

Estimating the Young's Modulus of Spaghetti with a Buckling Experiment

Explore Engineering Innovation

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July 18th, 2025

Abstract

Buckling forces are applied to three sizes of solid, cylindrical pasta—spaghetti, vermicelli, and angel hair—across eight span lengths between 8 and 20 cm. A sample is placed perpendicularly onto a weight scale, then a finger is pressed onto the pasta from the top to apply buckling forces onto it until it is buckling (close to snapping), and the weight on scale is measured. The maximum buckling weight before fracture is measured for the 24 samples, eight samples of each type of pasta varying in length. The slope of the inverse length squared-buckling load data is used to estimate Young's modulus of pasta. The Young's modulus averaged over 24 pasta samples is found to be 2.78 ± 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 in 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 the products. 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 the 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. Spaghetti acts as a good model for truss members, which are usually slender and theoretically experience only tensile or compressive forces. Long, slender members in compression fail by buckling. When the force exceeds the buckling load, the member no longer remains straight but bows out to one side and weakens. To design a truss, it is important to know the Young's modulus, which partially determines the maximum compressive force a truss member can support. It is also useful to know how pasta diameter and member length affect the maximum compressive force, known as the buckling load.

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.

Methods

Experiment Procedure

Sample Preparation

Three sizes of solid, cylindrical pasta are used for this experiment: angel hair, vermicelli, and spaghetti. This order is from smallest to largest diameter. The brand of pasta is San Giorgio for the vermicelli and spaghetti, and Barilla for Angel Hair. All samples are from boxes of mostly unbroken pasta purchased from a grocery store and stored indoors. Eight samples of each pasta type are tested to failure. Digital calipers are used to measure the diameter of each pasta sample before the test begins. The precision of the digital calipers is ± 0.1 mm.

A piece of tape is applied to electronic scales as shown in Figure 1. The length of eight pasta samples from each type are 20cm, 18cm, 16cm, 14cm, 12cm, 10cm, 8cm and 6cm, with errors to the ± 0.1 cm. The eraser that is placed between the finger and pasta helps alleviate discomfort when pushed with great force, shown in Figure 2. The piece of tape increases the resistance between electric scale and pasta so that most of the force on the pasta is directed along the vertical direction (e.x. buckling force).

Force Application

Force is vertically applied to each pasta sample using the fingers shown in Figure 1. Once the pasta sample is vertically placed on and perpendicular to the electric scale, vertical force is slowly added to the pasta to buckle significantly. Read the measurements while the pasta is buckling. If the fracture of the pasta happened before reading, then another sample should be prepared and tested; this may be a sign that part of the force contributed to buckling load is canceled by resistance. A scale is used to measure the force causing the pasta to buckle. The precision of the scale is ± 1 g.



Figure 1: The force that causes the onset of buckling is determined from the mass reading on the digital scale.

Data Analysis: Calculating Young's Modulus

The buckling load can be determined by

$$P_{buckling} = \frac{\pi^2 EI}{(KL)^2} \quad (1)$$

Where $P_{buckling}$ is the force being applied onto the pasta, E is the Young's modulus, K is the end condition, I is the area moment of inertia, and L is the column length. K is the ending condition, which is equal to 1, and is the same for all diameters of pasta tested in this experiment since both ends are pinned. Rewriting the equation and separating important variables, the original formula becomes

$$P_{buckling} = \left(\frac{\pi^2 EI}{K^2} \right) \frac{1}{L^2} \quad (2)$$

A plot of $P_{buckling}$ vs. $\frac{1}{L^2}$ would theoretically be linear with a slope shown between the parentheses in equation (2). Fitting a line to the data in the plot would produce an estimate of the slope, which can be used to solve for the Young's modulus as

$$E = \frac{K^2 s}{\pi^2 I} \quad (3)$$

Where K is the end condition, I is the area moment of inertia, and s is the slope for the line of best fit.

