

MicroTract: Revolutionizing Chitosan-Based Microfiber Removal

Adhrit Gopi and Smyan Reddy - Science Fair Final Paper

Lambert High School

9th Grade

Lee Fisher

2025

Abstract

This experiment aimed to create a biodegradable pill that effectively removes microfibers from the digestive system, as well as to investigate the effects of chitosan, lecithin, and citric acid on microplastics in the human body. The specific guiding research question selected for this topic was, "Which capsule formulation would remove the most microfibers?" The hypothesis was that

a pill containing 50% chitosan, 25% lecithin, and 25% citric acid would provide the best microfiber removal efficiency. Fifteen trials were carried out with five capsule formulations, all under identical conditions. Clumps were formed, pH levels changed, the mass of fibers captured on filters was measured, clumping was visually documented, and sediment was collected.

Interestingly, capsule 1, which contained 100% pure chitosan, had an extremely low removal efficiency (8.23%) and high variability. This implies a sort of synergy among the three materials.

The capsule with 33% chitosan, 33% lecithin, and 33% citric acid had the highest average removal efficiency (23.04%), closely followed by the 50% chitosan, 25% lecithin, and 25% citric acid formulation (21.64%). While the hypothesis predicted that a mixture of 50% chitosan, 25% lecithin, and 25% citric acid would be the most effective, the capsule containing equal amounts of each material achieved the highest removal rate. These findings indicate that balanced proportions of all three components improve microfiber removal and highlight the potential of biodegradable capsules to effectively remove microfibers from the human digestive system.

Introduction

Purpose

The purpose of this experiment was to develop and evaluate biodegradable capsules designed to maximize the removal of microfibers from the digestive system.

Problem

This study investigates the effectiveness of capsules containing chitosan, lecithin, and citric acid in removing microfibers from the digestive system.

Research

Microfibers have become a major environmental and health concern. In North America alone, 3.5 quadrillion microfibers are released into the ocean each year. These microfibers mainly come from washing synthetic clothing made of polyester, nylon, and acrylic materials (Lim et al., 2022). These microscopic particles enter the body via food and drinking water. Microfibers have been linked to serious health conditions, including respiratory inflammation, autoimmune diseases, and tissue damage (Osman et al., 2025). Studies have shown that microplastics accumulate in lung tissue, the digestive tract, and even the bloodstream, raising concerns about long-term systemic health consequences (Chartres et al., 2024). Chitosan, lecithin, and citric acid are natural compounds with distinct properties that make them ideal for use in biodegradable capsules. Chitosan, a biopolymer derived from chitin, functions as a natural coagulant by binding to microplastics via charge neutralization and bridging adsorption (Aranaz et al., 2021). Recent research has shown that ingesting chitosan can significantly promote microplastic removal, with human trials revealing large amounts of microplastics in feces after chitosan ingestion (Liu & Shimizu, 2025; Casella et al., 2025). However, no studies have been conducted to determine whether combining chitosan with lecithin and citric acid can produce synergistic effects that

improve removal efficiency beyond what chitosan can achieve alone. Lecithin, a naturally occurring phospholipid, acts as an emulsifier, increasing the hydrophobic interactions between chitosan and microplastic surfaces. These increase the stability of microfiber clumps (Wang et al., 2024). Citric acid helps by creating acidic conditions that increase chitosan solubility at low pH and can improve binding capacity during digestion (Zhang et al., 2025). The combination of these compounds in a pill has potential advantages over using only one material or nothing at all. Chitosan's coagulation effectiveness is pH dependent and can be improved with citric acid, whereas lecithin can stabilize aggregates, demonstrating how these three materials complement each other. The combination of these three materials has the greatest potential to achieve revolutionary microfiber removal due to their complementary interactions. This experiment fills a research gap by systematically testing five capsule formulations under simulated digestive conditions to determine the best ratio for maximum microfiber capture. Based on the known chemical properties of these compounds, a capsule containing them should significantly improve microplastic removal efficiency.

Hypothesis

A biodegradable pill containing 50% chitosan, 25% lecithin, and 25% citric acid will have the highest microfiber removal efficiency when compared to other formulations because this ratio best balances the complementary interactions of all three materials in the human digestive system.

