

# Estimating the Young's Modulus of Spaghetti with a Bending Experiment

Explore Engineering Innovation

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## Abstract

Bending loads are applied to three sizes of solid, cylindrical pasta—spaghetti, vermicelli, and angel hair—across three span lengths between 80 and 120mm. Spaghetti is tested across each span, and all three pastas are tested across the shortest span, for a total of five tests. Each pasta sample is suspended across a gap and a weighted bucket is hung from the center of the pasta sample. Mass is added in approximately 3-gram increments, and the deflection is measured. The maximum load before fracture is measured for the original five samples and an additional fifteen samples. The slope of the force-deflection data is used to estimate the Young's modulus of pasta. The Young's modulus averaged over five pasta samples is found to be  $3.03 \pm 0.77$  GPa.

## Introduction

Structures, both man-made and biological, are constantly subjected to forces that push, pull, bend, and twist them. The strength of those structures depends on both the type of material and the size of the structural components. For example, engineered spider silk can be several times stronger than a steel wire of similar size, but steel wire is usually stronger because it is thicker. Understanding material properties is essential when designing and building a structure.

Pasta is not commonly considered a building material, but knowledge of its material properties can be useful for two reasons. First, knowledge of the material properties can assist quality control during manufacturing. Dry pasta is a foodstuff commonly made of durum wheat and water that is mixed, shaped, then dried. The conditions within which it is manufactured, such as ambient humidity and drying temperature, affect the product. Some factories use material property tests to monitor the quality of their product. Breaking strength from a bending test, for instance, helps predict whether the pasta is likely to break in transit (Cole, 2007).

A second reason to be interested in material properties of spaghetti, and one that is more broadly applicable, is that pasta serves as a readily available and cost-effective building material for educational purposes. If a structure made of pasta experiences a bending load, such as the one shown in Figure 1, it is helpful to know how much force the sample can withstand before breaking. The maximum bending force depends on the span length, the cross-sectional shape of the beam, and the Young's modulus.

One prior study (Guinea, Rojo, & Elices, 2004) used an Instron 4111 universal testing machine to test Barilla spaghetti in tension and calculated the Young's modulus as 5.0 GPa from the slope of a stress-strain curve. Another study (Vargas-Calderón, Guerrero-González, & Fajardo, 2018) tested Colombian pasta brand Doria in bending and found Young's modulus to be between 2.2-2.6 GPa. The current study serves to provide additional experimental data to the literature and proposes a new method that is

simple and low-cost that may be of use for future studies that wish to determine the Young's modulus of spaghetti or other solid, cylindrical pasta.

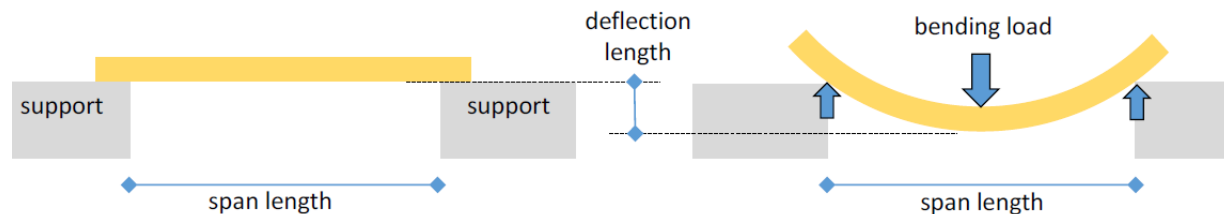


*Figure 1: The bending sample spans the distance between two supports and is deflected by a load. The distance that the specimen moves when it deforms is the deflection length.*

## Methods

### Experimental Procedure

#### Span

A diagram of the experimental setup is shown in Figure 2. One piece of pasta is placed across a gap that is approximately 80 mm wide. Two additional span lengths of 100 mm and 120 mm are also considered.