Data Analysis: The Effect of Diameter and Length on Buckling Load

The spaghetti, vermicelli, and angel hair pasta all have circular cross-sections, so the area moment of inertia is equal to

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

Where d is the diameter of the pasta sample. Substituting Equation (4) into Equation (2) and rearranging terms to separate the deflection variable, the relationship between the buckling load and diameter can then be determined as

$$P_{buckling} = \left(\frac{\pi^3 E}{4^3 K^2 L^2} \right) \cdot d^4 \quad (5)$$

From the above equation, it is seen that the buckling load is proportional to the fourth power of the diameter of the pasta sample. That is, the larger the diameter of the pasta is, the larger the buckling load will be, where the buckling load grows faster as the diameter increases.

Results

Direct Measurements

Based on the methods described above, measurements are taken, and the following results are obtained. Each eight samples of three different types of pasta are tested till buckling. The mass of each sample at the time of buckling is shown in Table 1 through 3.

Table 1: The diameter of each sample of angel hair was measured with a digital caliper. The length of each sample was cut to the supposed length and measured with a ruler. The force of the finger pressing down on the sample when it is buckling and close to fracturing was weighed on a scale.

Table 1: Angel Hair

Length (cm)	Diameter (mm)	Buckling Mass (g)	Buckling Load (N)
20	1.28	11	0.108
18	1.26	13	0.128
16	1.29	16	0.157
14	1.31	19	0.186
12	1.25	25	0.245
10	1.27	37	0.363
8	1.28	63	0.618
6	1.29	100	0.981

Table 22: The diameter of each sample of vermicelli was measured with a digital caliper. The length of each sample was cut to the supposed length and measured with a ruler. The force of the finger pressing down on the sample when it is buckling and close to fracturing was weighed on a scale.

Table 2: Vermicelli

Length (cm)	Diameter (mm)	Buckling Mass (g)	Buckling Load (N)
20	1.51	15	0.147
18	1.52	18	0.177
16	1.53	21	0.206
14	1.52	32	0.314
12	1.49	41	0.402
10	1.51	52	0.510
8	1.51	63	0.618
6	1.52	145	1.422

Table 3: The diameter of each sample of spaghetti was measured with a digital caliper. The length of each sample was cut to the supposed length and measured with a ruler. The force of the finger pressing down on the sample when it is buckling and close to fracturing was weighed on a scale.

Table 3: Spaghetti

Length (cm)	Diameter (mm)	Buckling Mass (g)	Buckling Load (N)
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20	1.78	54	0.530
18	1.79	72	0.706
16	1.76	84	0.824
14	1.79	104	1.020
12	1.78	145	1.422
10	1.75	211	2.070
8	1.77	385	3.777
6	1.76	489	4.797

The Young's Modulus

Using the procedure described in Data Analysis: Calculating Young's Modulus, Young's Modulus can be calculated using the slope of the linear regression of the buckling load as a function of one over length square.

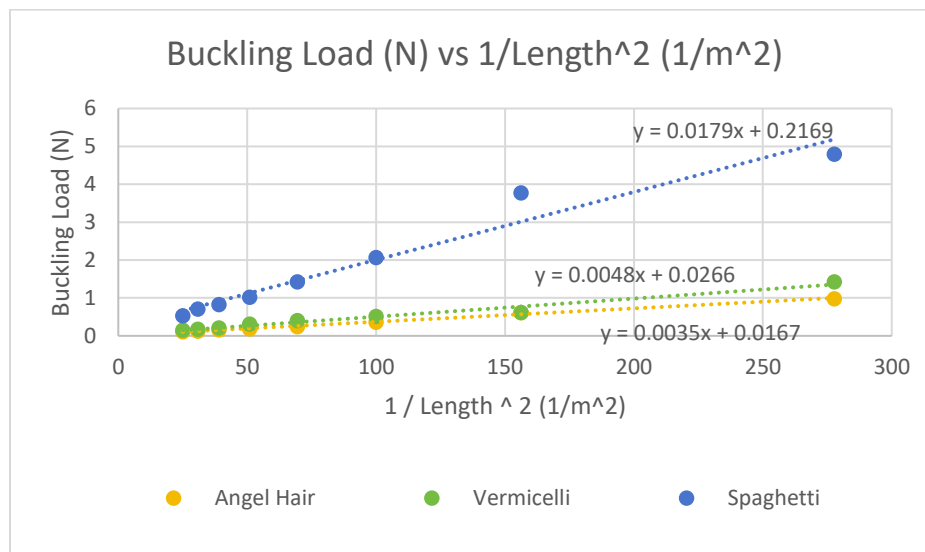


Figure 2: This is the linear regression of buckling load as a function of one over length square

