

## Introduction

People are exposed to micro- and nano- plastics (MNPs) every day through food, water, and air. Current estimates suggest that humans may ingest tens of thousands of microplastic particles each year, with particularly high exposure in children, and not all of these particles are excreted, so they may accumulate over time (Kannan & Vimalkumar, 2021).

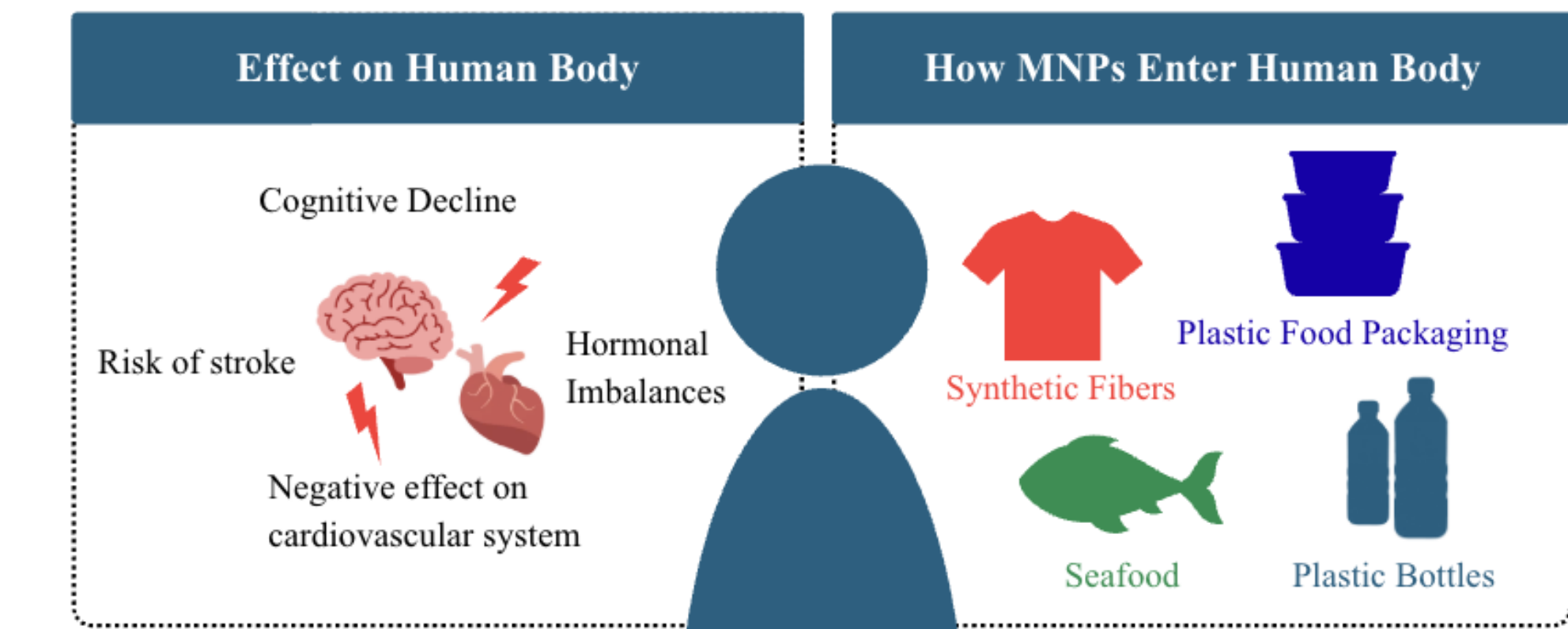


Fig. 1: Illustration created by Finalist in Canva, 2026; brain and heart vector icons retrieved from canva.com.

MNPs are building up in the human body, where they can cross barriers such as the gut lining and the blood–brain barrier. They are now being linked to higher risks of heart attack, stroke, and cognitive decline, yet there is no simple, food-safe way to remove these particles once ingested (Marfella et al., 2024).

## Background

Certain plants make a substance called mucilage, a sticky, gel-like material made of long-chain carbohydrates called natural polysaccharides. In water, these chains form a cloud around microplastic particles, causing them to clump together through bridging flocculation (Fig. 2). Instead of floating freely, these heavier clumps can be filtered out. I took this process a step further to test whether flocculation would still occur in simulated stomach conditions, which could prevent absorption into the bloodstream.

