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How concentration, temperature, and pH affect soapberry's cleaning power compared to commercially available detergents

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ABSTRACT

The widespread use of synthetic cleaning products significantly contributes to environmental pollution, creating the need for natural alternatives. In this study, the capillary tube method was used to investigate the effect of concentration, temperature and pH on the effectiveness of soapberry as a plant-based detergent and compare its effectiveness to commercially available detergent and bio-detergent. Effectiveness was measured as a decrease in surface tension, which in turn affects the formation of micelles that enclose lipids and dissolve grease and oils. The results of this study showed that greater effectiveness was achieved at higher concentration (5%), temperature (60°C) and pH (12) of soapberry surfactant and found soapberry to be more effective than water (control), similarly as effective as commercial bio-detergent, and less effective than commercial detergent. These findings support the use of soapberry in both domestic and industrial settings as an alternative to commercial cleaning products, reducing the chemical and plastic pollution associated with conventional detergents.

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YASJ Editors' Note: This study systematically investigates soapberry as a potential alternative to commercial cleaning products by examining the effects of concentration, temperature and pH on surface tension. Comparison with conventional detergent, bio-detergent and water provides a clear experimental framework. Readers should note that surface tension was used as a proxy for cleaning effectiveness rather than measuring soil or oil removal directly, and that the capillary-tube method introduces measurement assumptions and uncertainty. Further direct cleaning-performance testing would strengthen the practical conclusions of the investigation.

INTRODUCTION

Hygiene is one of the most significant aspects of human life. Maintaining good hygiene is crucial in order for humans to survive (Curtis, 2007). As a result, humans themselves have developed, engineered and produced an immense range of hygiene and cleaning products for their homes and environments. The widespread use of these products has contributed to the development of a substantial commercial industry, with the global household cleaners market generating approximately USD 39.79 billion in revenue in 2024 and projected to grow at a compound annual growth rate of 3.17% between 2024 and 2029 (Statista, 2024).

However, over time, with the discovery of more chemicals and resources, as well as increased knowledge of their properties and applications, these everyday cleaning products have become increasingly complex mixtures containing harsh and potentially toxic chemicals. Such chemicals can pose risks not only to humans, but also to the environment and the flora and fauna it encompasses, primarily through entering aquatic environments as greywater (Yuan et al., 2014). Persistent contaminants in particular can remain in environmental systems for extended periods due to their resistance to degradation, leading to their accumu-

lation within organisms when uptake occurs faster than elimination — a process known as bioaccumulation. Once absorbed, these chemicals may undergo biotransformation, whereby metabolic processes alter their chemical structure, further affecting their toxicity, persistence and elimination. Moreover, contaminants can be transferred between organisms through feeding and accumulate at higher trophic levels through biomagnification, increasing exposure among organisms higher in the food chain, including humans (Mackay et al., 2018).

For example, triclosan (TCS), an antimicrobial compound commonly used in products such as hand soaps and cosmetics, has been detected in human body fluids across all age groups, with evidence indicating that prolonged exposure may adversely affect multiple biological systems, including hormone homeostasis and liver function (Yueh & Tukey, 2016). Similarly, lead is a cumulative toxicant that can affect multiple body systems, including the neurological, haematological, gastrointestinal, cardiovascular and renal systems; long-term exposure is particularly harmful to children, in whom even relatively low exposure can cause serious and, in some cases, irreversible neurological effects (World Health Organization, 2025).

Additionally, commercial bio-detergents — while specifically designed to replace some harmful components found in conventional detergents using enzymes such as cellulase and lipases (Ito et al., 2005) — are still manufactured cleaning products that require industrial processing and plastic packaging. As a result, both detergents and bio-detergents contribute to the release of toxic chemicals that end up in the ocean, in marine ecosystems, and even in seafood (Couture, 2019), with the chemicals in their plastic packaging, such as flame retardants, also being highly persistent in the environment, impacting coral in particular (Aminot et al., 2020).