Figure 2 is the linear regression of buckling load as a function of one over length square. According to Data Analysis: Calculating Young's Modulus, Equation (3) demonstrates the relationship between the slope of the lines and Young's Modulus.

Based on Equation (3), calculations are made, and Table 4 is obtained through excel calculations as follows.

Sample Type	Angel Hair	Vermicelli	Spaghetti
Area Moment of Inertia (m ⁴)	1.31254E-13	2.57743E-13	4.84524E-13

Slope of Best Fit (N*m²)	0.0035	0.0048	0.0179
Average Young's Modulus (GPa)	2.70	1.89	3.74

Table 4: The slope of line of best fit was recorded based on the data from figure 2, and Young's Modulus of the samples was calculated.

The average Young's Modulus between the three 24 pasta samples of the three types is found to be 2.78 ± 0.77 GPa.

The Effect of Diameter on Buckling Load

Figure 3 plots the force needed to buckle the pasta sample as a function of average pasta diameter—data included in Table 1 through 3. As it shows the average effect of diameters. The results show that buckling load increases with sample diameter.

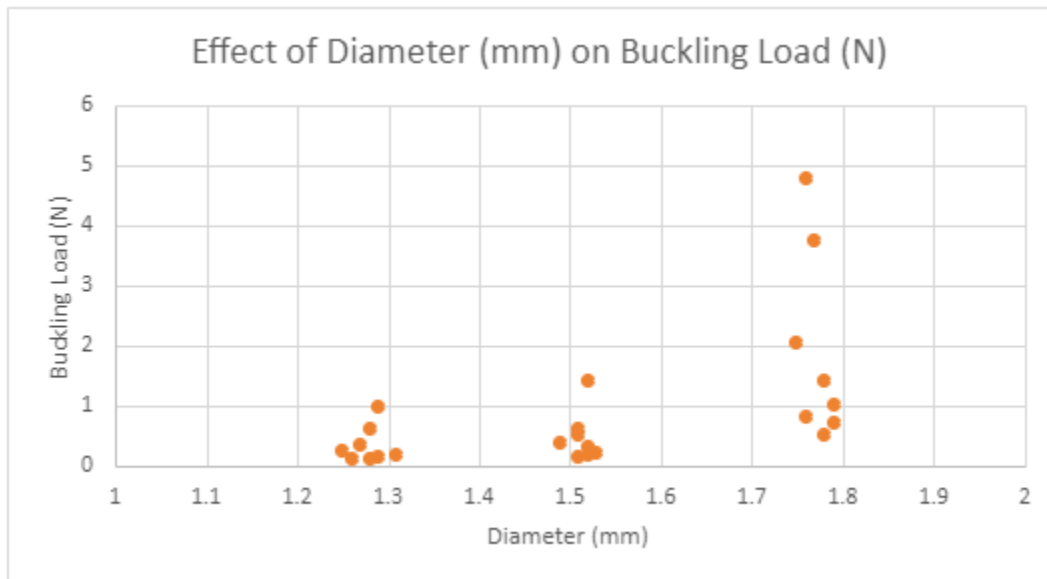


Figure 3: Buckling load vs. diameter of the pasta is shown in the figure

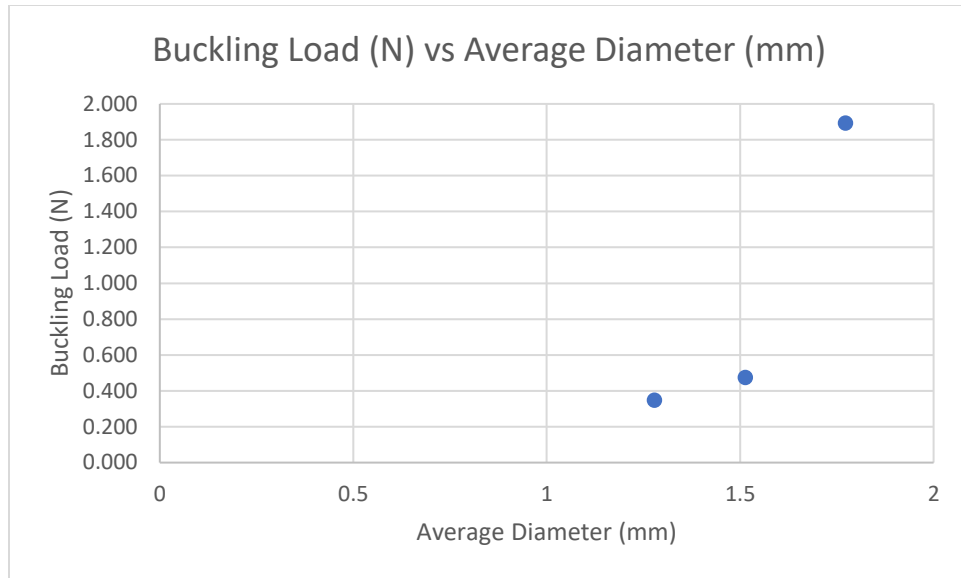


Figure 4: Buckling load vs. average diameter is shown for the average diameter of three types of pasta