Methods

Variables

Independent:

Capsule contents/treatment composition:

- 100% Chitosan
- 50% Chitosan + 50% Lecithin
- 33% Chitosan + 33% Lecithin + 33% Citric acid
- Empty sealed capsule (control)
- 50% Chitosan + 25% Lecithin + 25% Citric acid

Dependent:

- Mass of fibers captured on the coffee filter (final mass – empty filter mass)
- Number of fibers per mm²
- pH change (initial vs. final)
- Largest clump size after agitation
- Number of clumps > 2 mm
- Qualitative observations from photos

Constants:

- Containers
- Microfibers
- Filters

Materials

- Soy Lecithin
- Citric Acid
- Empty Gelatin Capsules
- Old fleece/athletic wear
- White Vinegar
- Distilled Water
- Table Salt
- Baking Soda
- 15 beakers/jars
- 15 coffee filters
- 15 collection containers
- Scale
- pH paper
- Timer
- Ruler
- Scissors
- Tweezers
- 3 stirring rods
- Magnifying glass
- Smartphone
- Gloves

- Goggles
- Mask
- 15 ziplock bags
- Permanent markers
- Notebook

Procedure

Microfiber Preparation:

1. Cut a 10 cm * 10 cm square of fabric from polyester clothing
2. Cut across the strip to create 2-4m length pieces
3. Label 15 ziplock bags

For each trial:

4. Add fibers to the scale until 0.033 g.
5. Transfer to a ziplock bag.

Setup:

1. Label and weigh 15 coffee filters
2. Group 1 (Trials 1-3):
 - a. Add 0.3 g of chitosan powder
 - b. Separate gelatin capsule
 - c. Pour chitosan into larger half
 - d. Tap gently, close the capsule, label, and store
3. Group 2 (Trials 4-6):
 - a. Add 0.15g chitosan and 0.15g lecithin
 - b. Mix, transfer, seal, and label the capsule
4. Group 3 (Trials 7-9):
 - a. Add 0.1g chitosan, 0.1g lecithin, and 0.1g citric acid
 - b. Mix, transfer, seal, and label the capsule
5. Group 4 (Trials 10-12)
 - a. Seal and label the capsule
6. Group 5 (Trials 13-15)
 - a. Add 0.15g chitosan, 0.075g lecithin, and 0.075g citric acid
 - b. Mix, transfer, seal, and label the capsule

Experiment:

For all 15 jars:

1. Label jar
2. Add 140 mL water, 10 mL vinegar, 0.033g table salt, and 0.133g baking soda

3. Stir and rinse the rod between jars
4. Measure initial pH
5. Add 0.033 g of microfibers, stir, and submerge the capsule.
6. Collect pH and sediment height during the trials.
7. Measure the largest clump size using a ruler after agitation (stir for 30 seconds) and count the number of clumps >2 mm in diameter.
8. After the trial, calculate pH and take photos.
9. Pour solution through filter, rinse jar, count fibers in 5 mm squares, and let dry 12-24 hours
10. Save the collection container with the filtrate

Primary Measurements:

For all 15 filters:

1. Verify it is completely dry and record the final mass
2. Primary Mass Captured = Final Mass - Empty Mass
3. Place on a white background with a ruler, take an overhead photo, and take a close-up
4. Mark the filter square with a ruler and count the visible individual fibers in 3 random squares, and calculate the average.

Results

The results of the experiment show a significant variation in microfiber removal efficiency across the five capsule combinations tested. Group 3, made up of 33% chitosan, 33% lecithin,

and 33% citric acid, had the highest average removal efficiency at 23.04%, followed by Group 5 (50% chitosan, 25% lecithin, 25% citric acid) at 21.64%. Group 2, which contained an even split of chitosan and lecithin, performed mediocrely at 13.89%, whereas Group 1, which was solely composed of chitosan, produced poor and variable results, with an average removal efficiency of only 8.23%. The control group showed minimal and unsatisfactory removal of 3.82%, which proved to be an extremely low baseline for comparison.

Group 1 (100% Chitosan): This capsule performed unexpectedly poorly and inconsistently, with removal rates ranging from 0.43% to 18.62%. The high standard deviation of 9.21% indicates unreliable removal efficiency, implying that pure chitosan is not suitable for proper microfiber binding in human digestive systems.