#### Deflection

The experimental setup shown in Figure 2 includes a ruler for measuring deflection and a mirror to ensure the pasta is at eye level when deflection is measured, thus minimizing parallax error. When the reflection is hidden behind the pasta, the pasta is at the viewer's eye level. The ruler is arranged so that 0 mm aligns with the bottom of a straight piece of pasta viewed at eye level.

#### Bending Load

Figure 2 shows the small bucket that is part of the bending apparatus. At the end of the bucket wire is a small loop that the pasta fits through, thus allowing the bucket to hang from the pasta. The bucket is placed in the center of the span. The deflection of the pasta caused by the empty bucket is recorded.

Steel shot is added in small increments. The amount of steel shot and the pasta deflection is recorded each time. This process repeats until the pasta breaks.

The mass of the empty bucket and wire is  $3 \pm 1$  g. The mass of one piece of steel shot is  $0.6 \pm 0.1$  g.

#### Pasta

Three sizes of solid, cylindrical pasta are used for this experiment: spaghetti, vermicelli, and angel hair. This order is from the largest to smallest diameter. Digital calipers are used to measure the diameter of each pasta sample before the test begins. The precision of the digital calipers is  $\pm 0.1$  mm. Straight, full-length pieces are chosen as bending samples. Spaghetti is tested across all three spans. Vermicelli and angel hair pasta are tested across the shortest span.

#### Data Analysis: Calculating Young's Modulus

The mass of the bucket and shot were measured. From this, the weight is calculated as

$$W = (m_b + N_s * m_s) * g \quad (1)$$

where  $W$  is the weight of the bucket and shot,  $m_b$  is the mass of the bucket,  $m_s$  is the mass of one piece of steel shot,  $N_s$  is the number of pieces of shot, and  $g$  is the acceleration due to gravity.