However, some resources in nature can be used to perform the same function as artificial cleaning products without causing as much harm. An example of such a resource is the soapberry tree, *Sapindus* — from 'sapo', Latin for 'soap' — which is found in warm temperate and tropical regions such as China and India (Liu et al., 2021). The fruits of this tree, also known as soapnuts, contain organic compounds called saponins, which act as natural surfactants. The key ingredient in detergents and soaps, surfactants are chemical compounds that decrease surface tension and form micelles, molecular structures that enclose lipids and dissolve grease and oils (Kregiel et al., 2017), allowing for effective cleaning. Not only is this property of soapberries not limited to domestic applications — soapberry-derived saponins have also been used to facilitate the removal of heavy metals from contaminated soil (Maity et al., 2013) — but their many beneficial properties make them an environmentally friendly alternative across a range of applications.

Soapberries are natural, free of artificial chemicals, hypoallergenic, greywater safe, zero waste, biodegradable, antibacterial and antifungal (Rai et al., 2021). By not needing to be contained in plastic packaging and being themselves fully biodegradable, as well as lacking artificial chemicals, soapberries completely eliminate any plastic and chemical pollution that could occur from their widespread use. In addition, soapberries are commercially viable due to their low cost and accessibility; they are readily available for purchase online with a 1 kg bag costing approximately 10c per wash, compared with around 50c per wash for commercial bio-detergent (Only 1 Earth, 2022).

However, despite soapberries' numerous beneficial qualities, their use by the public and in the industry is very limited. This is likely due to the greater trust, chemical strength, and cleaning efficiency that conventional cleaning products possess. Therefore, more research into the properties of soapberries and how they function, how to enhance their properties, and their effectiveness in comparison to conventional cleaning products can increase their cleaning capability and make their use as an alternative more widespread, benefiting the environment.

Thus, this study was designed to determine the optimum conditions for the use of soapberries as a cleaning agent and assess their effectiveness as an alternative to commercially available cleaning products. Specifically, it investigated the effect of surfactant concentration, temperature and pH on soapberry effectiveness, measured through surface tension, and compared the effectiveness of soapberry with water (control), commercial detergent and commercial bio-detergent. Lower surface tension facilitates the formation of micelles, which enclose lipids and dissolve grease and oils, thereby contributing to cleaning effectiveness. The critical micelle concentration (CMC) is the concentration

point at which micelles are formed and after which surface tension remains relatively constant; therefore, determining the CMC of soapberry provides an indication of the concentration required for effective surfactant activity.

The variables surfactant concentration, temperature and pH were selected based on their potential effects on surfactant performance. As indicated by the CMC, a certain concentration of surfactant is required to form micelles and hence function effectively; the CMC of the *Sapindus* saponin extracted from pods has been determined to be 0.75%, and 0.45% when extracted from the pericarp (Balakrishnan et al., 2006; Rai et al., 2021). Temperature was selected because changes in molecular thermal activity can alter cohesive forces and intermolecular interactions within a solution, and temperature has been shown to impact the efficiency of soapberry-derived saponin (Maity et al., 2013). Additionally, commercial laundry detergents have been shown to contain ingredients to control and maintain pH, commonly including alkaline builders that help produce and maintain an alkaline environment, which can contribute to cleaning effectiveness.

Hence, it was hypothesised that increases in soapberry surfactant concentration (until a CMC level of 0.75%), temperature and pH would lead to a decrease in surface tension and hence an increase in effectiveness; and that soapberry would perform more effectively than water, similarly as effectively as commercial bio-detergent, and less effectively than commercial detergent.

MATERIALS AND METHODS

Method for calculating surface tension

Surface tension was determined using the capillary tube method. Capillary tubes of 1 mm inner diameter and the Duratech TD-2081 Digital vernier calliper were used to measure the change in water level and the following formula was used to calculate surface tension:

$$T = \frac{\rho \times \pi \times g \times r^2 \times h}{\cos(\theta) \times 2 \times \pi \times r}$$

where T is the surface tension (N/m); ρ is the density (kg/m^3); π is the constant 3.14; g is the force of gravity (9.8 m/s^2); r is the capillary tube radius (0.0005 m); h is the height travelled (m); and $\cos(\theta) = 1$ (where θ is the contact angle between the liquid and the glass of the capillary tube, assumed to equal 0°).