Group 2 (50% chitosan, 50% lecithin) performed mediocrely but consistently, with removal efficiencies ranging from 12.74% to 15.40%. This formula had a consistent standard deviation of 1.36% and collected an average of 0.128 g of microfibers per trial.

Group 3 (33% chitosan, 33% lecithin, and 33% citric acid): This pill had the highest removal efficiency, ranging from 17.74% to 30.46%. Despite having a relatively high standard deviation of 6.67%, the average removal efficiency of 23.04% demonstrated the most effective formula for microfiber elimination. This balanced capsule also absorbed an average of 0.214 g of binding material, demonstrating its excellent fiber aggregation.

Group 4 (Empty Capsule - Control): The control group had minimal impact, with an average removal efficiency of 3.82%. This confirmed that active ingredients are required for effective microfiber capture.

Group 5 (50% Chitosan, 25% Lecithin, 25% Citric Acid): Similar to Group 3, this group achieved removal efficiencies ranging from 16.11% to 30.57%, with a promising average of 21.64%. This was the optimal formulation, according to the hypothesis.

Table(s)

Trial	Group	Capsule Composition	Empty Filter (g)	Final Filter (g)	Mass Captured (g)	Removal Efficiency	Binding Material (g)	Average Fiber Density (# of fibers/cm ²)
1	1	100% Chitosan	0.929	1.102	0.173	18.6221743 8%	0.14	0.191
2	1	100% Chitosan	0.923	0.975	0.052	5.63380281 7%	0.019	0.166

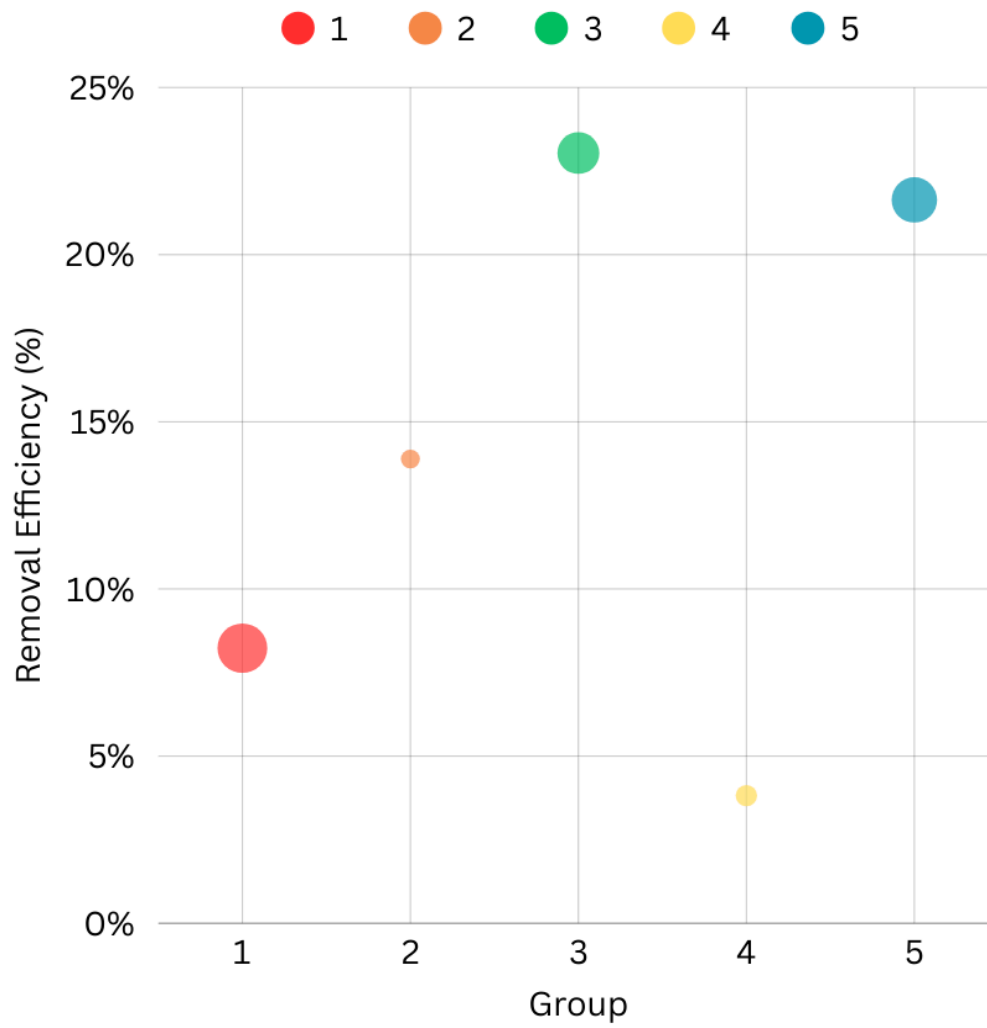
3	1	100% Chitosan	0.928	0.932	0.004	0.43103448 28%	-0.029	0.102
4	2	50% Chitosan, 50% Lecithin	0.925	1.05	0.125	13.5135135 1%	0.092	0.255
5	2	50% Chitosan, 50% Lecithin	0.926	1.044	0.118	12.7429805 6%	0.085	0.166
6	2	50% Chitosan, 50% Lecithin	0.922	1.064	0.142	15.4013015 2%	0.109	0.293
7	3	33% Chitosan, 33% Lecithin, 33% Citric Acid	0.93	1.095	0.165	17.7419354 8%	0.132	0.191
8	3	33% Chitosan, 33% Lecithin, 33% Citric Acid	0.923	1.116	0.193	20.9100758 4%	0.16	0.229
9	3	33% Chitosan, 33% Lecithin, 33% Citric Acid	0.929	1.212	0.283	30.4628632 9%	0.25	0.204
10	4	Empty	0.924	0.944	0.02	2.16450216 5%	-0.013	0.153
11	4	Empty	0.927	0.961	0.034	3.66774541 5%	0.001	0.076
12	4	Empty	0.924	0.976	0.052	5.62770562 8%	0.019	0.14
13	5	50% Chitosan, 25% Lecithin, 25% Citric Acid	0.927	1.096	0.169	18.2308522 1%	0.136	0.255
14	5	50% Chitosan, 25% Lecithin, 25% Citric Acid	0.929	1.213	0.284	30.5705059 2%	0.251	0.115
15	5	50% Chitosan, 25% Lecithin, 25% Citric Acid	0.925	1.074	0.149	16.1081081 1%	0.116	0.076