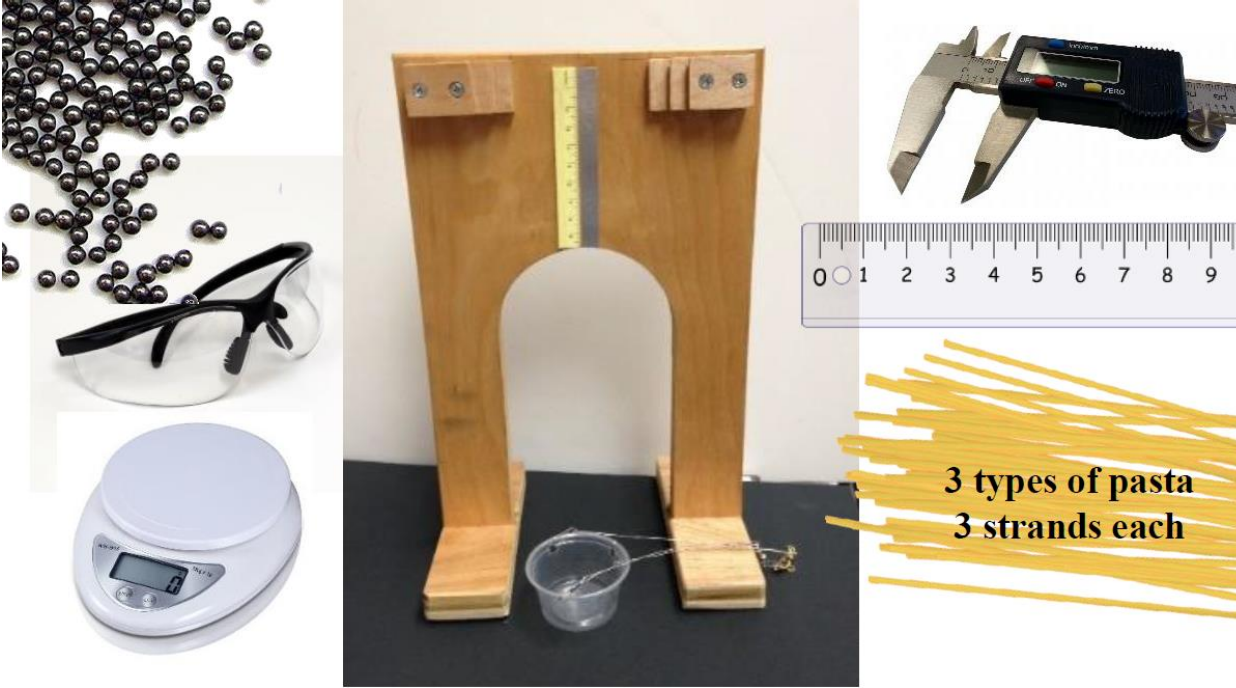


Figure 2: The bending testing system consists of a piece of pasta suspended across a gap at the top of the bending apparatus. There are three span distances. A weighted bucket provides a force at the pasta center. Steel shot is added to the bucket to increase the load.

The bending equation that relates the added weight to the measured deflection is

$$W = \frac{48 E I y}{L^3} \quad (2)$$

where  $W$  is the applied weight,  $y$  is the deflection,  $I$  is the area moment of inertia,  $E$  is the Young's modulus of the material, and  $L$  is the span. The spaghetti, vermicelli, and angel hair pasta all have circular cross-sections, so the area moment of inertia is equal to

$$I = \frac{\pi}{64} d^4 \quad (3)$$

where  $d$  is the diameter of the pasta sample. Substituting Equation (3) into Equation (2) and rearranging terms to separate the deflection variable, we have

$$W = \left( \frac{3\pi E d^4}{4L^3} \right) y. \quad (4)$$

A plot of weight vs. deflection—which can be made for each combination of pasta diameter and span—would theoretically be linear with a slope shown between the parentheses in Equation (4). Fitting a line to the data in each plot would produce an estimate of the slope, which can be used to solve for the Young’s modulus as

$$E = \frac{4L^3 s}{3\pi d^4} \quad (5)$$

where  $d$  is the pasta diameter,  $L$  is the span, and  $s$  is the slope for the line of best fit.

## Results

### Direct Measurements

Based on the methods described above, measurements are taken, and the following results are obtained. One sample of angel hair and vermicelli on the gap 80 mm, and 3 samples of spaghetti on gaps 80, 100, and 120 mm were tested till failure. The deflection of each sample and the mass of the bucket and steel shot at the time of failure are shown in Table 1 through 5.

**Table 1: Spaghetti 120mm**

| Deflection (mm) | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13 (Break) |
|-----------------|------|------|------|------|------|------|------|------|------|------|------|------|------------|
| Weight (g)      | 8    | 15   | 21   | 29   | 36   | 40   | 42   | 45   | 49   | 52   | 55   | 57   | 60         |
| Weight (N)      | 0.08 | 0.15 | 0.21 | 0.29 | 0.35 | 0.39 | 0.41 | 0.44 | 0.48 | 0.51 | 0.54 | 0.56 | 0.59       |

*Table 1: The deflection of one sample of spaghetti suspended on a gap of 120mm was measured with a ruler on the setup and eyes on level with the ruler. The bucket filled with steel shots was weighed on a scale after each millimeter of deflection and after the pasta broke.*

**Table 2: Spaghetti 100mm**

| Deflection (mm) | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 7.5 (Break) |
|-----------------|------|------|------|------|------|------|------|-------------|
| Weight (g)      | 25   | 36   | 46   | 55   | 64   | 74   | 81   | 84          |
| Weight (N)      | 0.25 | 0.35 | 0.45 | 0.54 | 0.63 | 0.73 | 0.79 | 0.82        |

*Table 2: The deflection of one sample of spaghetti suspended on a gap of 100mm was measured with a ruler on the setup and eyes on level with the ruler. The bucket filled with steel shots was weighed on a scale after each millimeter of deflection and after the pasta broke.*

**Table 3: Spaghetti 80mm**

| Deflection (mm) | 1    | 2    | 3    | 4    | 5 (Break) |
|-----------------|------|------|------|------|-----------|
| Weight (g)      | 24   | 42   | 60   | 84   | 97        |
| Weight (N)      | 0.24 | 0.41 | 0.59 | 0.82 | 0.95      |

