29 cm. Samples 8 through 19, 22, 23, and 24: o.d. 0.60 cm.; i.d. 0.25 cm.

where D = the outer diameter of the macaroni in cm.;
d = the inner diameter of the macaroni in cm.;
l = the distance of the supporting edges in cm. (here 15 cm.);
P = the load necessary to break the macaroni specimen in kg.

Cooking Time and Cooking Characteristics. For determining the cooking time and cooking characteristics 10 g. of macaroni are cooked in 100 ml. of water to an equal grade of tenderness, filtered on a Büchner funnel, and rinsed with lukewarm water two or three times. After filtration and cooling the macaroni is weighed and examined for possible discontinuity, appearance of the surface and cross section, elasticity, and ease of mastication.

The equal grade of tenderness is determined by gently pressing a macaroni or spaghetti specimen under cooking against the side wall of the beaker with a glass rod. Cooking is complete when the specimen can be cut fairly easily in this manner.

Results and Discussion

The mechanical and cooking characteristics of 25 samples of macaroni representing several types are recorded in Table I. The standard error of the mean values for torsional strength, computed from the variance for "within samples," was 1.8 kg. per cm^2. This error is influenced not only by the reproducibility of the measuring technique but also by the lack of uniformity in the test specimens. A bran particle or an air bubble will cause wide variations in mechanical strength and it is necessary to make several measurements on each lot of macaroni or spaghetti to obtain meaningful values.

Simple correlations computed between the two indices of mechanical strength and wet weights of the cooked samples are given below:

Nature of Correlation	*r*[a]
Torsional strength × bending strength	+0.85
Torsional strength × wet weight	+0.22
Bending strength × wet weight	+0.12

[a] Value of r at 5% point = 0.38; at 1% point = 0.49.

The correlation between the two measures of mechanical strength is highly significant, but these data are not associated with the wet weight of the samples. The latter finding is rather surprising, since the quality of macaroni products is usually based upon the determination of the swelling power, that is, the increase in weight (wet weight) upon cooking. However, the data in Table I show a rather remarkable parallelism between torsional and bending strength along with diverse cooking characteristics. Nevertheless, samples of low mechanical strength invariably have undesirable properties such as checking or splitting of the uncooked macaroni and an inelastic, pulpy product upon cooking.

For evaluating the mechanical characteristics of macaroni, the assessment of torsional strength and bending strength appears to be equally useful. There are cases, however, in which the bending strength value does not clearly indicate the real quality of the product. For example, a fissure can occur in a macaroni specimen which runs in a straight line along the axis of the cylinder; also, there may be fine irregular cracks, called checks, that can hardly be seen by the naked eye. Such a macaroni could show a rather high bending value but a low twisting strength; during cooking, it would doubtless disintegrate. This opinion is supported by data obtained in storage trials. In the case of one sample, the bending strength decreased only 27% (from 223 to 162 kg. per cm.^{2}) during about 4 months' storage; its torsional strength, however, decreased 65% (from 25.7 to 9.1 kg. per cm.^{2}). In another sample the initial and final bending strength values were the same (135 and 134 kg. per cm.^{2} respectively), whereas the torsional strength showed a reduction of 66.5% (from 26.2 to 8.8 kg. per cm.^{2}) during the same interval. The behavior of these products during cooking supported the evaluation obtained by measuring the torsional strength. It may be concluded that the measurement of torsional strength gives an accurate index of the quality of macaroni samples, even in those cases where the determination of bending strength does not yield a reliable value.

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