Experiment 1: Effect of concentration on surface tension

Organic soapnut powder (*Sapindus mukorossi*) from Root2Leaf Organic, laundry detergent powder from Cussons Radiant, laundry bio-detergent powder from Earth Choice, and an AMIR Digital Mini Scale and Intllab magnetic stirrer were used. Solutions of 0%, 0.5%, 1%, 2%, 3%, 4% and 5% (w/v) concentration of each of the agents were prepared by weighing 0 g, 0.5 g, 1 g, 2 g, 3 g, 4 g and 5 g of powder, adding to 100 ml of deionised water and stirring for 1 min at bar 4. Surface tension was calculated using the method provided. The Critical Micelle Concentration (CMC) point for each agent was identified graphically using the data collected.

Experiment 2: Effect of temperature on surface tension

The IVYX Scientific Thermostatically controlled water bath and Pasco Temperature Probe were used to achieve solution temperatures of 20°C, 25°C, 30°C, 40°C, 50°C and 60°C for water (control), and 1% concentration solutions of soapberry, detergent and bio-detergent (prepared using the method in Experiment 1). Surface tension was calculated using the method provided.

Experiment 3: Effect of pH on surface tension

Solutions of pH 4, 7 and 12 of each of the agents at 1% concentration were prepared by addition of hydrochloric acid (0.01 M) or sodium hydroxide (1 M) to deionised water [soapberry — 20:0:80, 0:0:100, 0:10:90; detergent and bio-detergent — 60:0:40, 10:0:90, 0:0:100]. The pH values were measured using the Techvida Digital pH Meter. Surface tension was calculated using the method provided.

Data analysis

To ensure precision, all the experiments were performed in replicate and results were presented as averages of the replication values. A One-Way ANOVA statistical analysis was performed using the Data Analysis Tool in Excel, which compared the surface tension of the different types of surfactants at critical micelle concentration level and water (control) in order to see if they were signif-

icantly different ($\alpha = 0.05$). A series of t-tests were further performed using the Data Analysis Tool in Excel, which compared surface tension at the critical micelle concentration for different types of surfactants in order to see if they were significantly different.

RESULTS

The results of Experiment 1 showed that surface tension decreased as the concentration of all three surfactants (soapberry, detergent and commercial bio-detergent) increased until the critical micelle concentration levels of 0.65% (Figure 1), 0.70% (Figure 2) and 1.06% (Figure 3) were reached, respectively.

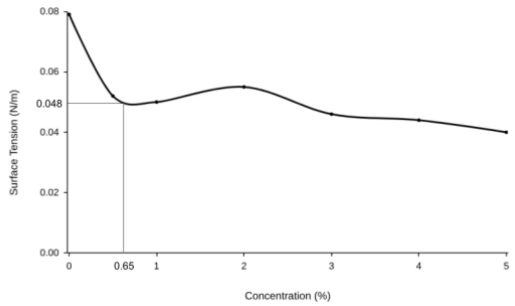


Figure 1. Average surface tension (N/m) of soapberry at increasing concentrations. Surface tension decreased until the critical micelle concentration (CMC) of 0.65% was reached, after which it remained relatively constant.

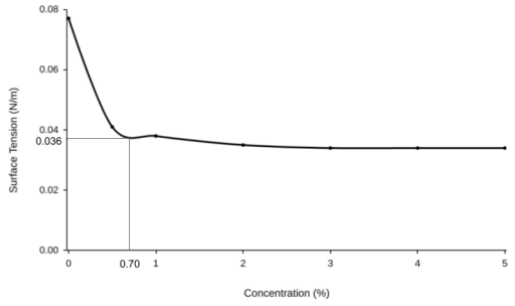


Figure 2. Average surface tension (N/m) of detergent at increasing concentrations. Surface tension decreased until the critical micelle concentration (CMC) of 0.70% was reached, after which it remained relatively constant.