*Table 3: The deflection of one sample of spaghetti suspended on a gap of 80mm was measured with a ruler on the setup and eyes on level with the ruler. The bucket filled with steel shots was weighed on a scale after each millimeter of deflection and after the pasta broke.*

**Table 4: Vermicelli 80mm**

| Deflection (mm) | 1    | 2    | 3    | 4    | 5    | 6 (Break) |
|-----------------|------|------|------|------|------|-----------|
| Weight (g)      | 11   | 15   | 23   | 28   | 32   | 37        |
| Weight (N)      | 0.11 | 0.15 | 0.23 | 0.28 | 0.31 | 0.36      |

*Table 4: The deflection of one sample of vermicelli suspended on a gap of 80mm was measured with a ruler on the setup and eyes on level with the ruler. The bucket filled with steel shots was weighed on a scale after each millimeter of deflection and after the pasta broke.*

**Table 5: Angel Hair 80mm**

| Deflection (mm) | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9 (Break) |
|-----------------|------|------|------|------|------|------|------|------|-----------|
| Weight (g)      | 5    | 7    | 10   | 15   | 18   | 21   | 24   | 27   | 29        |
| Weight (N)      | 0.05 | 0.07 | 0.10 | 0.15 | 0.18 | 0.21 | 0.24 | 0.26 | 0.28      |

*Table 5: The deflection of one sample of angel hair suspended on a gap of 80mm was measured with a ruler on the setup and eyes on level with the ruler. The bucket filled with steel shots was weighed on a scale after each millimeter of deflection and after the pasta broke.*

## The Young's Modulus

The weight of the bucket and steel shot is calculated from its mass using Equation (1). The Young's Modulus is introduced by presenting the relationship between force applied to the pasta and the measured deflection is calculated using Equation (2).

The diameter is used to calculate the area moment of inertia using Equation (3). Span length (L) and diameter (d) are related by plugging area moment inertia in Equation (3) to Equation (4), which is concluded as Equation (5). Slope for each pasta sample is produced by drawing lines of best fit for each

Diameter v.s. Bending Load dot diagram can be used to solve for the Young's modulus by using Equation 5. Figure 3 is a linear graph fit to the force and diameter data presented in Table 1 to Table 5, respectively. The Young's Modulus for each sample and the average for each pasta with different spans and type are shown in Table 6. The average Young's Modulus over all samples is 3.03 GPa and the standard deviation is 0.77 GPa.

**Table 6: Young's Modulus**

| Sample Type              | Spaghetti 120mm | Spaghetti 100mm | Spaghetti 80mm | Vermicelli 80mm | Angel Hair 80mm |
|--------------------------|-----------------|-----------------|----------------|-----------------|-----------------|
| Young's Modulus (GPa)    | 2.98            | 3.45            | 4.08           | 2.18            | 2.44            |
| Slope of Best Fit (N/mm) | 0.0408          | 0.0893          | 0.1844         | 0.0521          | 0.0311          |

*Table 6: The slopes from the lines of best fit according to Figure 3, and the calculated Young's Modulus for each of the samples.*