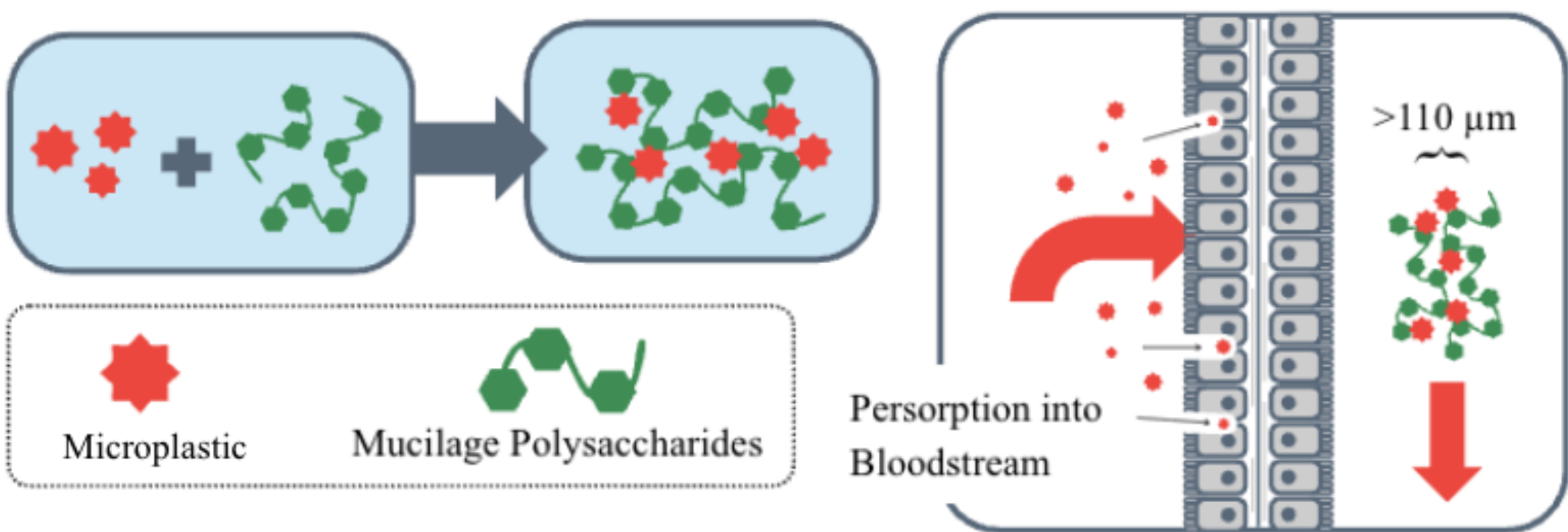


Fig. 2: Illustration created by Finalist in Canva, 2026.

**Objective:** The objective of this study is to compare okra, fenugreek, and psyllium husk mucilage as natural flocculants for removing microplastics from simulated gastric fluid. This project seeks to identify a functional, food-safe solution using natural flocculants that have already been proven to work in water treatment.

## Hypothesis

*Plantago ovata* (psyllium husk) powder will demonstrate similar or better MNP flocculation efficiency in simulated gastric conditions compared to *Trigonella foenum-graecum* (fenugreek) and *Abelmoschus esculentus* (okra) extracts, due to its unique high-viscosity mucilage and binding properties.

### Research Questions

- What is the most effective natural, food-safe flocculant among okra, fenugreek, and psyllium husk extract powders?
- Will the pH of simulated gastric fluid affect MNP flocculation efficiency?
- Can we demonstrate the viability of okra, fenugreek, and psyllium husk extracts for removing MNPs from the human body?

# A Novel Method for Microplastic Removal From Simulated Gastric Fluid Using Plant Mucilage Flocculants

## Materials & Variables

**Independent variables:** Treatment type (control, okra, fenugreek, psyllium) and concentration (0%, 1%, 2%)

**Dependent variable:** Percent mass of microplastics removed

**Controlled variables:** Temperature, mixing time

### Materials

- Okra powder
- Fenugreek powder
- Psyllium husk powder
- Filtered water
- 24 glass jars
- Polyethylene terephthalate (PET) plastic
- pH test strips
- Digital scale
- Distilled white vinegar (5% acetic acid)
- Table salt
- RStudio

## Data Collection

My control group, with no plant powder, removed only 1.5% of microplastics. Psyllium husk was the clear winner: at 1% concentration, it removed 88% of microplastics, and at 2% concentration, it reached 93.3%. Fenugreek came in second (78-83%), and okra came in third (75-81%).