Group	Capsule	Average Removal	Standard	Average	Average	Average Clump
-------	---------	-----------------	----------	---------	---------	---------------

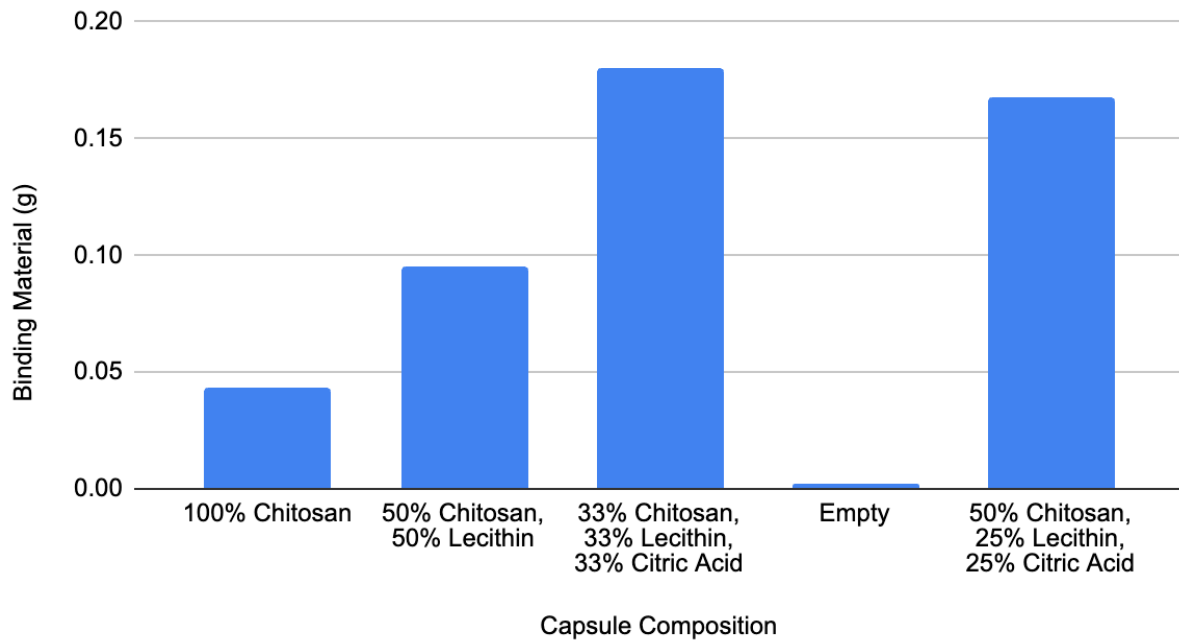
	Composition	Efficiency	Deviation	Binding Material (g)	Settling Rate (mm/min)	Size (mm)
1	100% Chitosan	8.229003894%	9.369135188 %	0.043333333 3	0	4
2	50% Chitosan, 50% Lecithin	13.88593186%	1.367731388 %	0.095333333 3	0.007407407 41	4.166666667
3	33% Chitosan, 33% Lecithin, 33% Citric Acid	23.03829154%	6.622120328 %	0.180666666 7	-0.022222222 222	4
4	Empty	3.819984403%	1.736613684 %	0.002333333 333	-0.00370370 37	4.333333333
5	50% Chitosan, 25% Lecithin, 25% Citric Acid	21.63648875%	7.809545939 %	0.167666666 7	-0.02962962 963	4.166666667

Graph(s)