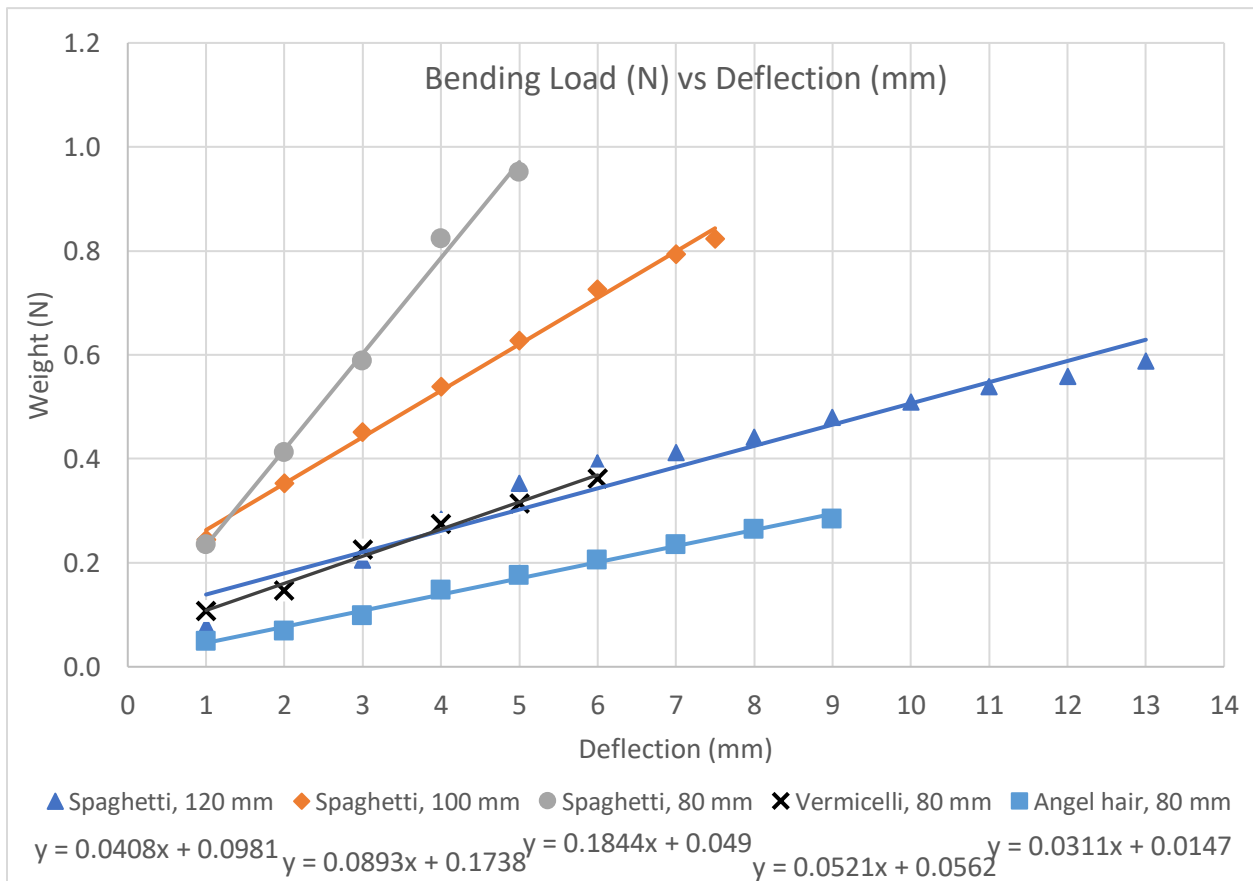


*Figure 3: Bending load vs. deflection is shown for each sample. Lines of best fit for each sample are also included.*

### The Effect of Span and Diameter on Maximum Load

Based on the data measured, some additional trends can be observed. Figure 4 is graphed using data of maximum bending loads and spans from Table 1, Table 2, and Table 3, demonstrating the effect of span on maximum load. Figure 4 indicates that the larger the span is, the smaller the maximum load will be.