Figure 3 illustrates the relationship between the buckling load and the diameters of the pasta. The buckling load of the pasta grows as the diameter of the pasta increases. Additionally, the growth rate of buckling load increases as the diameter increases.

To show the relationship between the buckling load and the diameter of the pasta more clearly and to reduce the effect of length on buckling load as much as possible, Figure 4, a figure of buckling load as a function of the average diameter of the different types of pasta, is drawn. In Figure 4, a clearer increasing trend with an increasing rate of change can be seen.

In conclusion, when the diameter of pasta increases, the buckling load grows at a larger rate.

The Effect of Length on Buckling Load

Figure 5 plots the force needed to buckle the pasta sample as a function of pasta length(L)— data included in Table 1 through 3. The results show that buckling load decreases with sample length.

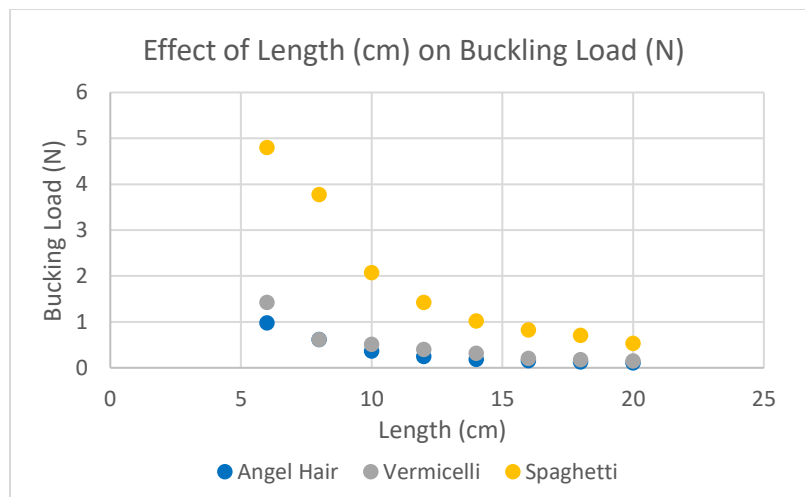


Figure 5: Buckling load vs. length is shown for each sample

Figure 5 illustrates the relationship of a quadratic inverse function that fits the force and diameter data presented in Table 1 through 3, respectively. This illustrates that buckling load scales with the inverse of diameter to the square of diameter.