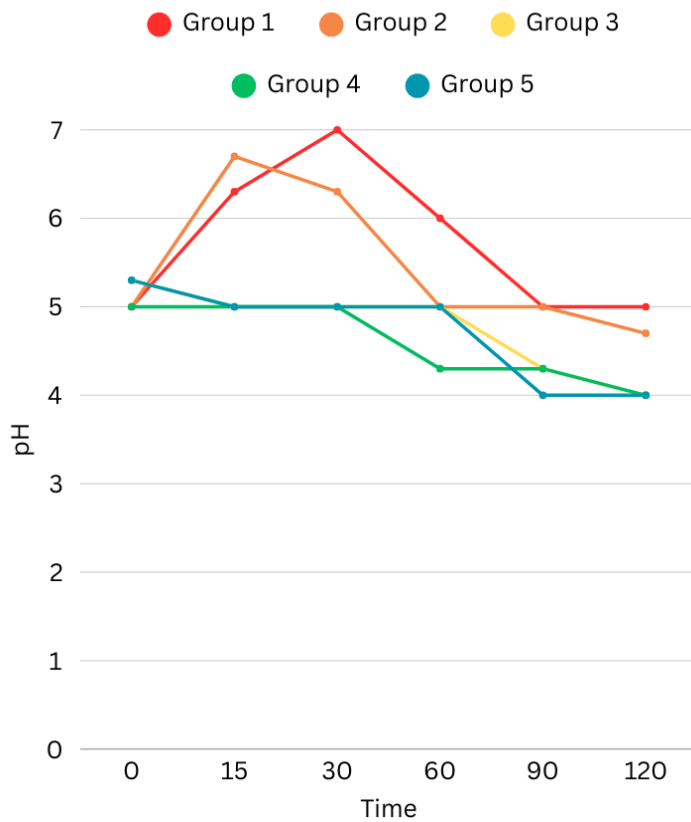
Average Removal Efficiency

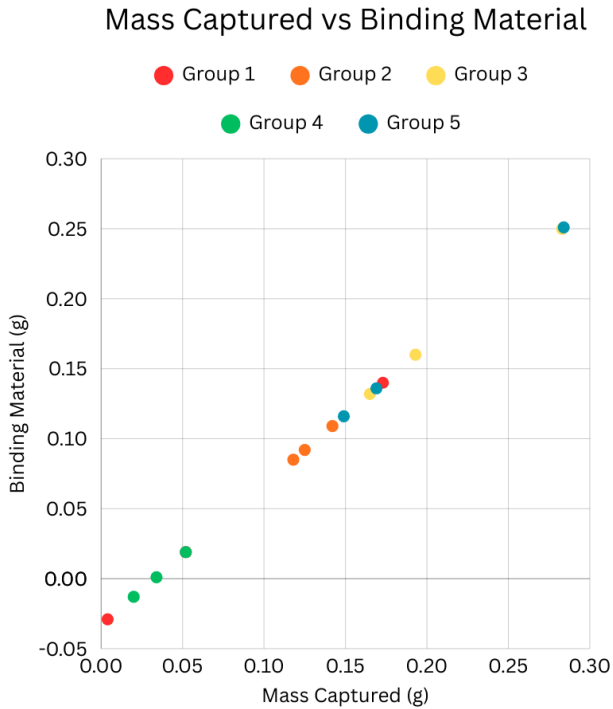


Average Binding Material



pH Change





Analysis

Each group measured:

1. Average Removal Efficiency = (Trial x% + Trial y% + Trial z%) / 3
2. Standard Deviation = STDEV (Trial x%, Trial y%, Trial z%)
3. Average Binding Material = (Trial x binding + Trial y binding + Trial z binding) / 3
4. Each trial: pH change = pH at 120 min - pH at 0min. Average x, y, z
5. Each trial: Settling rate = (Sediment height at 120 min - Height at 30min) / 90min.
Average x, y, and z. Units: mm/min
6. Each trial: Average Clump Size = Largest clump measurement at 110 min. Average x, y, z
7. Each trial: Average Fiber Embedding Efficiency = [(Control count - Treatment count) / Control count]*100%. Average x, y, z
8. Each trial: Mass Recovery = (Total captured / 0.333 g) * 100%
9. Each trial: pH Change Rate = (Final pH - Initial pH) / 2 hours

Across all 15 trials, the capsule compositions produced clear differences in filtering performance. The 100% chitosan group (Trials 1–3) showed low and inconsistent removal efficiencies, ranging from 0.43% to 18.62%, with generally low fiber density values. The 50% chitosan and 50% lecithin group (Trials 4–6) performed more consistently, with removal efficiencies between 12.74% and 15.40% and higher fiber densities than the pure chitosan group. The strongest performance came from the capsules containing equal parts chitosan, lecithin, and citric acid (Trials 7–9), which achieved the highest removal efficiencies, between 17.74% and 30.46%,

along with high captured mass and strong binding material totals. The empty capsule control group (Trials 10–12) produced the lowest efficiencies, ranging from 2.16% to 5.63%. The final group, containing 50% chitosan, 25% lecithin, and 25% citric acid (Trials 13–15), also performed well, with efficiencies between 16.10% and 30.57%, similar to the equal-ratio group. Overall, mixtures containing citric acid showed the highest captured mass, the strongest binding measurements, and the highest removal efficiencies across trials.

Conclusion