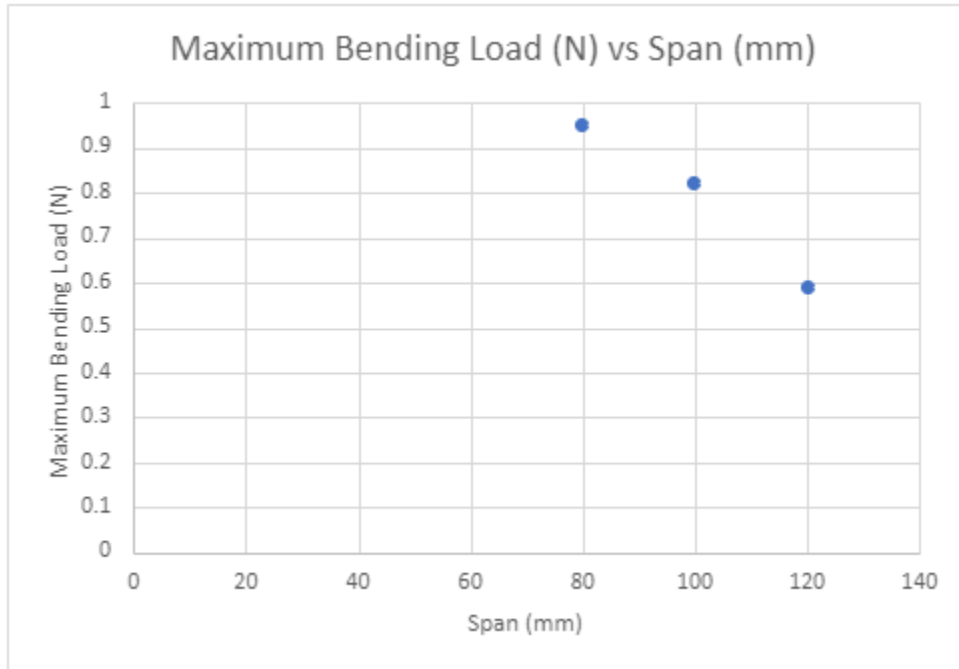


*Figure 4: This is a plot of the maximum bending load vs. span for each spaghetti sample.*

Figure 5 plots the force needed to break the pasta sample as a function of its diameter from the data included in Table 3, Table 4 and Table 5. The results show that maximum bending load increases with sample diameter. Moreover, the maximum bending load grows faster as the diameter increases.

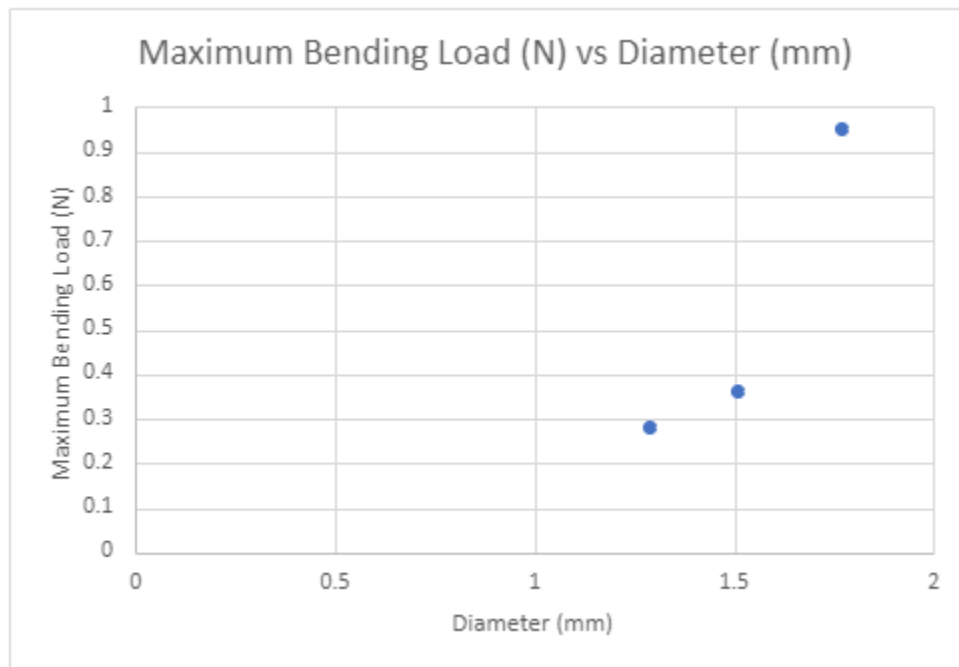


*Figure 5: This is a plot of the maximum bending load vs. diameter for each pasta sample tested across the 80 mm span.*

## Discussion

According to the calculations, Young's Modulus for different samples is not the same. The calculated values for Young's Modulus vary among the same pasta samples. The spaghetti has a spread of 2.98 to 4.08 GPa. Nevertheless, Young's Modulus for different samples should be the same theoretically, because though different in diameter, the samples are made from the same material. Since Young's Modulus is an intensive property that only depends on the type of material, Young's Modulus should be the same for the samples. The different results for Young's Modulus indicate inaccuracy during the experiment process. Moreover, in, theoretically, the maximum bending load should be inversely proportional to the span to the power of three. Nonetheless, this trend is not explicit for data points. That is probably because there are too few data in the dataset, making it insufficient to show the trend.