### Formula used to calculate removal percentage:

Removal % = ((Initial mass – Mass remaining in solution) ÷ Initial mass) × 100

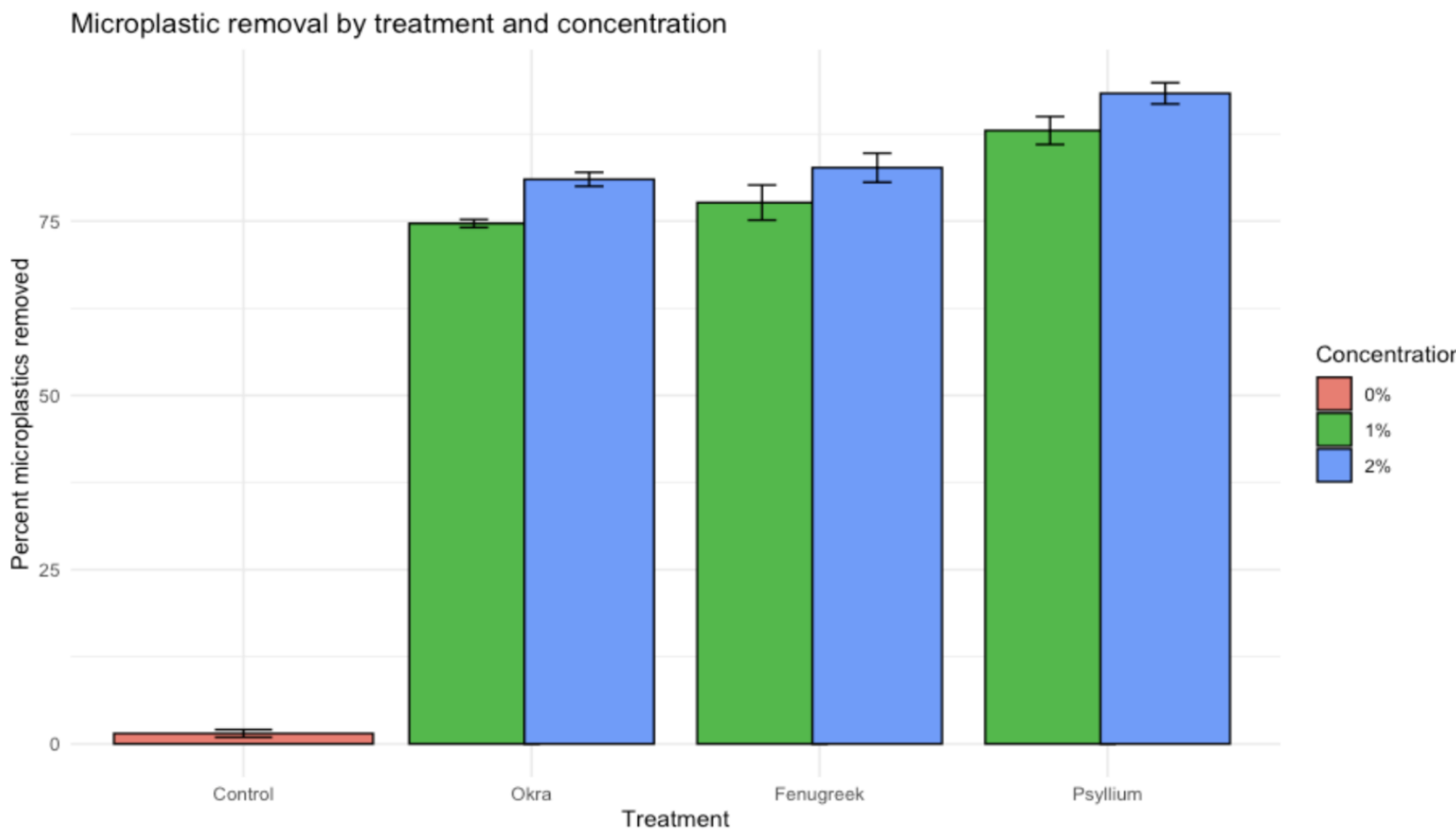


Fig. 4: Graph created by Finalist in RStudio, 2026.