The experiment showed that the capsule containing equal amounts of chitosan, lecithin, and citric acid had the highest removal efficiency (23.04%), slightly outperforming the hypothesized optimal combination of 50% chitosan, 25% lecithin, and 25% citric acid (21.64%). Together, these compounds form a mixture that can aggregate microplastics. Interestingly, pure chitosan (Group 1) had a low removal efficiency (8.23%), indicating that all three components work together rather than one material driving removal efficiency. This represents a 2.8-fold improvement over pure chitosan in the optimal formulation, demonstrating the importance of component synergy for effective microfiber capture. These properties make chitosan, lecithin, and citric acid an excellent choice for a biodegradable pill designed to collect microplastics. Their ability to bind and clump fibers allows for more efficient removal from the digestive system. With up to 6-fold higher removal efficiency than the control group (23.04% vs 3.82%), these biodegradable capsules could be a useful intervention for reducing microplastic retention in populations with high environmental contamination. Future research should test these capsules at body temperature, incorporate digestive enzymes, and compare their performance against various types of microplastics to determine their overall efficacy. Furthermore, extending observation times to 24-72 hours would simulate the entire digestive transit time and provide insights into long-term binding stability under realistic physiological conditions. While the hypothesis predicted that the 50% chitosan, 25% lecithin, 25% citric acid formulation (Group 5) would be most effective, experimental results showed that the balanced 33/33/33 formulation (Group 3) achieved slightly higher removal efficiency (23.04% vs 21.64%). This implies that equal proportions of all three components optimize synergistic interactions, resulting in efficient microfiber removal. The mechanism likely involves chitosan providing electrostatic binding, lecithin stabilizing aggregates through emulsification, and citric acid creating optimal pH conditions for maximum chitosan solubility, with balanced ratios preventing any single component from becoming rate-limiting. This study shows that multi-component biodegradable capsules are a promising and accessible strategy for mitigating the growing health risk posed by microfiber contamination in the human body.