Synthesizing information from the collected data, it has been observed that the span is inversely related to the maximum load while diameter is directly proportional to the maximum load. The conclusions of easy-equipped experiments can be applied to large-scale engineering projects. For engineers designing beams, the observed trends illustrate the importance of increasing diameter and decreasing span. Young's modulus is an indicator of the material's ability to resist compressive deformation in the elastic state. Ultimately, when working on engineering projects, engineers should consider all Young's Modulus for material selection, diameter and span together to make better decisions regarding bending performance. If one is small, the other should not be too small.

Some possible sources of error in this experiment are: First, small deflections are hard to measure accurately with the given ruler, especially due to the curvature in the deflected pasta and the viewing angle. This would be a random error since it is due to variations in eye level and slight inconsistencies in ruler alignment. Another potential source of error is the pasta itself, as there may be slight variances in each stick, resulting in inconsistent measurements of the diameter. This is also a random error as inconsistency is not predictable. Then, a potential source is errors in the equipment provided. The different span gaps on the bending apparatus might not be exactly 80, 100, and 120 mm, resulting in deviation in calculated values. This is a systematic error as it is predictable and the same for every independent trial. Lastly, one possible source of error would be the inconsistency in the placement of the weight; specifically, it is hard to get the string that is attached to the weight to be exactly centered along the span, thus there might be slight differences in each trial. This is a random error as it is unpredictable and differs from trial to trial. All of these errors would affect the final Young's Modulus value.

## Conclusion

One sample each of angel hair, vermicelli, and spaghetti were tested for bending using the bending testing system with a gap of 80 mm, while the spaghetti was also evaluated for 100 mm and 120 mm. The Young's modulus averaged over five pasta samples is found to be  $3.03 \pm 0.77$  GPa. Future studies should include a larger number of samples in various gap lengths to improve accuracy and precision.

Through this experiment, knowledge of material properties is gained, not only assisting quality control during manufacturing, but also testing the effectiveness of each pasta as building materials for educational use.

The results demonstrate that the larger the diameter of the pasta is, the greater the maximum bending load will be, and the larger the span of the pasta is, the smaller the maximum bending load will be. Those results can be applied to a greater world, implying engineers try to reduce the span between beam supports and increase thickness.

The brand of pasta used for this experiment was San Giorgio. Other brands may use different ingredients or recipes to manufacture their pasta, so it is unclear how broadly these results apply. Additionally, it would be interesting to study the effect of temperature and humidity on material properties. In terms of improvements in future experiments, digital displacement sensors could be used to measure deflection more precisely and eliminate the common yet hard-to-solve parallax issue. This, combined with a wider range of pasta brands and types as mentioned above, would help further determine and confirm the consistency of the calculated Young's modulus across samples.

## References

- Cole, M. E. (2007). Prediction and measurement of pasta quality. *International Journal of Food Science & Technology*, 26(2), 133–151. <https://doi.org/10.1111/j.1365-2621.1991.tb01149.x>
- Guinea, G. V., Rojo, F. J., & Elices, M. (2004). Brittle failure of dry spaghetti. *Engineering Failure Analysis*, 11(5), 705–714. <https://doi.org/10.1016/j.engfailanal.2003.10.006>
- Vargas-Calderón, V., Guerrero-González, A. F., & Fajardo, F. (2018). Experimental study of elastic properties of noodles and bucatini. *ArXiv*. <https://doi.org/10.1142/S2661339519500100>