| Treatment | Conc. (%) | Initial Mass (g) | Remaining Mass (g) | Removed (g) | Removal (%) |
|-----------|-----------|------------------|--------------------|-------------|-------------|
| Trial 1   |           |                  |                    |             |             |
| Control   | 0         | 0.5              | 0.49               | 0.01        | 2           |
| Control   | 0         | 0.5              | 0.495              | 0.005       | 1           |
| Okra      | 1         | 0.5              | 0.13               | 0.37        | 74          |
| Okra      | 2         | 0.5              | 0.09               | 0.41        | 82          |
| Fenugreek | 1         | 0.5              | 0.11               | 0.39        | 78          |
| Fenugreek | 2         | 0.5              | 0.075              | 0.425       | 85          |
| Psyllium  | 1         | 0.5              | 0.06               | 0.44        | 88          |
| Psyllium  | 2         | 0.5              | 0.025              | 0.475       | 95          |
| Trial 2   |           |                  |                    |             |             |
| Control   | 0         | 0.5              | 0.49               | 0.01        | 2           |
| Control   | 0         | 0.5              | 0.49               | 0.01        | 2           |
| Okra      | 1         | 0.5              | 0.125              | 0.375       | 75          |
| Okra      | 2         | 0.5              | 0.095              | 0.405       | 81          |
| Fenugreek | 1         | 0.5              | 0.1                | 0.4         | 80          |
| Fenugreek | 2         | 0.5              | 0.095              | 0.405       | 81          |
| Psyllium  | 1         | 0.5              | 0.07               | 0.43        | 86          |
| Psyllium  | 2         | 0.5              | 0.04               | 0.46        | 92          |
| Trail 3   |           |                  |                    |             |             |
| Control   | 0         | 0.5              | 0.495              | 0.005       | 1           |
| Control   | 0         | 0.5              | 0.49               | 0.01        | 2           |
| Okra      | 1         | 0.5              | 0.125              | 0.375       | 75          |
| Okra      | 2         | 0.5              | 0.1                | 0.4         | 80          |
| Fenugreek | 1         | 0.5              | 0.125              | 0.375       | 75          |
| Fenugreek | 2         | 0.5              | 0.09               | 0.41        | 82          |
| Psyllium  | 1         | 0.5              | 0.05               | 0.45        | 90          |
| Psyllium  | 2         | 0.5              | 0.035              | 0.465       | 93          |

Fig. 3: Table created by Finalist in Excel, 2026.

## Statistical Analysis

### Post Hoc Tukey Tests

| contrast                    | estimate  | SE       | df | t.ratio | p.value |
|-----------------------------|-----------|----------|----|---------|---------|
| Control 0% - Okra 1%        | -73.16667 | 1.059504 | 17 | -69.057 | <0.0001 |
| Control 0% - Fenugreek 1%   | -76.16667 | 1.059504 | 17 | -71.889 | <0.0001 |
| Control 0% - Psyllium 1%    | -86.50000 | 1.059504 | 17 | -81.642 | <0.0001 |
| Control 0% - Okra 2%        | -79.50000 | 1.059504 | 17 | -75.035 | <0.0001 |
| Control 0% - Fenugreek 2%   | -81.16667 | 1.059504 | 17 | -76.808 | <0.0001 |
| Control 0% - Psyllium 2%    | -91.83333 | 1.059504 | 17 | -86.676 | <0.0001 |
| Okra 1% - Psyllium 2%       | -18.66667 | 1.223410 | 17 | -15.258 | <0.0001 |
| Fenugreek 1% - Psyllium 2%  | -15.66667 | 1.223410 | 17 | -12.806 | <0.0001 |
| Okra 1% - Psyllium 1%       | -13.33333 | 1.223410 | 17 | -10.899 | <0.0001 |
| Okra 2% - Psyllium 2%       | -12.33333 | 1.223410 | 17 | -10.081 | <0.0001 |
| Fenugreek 2% - Psyllium 2%  | -10.66667 | 1.223410 | 17 | -8.719  | <0.0001 |
| Fenugreek 1% - Psyllium 1%  | -10.33333 | 1.223410 | 17 | -8.446  | <0.0001 |
| Okra 1% - Fenugreek 2%      | -8.00000  | 1.223410 | 17 | -6.539  | <0.0001 |
| Psyllium 1% - Okra 2%       | 7.00000   | 1.223410 | 17 | 5.722   | 0.0004  |
| Okra 1% - Okra 2%           | -6.33333  | 1.223410 | 17 | -5.177  | 0.0012  |
| Psyllium 1% - Fenugreek 2%  | 5.33333   | 1.223410 | 17 | 4.359   | 0.0063  |
| Psyllium 1% - Psyllium 2%   | -5.33333  | 1.223410 | 17 | -4.359  | 0.0063  |
| Fenugreek 1% - Fenugreek 2% | -5.00000  | 1.223410 | 17 | -4.087  | 0.0110  |

Fig. 5: Table created by Finalist in RStudio, 2026.