Discussion

The Young's Modulus is different between Angel Hair, Vermicelli and Spaghetti, respectively 2.70, 1.89 and 3.74 GPa, according to Table 4. Three Young's Modulus are supposed to be the same across samples as intrinsic property, as they were manufactured in the same condition and with the same material. However, differences may arise due to measurements of differences in force, finger displacement, or inconsistency of cross-sectional areas. Trends like inconsistent diameters of the same type of pasta shown in Table 1, 2 and 3 and length-force scatter points that deviate from the line of best fit in Figure 2 may indicate variability in material properties or the occurrence of systematic errors such as misalignment in loading and misread of correct buckling load values.

Theoretically, according to Equation 5, the buckling load should be proportional to the fourth power of the diameter. In Figure 3, a quartic relationship should be presented to fit the diameter and buckling load data in Table 1 through 3, respectively, supporting the theoretical conclusion. However, due to the limited amount of pasta type involved in the experiment, only 3 scatter points could be plotted for the diameter-buckling load, which is not enough to form a line of best fit for a quartic function, thus the accuracy of the results cannot be visualized. The analysis can be inaccurate attributed to systematic errors of the diameter while calculating the average, which is further amplified due to the fourth power in equation 4. The consistency of diameters of the same pasta type can be improved by applying a more standardized measuring approach and adding more pasta samples to draw a line of best fits the diameter-buckling load function.

Theoretically, according to Equation (2), the buckling load is inversely proportional to the square of diameter. The results from Figure 4 show a similar trend: the larger the length of the pasta is, the smaller the buckling load will be, and as the length grows proportionally, the buckling load decreases with a slower rate, all of which is generally aligned with a quadratic inverse function. However, although the results and the equation show general alignment, there are still some differences. For example, a quadratic inverse function should be smooth, while the data points in Figure 4 seem to fluctuate slightly around the quadratic inverse trend. Due to limitations of the data analyzing tool used, an inverse quadratic line of best fit cannot be drawn. Nevertheless, the data points in the graph should be perfectly aligned with the equation. This comparison suggests that there is still room for improvement in the experiment method. More samples with different lengths can be used during the experiment to reduce error and get a more accurate figure.

Some possible sources of errors in this experiment are as follows. First, it's difficult to place the finger vertically above another pin of the pasta while adding force, therefore, random errors could arise that could cause inaccurate buckling load measurements. Particularly, part of the force contributed to buckling load is canceled by resistance, excluded from scale measurements. What's more, variability in material properties could cause random errors, especially inconsistency in diameters and evenness of materials of different samples across the same pasta type. Also, some samples might have small cracks or chips on it, and since buckling load measurements are affected by the weakest part of a pasta and

random errors of diameters will affect the slope of best fit, Young's Modulus calculations are derived from the true value as a result.

Conclusion

Eight samples of each type of pasta---angel hair, vermicelli, and spaghetti, in length between 6 and 20 cm, were tested for buckling using the finger pressing the pasta samples onto the scale. The Young's modulus averaged over five pasta samples is found to be 3.78 ± 0.77 GPa. Future studies should include a larger number of samples of the same length 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 maximum buckling load increases with the diameter to the fourth power, and the maximum buckling load decreases with the inverse of the length squared. Experiment results enlightened engineers to make better designs, such as the construction of beams, implying engineers try to reduce the length of beams between ends and increase the thickness. Moreover, increasing the diameter is a more effective way to improve buckling performance. This is because diameter has a fourth-power effect, while length has only a second-power effect.

For future work on this topic, engineers could perform test trials on a wider range of pasta types and diameters, allowing for a more comprehensive understanding of the effects of geometry on buckling behavior. The brand of pasta used for this experiment was San Giorgio for Vermicelli and Spaghetti, and Berilla for Angel Hair. Other brands may use different ingredients or recipes to manufacture their pasta, so it is unclear how broadly these results apply. Additionally, engineers could perform trials under a variety of end conditions (e.g., fixed-fixed vs. pinned-pinned vs. pinned-fixed) to demonstrate the impact of the end condition K on buckling loads. As a farther extension to the lab, engineers could investigate environmental factors such as humidity and temperature and their influence on the material properties of the pasta, particularly its stiffness and susceptibility to buckling.

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>