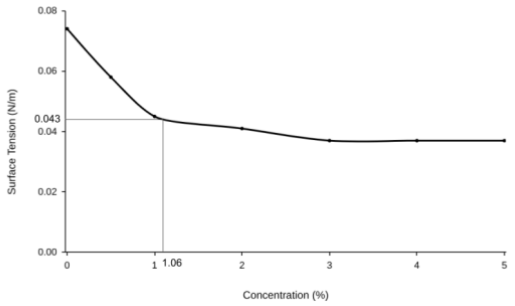


Figure 3. Average surface tension (N/m) of bio-detergent at increasing concentrations. Surface tension decreased until the critical micelle concentration (CMC) of 1.06% was reached, after which it remained relatively constant.

Comparing soapberries, detergent, and commercial bio-detergent based on their critical micelle concentration and water (control) showed that water had the highest surface tension of 0.077 N/m as expected, detergent had the lowest surface tension of 0.036 N/m, soapberry and commercial bio-detergent had similar surface tension of 0.048 N/m and 0.043 N/m, respectively, and the surface tension of soapberry and commercial bio-detergent was higher than detergent and lower than water (Figure 4). The data analysis showed that the surface tension of surfactants and water was significantly different (F-value = 7.918, p = 0.001, α = 0.05, One-Way ANOVA) and the surface tension of soapberry was significantly different from the surface tension of detergent (p = 0.022, α = 0.05, t-test) and water (control) (p = 0.035), but not significantly different from commercial bio-detergent (p = 0.429). The results of Experiment 2 showed that as the temperature increased the surface tension of all three types of surfactants and water (control) decreased; higher surface tensions were achieved at the lowest temperature of 20°C and lower surface tension was observed at 50°C–60°C (Figure 5). The results of Experiment 3 showed that as the pH level increased, the surface tension decreased for all three surfactants; higher surface tensions (0.062 N/m, 0.053 N/m, 0.0471 N/m) were observed in the acidic environment pH 4, and lower surface tensions were noted at the neutral pH 7 and basic pH 12 levels (Figure 6).

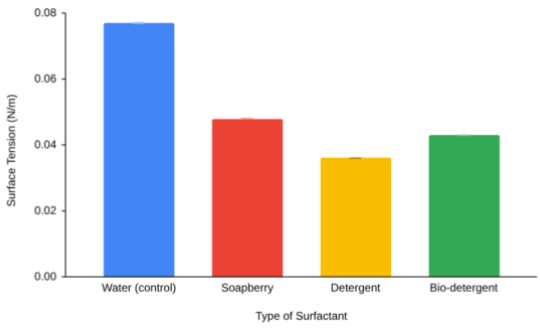


Figure 4. Average surface tension (N/m) of water (control), soapberry, detergent and bio-detergent at their respective critical micelle concentrations. Water had the highest surface tension (0.077 N/m), while detergent had the lowest (0.036 N/m); soapberry and bio-detergent had surface tensions of 0.048 N/m and 0.043 N/m, respectively.

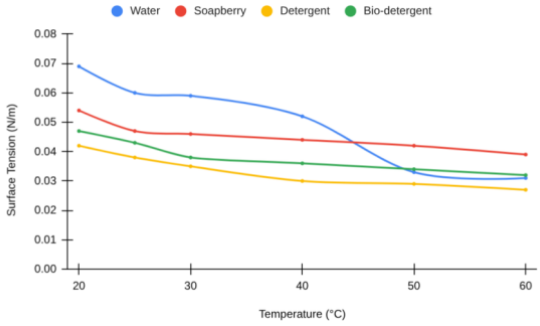


Figure 5. Average surface tension (N/m) of water (control), soapberry, detergent and bio-detergent at increasing temperatures. Surface tension decreased as temperature increased across all four substances.