### Two-Way ANOVA

|                                                               | Df | Sum Sq | Mean Sq | F value  | Pr(>F)  |
|---------------------------------------------------------------|----|--------|---------|----------|---------|
| Treatment                                                     | 3  | 30369  | 10123   | 4509.003 | < 2e-16 |
| Concentration                                                 | 1  | 139    | 139     | 61.863   | 4.6e-07 |
| Treatment:Concentration                                       | 2  | 1      | 1       | 0.322    | 0.729   |
| Residuals                                                     | 17 | 38     | 2       |          |         |
| ---                                                           |    |        |         |          |         |
| Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 |    |        |         |          |         |

Fig. 6: Table created by Finalist in RStudio, 2026.

### Summary Statistics

|   | Treatment | Concentration | n     | mean_rem | sd_rem | var_rem |
|---|-----------|---------------|-------|----------|--------|---------|
|   | <fact>    | <fact>        | <int> | <dbl>    | <dbl>  | <dbl>   |
| 1 | Control   | 0%            | 6     | 1.5      | 0.548  | 0.3     |
| 2 | Okra      | 1%            | 3     | 74.7     | 0.577  | 0.333   |
| 3 | Okra      | 2%            | 3     | 81       | 1      | 1       |
| 4 | Fenugreek | 1%            | 3     | 77.7     | 2.52   | 6.33    |
| 5 | Fenugreek | 2%            | 3     | 82.7     | 2.08   | 4.33    |
| 6 | Psyllium  | 1%            | 3     | 88       | 2      | 4       |
| 7 | Psyllium  | 2%            | 3     | 93.3     | 1.53   | 2.33    |

Fig. 7: Table created by Finalist in RStudio, 2026.