References

- Aranaz, I., Alcántara, A. R., Civera, M. C., Arias, C., Elorza, B., Heras Caballero, A., & Acosta, N. (2021). Chitosan: An overview of its properties and applications. *Polymers*, 13(3), 396. <https://doi.org/10.3390/polym13030396>
- Casella, C., Scheggia, A., Pedron, S., Moretto, L., Vallese, F., Tallandini, L., De Lazzari, F., Costa, R., Arcidiacono, D., Cagnin, S., & Ravarotto, L. (2025). Preliminary study on PCC-chitosan's ability to enhance microplastic excretion in human stools from healthy volunteers. *Foods*, 14(13), 2190. <https://doi.org/10.3390/foods14132190>
- Chartres, N., Bero, L. A., & Norris, S. L. (2024). Effects of microplastic exposure on human digestive, reproductive, and respiratory health: A rapid systematic review. *Environmental Science & Technology*, 58(3), 1545-1562. <https://doi.org/10.1021/acs.est.3c09524>
- Effect of microplastics deposition on human lung airways: A review with computational benefits and challenges. (2024). *Environmental Research*, 245, 118009. <https://pmc.ncbi.nlm.nih.gov/articles/PMC10826726/>
- Entoplast. (2025, March 26). The versatile efficacy of chitosan for microplastic removal: A sustainable solution. <https://www.entoplast.com/post/the-versatile-efficacy-of-chitosan-for-microplastic-removal-a-sustainable-solution>
- Experimental set-up in building models of the intestine. (n.d.). University of California, San Diego. <https://www.scripps.edu/education/undergraduate/experiments/intestinal-model/>
- Generic immunofluorescence protocol for paraffin-embedded tissue. (n.d.). University of Pennsylvania Digestive and Liver Center. <https://www.med.upenn.edu/digestive-and-liver-center/assets/user-content/documents/mpic-protocols/genericifprotocolparaffin.doc>
- Haider, A., Khan, S., Iqbal, D. N., Shrahili, M., Haider, S., Mohammad, K., Mohammad, F., Alothman, O. Y., Kanchi, S., & Sabir, A. (2024). Advances in chitosan-based drug delivery systems. *International Journal of Pharmaceutics*, 616, 121509. <https://doi.org/10.1016/j.ijpharm.2024.121509>
- Hejazi, R., & Amiji, M. (2003). Chitosan-based gastrointestinal delivery systems. *Journal of Controlled Release*, 89(2), 151-165. [https://doi.org/10.1016/S0168-3659\(03\)00126-3](https://doi.org/10.1016/S0168-3659(03)00126-3)

Kristia, H., Boedisantoso, R., Assomadi, A. F., & Slamet, A. (2025). Utilization of chitosan as a natural coagulant for polyethylene microplastic removal. *Cleaner Water*, 3, 100053. <https://doi.org/10.1016/j.clwat.2025.100053>

Kupec, B. (2021, October 17). Your clothes may be after you: How microfibers affect human health. PlanetCare. <https://blog.planetcare.org/microfibers-health-risks/>

Laboratory experimental set-up for anaerobic digestion tests. (n.d.). University of California, Berkeley. https://www.ocf.berkeley.edu/~johannac/anaerobic_digestion_protocol/

Lecithin. (2025). In *Wikipedia*. <https://en.wikipedia.org/wiki/Lecithin>

Ligare, M. (2024, February 7). Microfibers: Tiny pieces of plastic pollution that require big solutions. The Surfrider Foundation. <https://www.surfrider.org/news/microfibers-tiny-pieces-of-plastic-pollution-that-require-big-solutions>