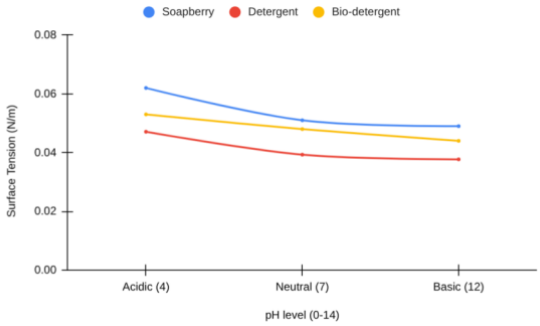


Figure 6. Average surface tension (N/m) of soapberry, detergent and bio-detergent under acidic (pH 4), neutral (pH 7) and basic (pH 12) conditions. Surface tension decreased as pH increased across all three surfactants.

DISCUSSION

The widespread use of commercial cleaning products contributes to increasing levels of environmental pollution and plastic waste, creating a need for effective and environmentally sustainable alternatives. The findings of this study support the potential of soapberry as such an alternative, suggesting that although soapberry may not provide equivalent surfactant performance to conventional detergent, it has potential as a lower-impact alternative to commercial bio-detergents.

The results supported the established inverse relationship between surfactant concentration and surface tension until the critical micelle concentration (CMC) is reached (Yuan et al., 2014). The surface tension of all three surfactants (soapberry, detergent and commercial bio-detergent) decreased as concentration increased until their respective CMC levels were reached, with the CMC of soapberry (0.65%) being close to the hypothesised and previously reported value of 0.75% (Balakrishnan et al., 2006; Kregiel et al., 2017; Rai et al., 2021). This indicated that all three substances had functioned as surfactants under the conditions tested.

The lower surface tension of detergent compared with soapberry and commercial bio-detergent was consistent with previous research showing that conventional detergents can produce greater reductions in surface tension due to their additional chemical components (Fuchs, 2015), while the similar (not significantly different) surface tension of soapberry and commercial bio-detergent was consistent with research indicating that commercial bio-detergents contain plant-based ingredients similar to those present in soapberry (Azuokwu et al., 2021). This suggests that soapberry may provide similar surfactant performance to commercial bio-detergent while avoiding the need for industrial processing and plastic packaging.

To further enhance this performance, conditions such as temperature and pH are important to consider. The observed trend of decreasing surface tension as temperature and pH increased supported the hypothesis and was consistent with previous research (Rai et al., 2021). This trend was observed across all three surfactants, as well as water (control) for temperature, suggesting that the effects of temperature and pH on surface tension are not unique to soapberry but may reflect more general effects on surfactant performance. This supports the potential for optimisation of temper-

ature and pH conditions to further improve the cleaning effectiveness of soapberry and incentivise its use.

The findings have implications for the use of soapberries as an alternative cleaning product in domestic settings. Although soapberry had lower surfactant performance than commercial detergent, its similar performance to commercial bio-detergent suggests that it may provide a lower-impact alternative to manufactured bio-detergents. This is particularly relevant given that soapberries do not require industrial processing or plastic packaging, potentially reducing the environmental impacts associated with manufactured cleaning products. The optimisation of concentration, temperature and pH conditions may further enhance the appeal and practical application of soapberry and support investigation into its use in other settings, including industrial applications such as soil and oil remediation.

The reliability of the findings was supported by the close agreement between the calculated density of water (921 kg/m^3) and its accepted value (1000 kg/m^3), as well as between the measured surface tension of water at 25°C (0.060 N/m) and its accepted value (0.071 N/m). Measurement readings were performed at eye level to minimise parallax error, and the small standard deviation and range across the data indicated consistency between repeated trials. All variables, apart from the independent variable in each experiment, were controlled, supporting the reproducibility of the results. These factors support the validity of the capillary tube method as a measure of surface tension. The presence of foam in the soapberry solution initially introduced measurement error; however, this was minimised by determining the stirring intensity that produced the least foam and maintaining the same stirring intensity and duration throughout the experiments. In addition, assuming that the contact angle θ was always equal to 0°, giving $\cos(\theta) = 1$, was a potential source of error. This could be addressed in future measurements by using a tensiometer to directly measure the contact angle and improve the accuracy of surface tension measurements.