## Methods

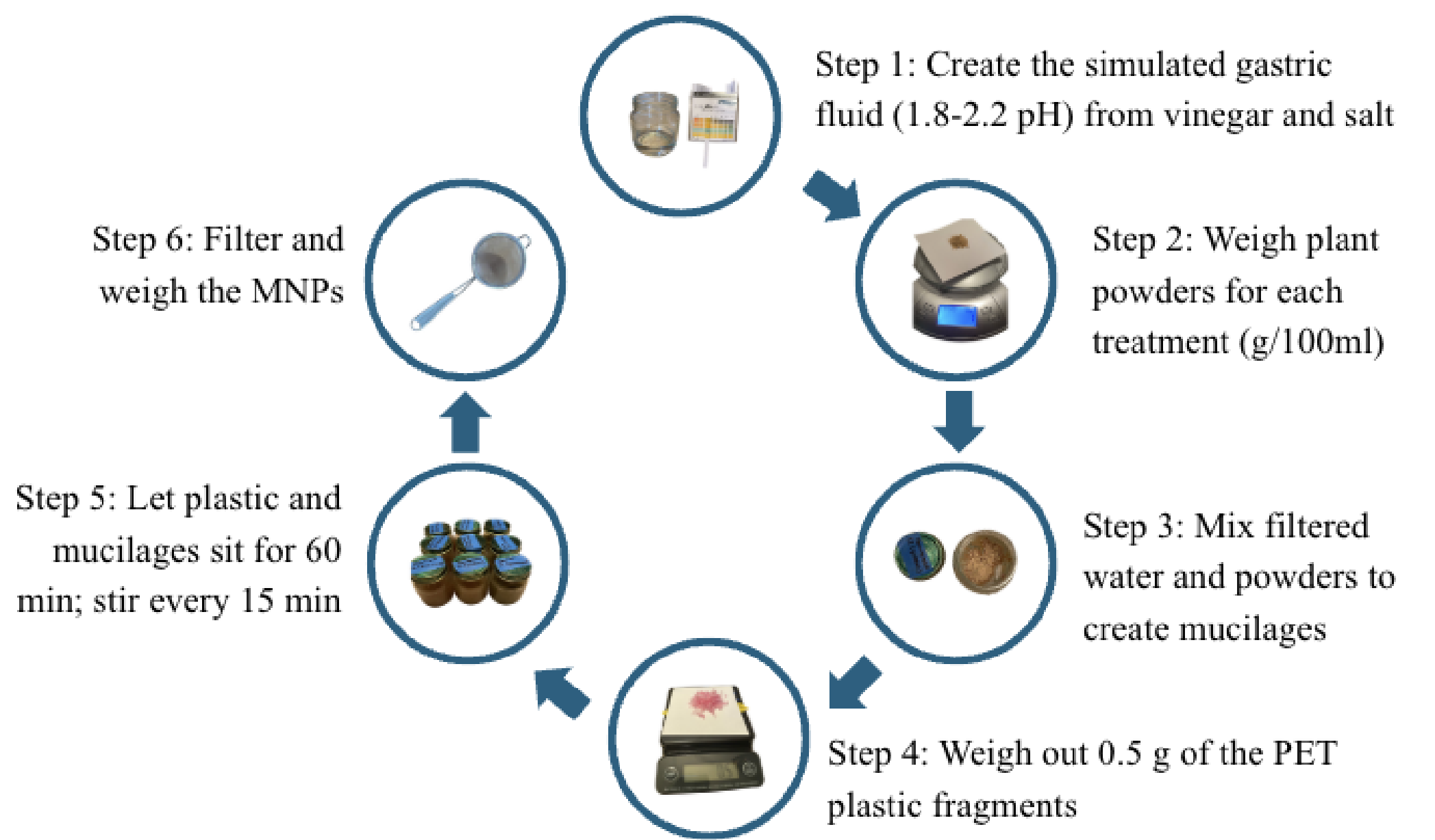


Fig. 8: Illustration created by Finalist in Canva, 2026.

## Polysaccharide Selection

|                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Okra</b><br><br>Fig. 9: Graphic of Okra<br><b>Origin:</b><br><i>Abelmoschus esculentus</i><br><b>Properties:</b> <ul style="list-style-type: none"><li>Forms a slippery, sticky gel</li><li>Common food vegetable; safe and non-toxic</li><li>Gel net can bind together particles</li><li>Has pH-tolerant gelling behavior, suitable for GI conditions</li></ul> | <b>Fenugreek</b><br><br>Fig. 10: Graphic of Fenugreek<br><b>Origin:</b><br><i>Trigonella foenum-graecum</i><br><b>Properties:</b> <ul style="list-style-type: none"><li>Swells in acidic and neutral pH</li><li>Food safe; commonly used in herbal medicine</li><li>Gel net can bind together particles</li><li>Biocompatible fibers that move through the gut and are excreted from the body</li></ul> | <b>Psyllium Husk</b><br><br>Fig. 11: Graphic of Psyllium<br><b>Origin:</b><br><i>Plantago ovata</i><br><b>Properties:</b> <ul style="list-style-type: none"><li>Forms mucilage in water</li><li>Food-safe soluble fiber; used as a laxative</li><li>Gel net can bind together particles</li><li>Fermentation in the gut is limited</li></ul> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Fig. 12: Illustration created by Finalist in Canva, 2026.

## Future Work

In future testing, this project could be expanded upon by:

- Creating a more realistic model of digestion. I plan to add digestive enzymes and bile salts to better mimic how mucilage behaves in the human body.
- Upgrading lab equipment and testing smaller plastics. Using advanced tools such as a centrifuge and measuring zeta potential would provide more data.
- Testing a wider variety of plastics, such as polypropylene from bottle caps and polystyrene from utensils, to compare how different plastics react to each mucilage.

## Sources

- Kannan, K., & Vimalkumar, K. (2021). A review of human exposure to microplastics and insights into microplastics as obesogens. *Frontiers in Endocrinology*, 12, Article 724989. <https://doi.org/10.3389/fendo.2021.724989>
- Marfella, R., et al. (2024). Microplastics and nanoplastics in atheromas and cardiovascular events. *The New England Journal of Medicine*, 390(10), 900–910. <https://doi.org/10.1056/NEJMoa2309822>
- Figs. 1, 2, 8, and 12: Illustrations created by Finalist in Canva, 2026.
- Fig. 3: Table created by Finalist in Excel, 2026.
- Figs. 4–7: Graph and tables created by Finalist in RStudio, 2026.
- Fig. 9: Fruit Link Co. (2025). *Okra*. Retrieved from <https://fruitlinkco.com/home/products/vegetables/okra/>
- Fig. 10: Rodkina, L. (2025). *Element Illustration* [Digital image]. Canva. <https://www.canva.com/>
- Fig. 11: Adalix Global Exports. (2025). *Psyllium husk*. <https://adalizglobalexports.com/psyllium-husk/>