Lim, J., Jeong, S., & Oh, K. W. (2022). Cause of microfibers found in the domestic washing process of clothing. *Fashion and Textiles*, 9(1), 12. <https://doi.org/10.1186/s40691-022-00306-8>

Liu, D., & Shimizu, M. (2025). Ingesting chitosan can promote excretion of microplastics. *Scientific Reports*, 15(1), 9050. <https://doi.org/10.1038/s41598-025-96393-w>

Maverik Oils. (2025, April 26). Why lecithin is the best emulsifier. <https://maverikoils.com/why-lecithin-is-the-best-emulsifier/>

McConnell, E. L., Fadda, H. M., & Basit, A. W. (2008). An investigation into the digestion of chitosan (noncrosslinked and crosslinked) by human colonic bacteria. *Journal of Pharmaceutical Sciences*, 97(9), 3820-3829. <https://doi.org/10.1002/jps.21271>

Microplastic and plastic pollution: Impact on respiratory disease and health. (2024). *European Respiratory Review*, 33(173), 240074. <https://doi.org/10.1183/16000617.0074-2024>

Osman, A. I., Hosny, M., Eltaweil, A. S., Omar, S., Elgarahy, A. M., Farghali, M., Yap, P.-S., Wu, Y.-S., Nagandran, S., Batumalaie, K., Gopinath, S. C. B., Mehta, N., Makhoul, A. S. H., Amen, B. H., Abdel-Khalek, M. A., Mahmoud, H. A., Morsi, M. E., Rooney, D. W., & Wen, J. (2025). Impact of microplastics on human health: Risks, diseases, and affected body systems. *Pollutants*, 4(2), 23. <https://doi.org/10.3390/pollutants4020023>

Patel, J., Mungray, A., & Joshi, D. (2024). Impacts of micro and nanoplastics on human health. *Bulletin of the National Research Centre*, 48(1), 103. <https://doi.org/10.1186/s42269-024-01268-1>

Pelch, K. (2025, June 16). New review highlights human health risks from microplastic exposure. NRDC.

<https://www.nrdc.org/bio/katie-pelch/new-review-highlights-human-health-risks-microplastic-exposure>

Potential health impact of microplastics: A review of environmental distribution, human exposure, and toxic effects. (2024). *Environment & Health*, 1(4), 231-250.

<https://doi.org/10.1021/envhealth.3c00052>

Shalumon, C. S., Anjali, P., Joseph, J., Kalarikkal, N., Sivakumar, P. M., & Jayakumar, R. (2023). A novel simplified method for extraction of microplastic particles from face scrub and laundry wastewater. *Scientific Reports*, 13(1), 14168.

<https://doi.org/10.1038/s41598-023-41457-y>

Shevchenko, A., Tomas, H., Havliš, J., Olsen, J. V., & Mann, M. (2006). In-gel digestion for mass spectrometric characterization of proteins and proteomes. *Nature Protocols*, 1(6), 2856-2860. <https://doi.org/10.1038/nprot.2006.468>

Stabilization of oil/water emulsions using soybean lecithin as a biobased surfactant for enhanced oil recovery. (2023). *Journal of Engineering and Applied Science*, 70(1), 187.

<https://doi.org/10.1186/s44147-023-00322-5>

Stanford Medicine. (2025, January 29). Microplastics and our health: What the science says.

<https://med.stanford.edu/news/insights/2025/01/microplastics-in-body-polluted-tiny-plastic-fragments.html>

Wang, X., Wang, Z., Sun, N., He, L., Liu, Y., & Wang, L. (2024). Interactions with soy lecithin regulate the emulsification capacity of pea protein: Effects of soy lecithin concentration. *Food Hydrocolloids*, 156, 110283. <https://doi.org/10.1016/j.foodhyd.2024.110283>

Zhang, J., Zhang, Y., Wu, Y., Wang, X., Zhang, Y., Guo, X., & Yan, W. (2025). Impact of chitosan on lipid digestion under simulated gastrointestinal conditions. *Food Chemistry*, 426, 136780. <https://doi.org/10.1016/j.fchem.2024.136780>