Further research could investigate the antibacterial and antifungal properties of soapberries using agar plates and the disk diffusion method, which would allow the soapberry extract to diffuse through the agar medium. The cleaning effectiveness of soapberries could also be assessed directly using oil or soil remediation experiments under varying concentration, temperature and pH conditions. Such investigations would provide further evidence of the practical cleaning applications of soapberries beyond surface tension measurements.

CONCLUSION

This study showed that higher concentration (5%), temperature (60°C) and pH (12) of soapberry surfactant resulted in lower surface tension, indicating greater cleaning effectiveness, and that soapberry was more effective than water, less effective than commercial detergent and similarly as effective as commercial bio-detergent. These findings support the use of soapberries in both domestic and industrial applications and demonstrate their potential as an environmentally friendly cleaning alternative.

AUTHORSHIP STATEMENT

Alexandra Prokhorov: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing — Original Draft, Writing — Review & Editing, Visualization, Project administration, Funding acquisition.

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REFERENCES

Aminot, Y., Lanctôt, C., Bednarz, V., Robson, W. J., Taylor, A., Ferrier-Pagès, C., Metian, M., & Tolosa, I. (2020). Leaching of flame-retardants from polystyrene debris: Bioaccumulation and potential effects on coral. *Marine Pollution Bulletin*, *151*, 110862. https://doi.org/10.1016/j.marpolbul.2019.110862

Azuokwu, A. A., Yerima, Y., & Azike, R. U. (2021). Production and performance evaluation of biodetergents as an alternative to conventional drilling detergent. *SPE Nigeria Annual International Conference and Exhibition*. https://doi.org/10.2118/207167-MS

Balakrishnan, S., Varughese, S., & Deshpande, A. P. (2006). Micellar characterisation of saponin from Sapindus Mukorossi. *Tenside Surfactants Detergents*, *43*(5). https://doi.org/10.3139/113.100315

Couture, S. (2019). *Are corals and seafood affected by common chemicals?* International Atomic Energy Agency. https://www.iaea.org/newscenter/news/are-corals-and-seafood-affected-by-common-chemicals

Curtis, V. A. (2007). A natural history of hygiene. *Canadian Journal of Infectious Diseases and Medical Microbiology*, *18*(1), 11–14.

Fuchs, J. (2015). *How do you measure surface tension?* CTG Technical Blog. https://techblog.ctgclean.com/2015/12/measure-surface-tension

Ito, S., Kobayashi, T., Hatada, Y., & Horikoshi, K. (2005). Enzymes in modern detergents. In *Microbial enzymes and biotransformations* (pp. 151–161). https://doi.org/10.1385/1-59259-846-3:151

Kregiel, D., Berlowska, J., Witonska, I., Antolak, H., Proestos, C., Babic, M., Babic, L., & Zhang, B. (2017). Saponin-based, biological-active surfactants from plants. In *Application and characterization of surfactants*. InTech. https://doi.org/10.5772/68062

Liu, J., Wang, L., Sun, C., Xi, B., Li, D., Chen, Z., He, Q., Weng, X., & Jia, L. (2021). Global distribution of soapberries (*sapindus* L.) habitats under current and future climate scenarios. *Scientific Reports*, *11*, 19740. https://doi.org/10.1038/s41598-021-98389-8

Mackay, D., Celsie, A. K. D., Powell, D. E., & Parnis, M. J. (2018). Bioconcentration, bioaccumulation, biomagnification and trophic magnification: A modelling perspective. *Environmental Science: Processes & Impacts*, *20*, 72–85. https://doi.org/10.1039/C7EM00485K

Maity, J. P., Huang, Y.-M., Hsu, C.-M., Wu, C.-I., Chen, C.-C., Li, C.-Y., Jean, J.-S., Chang, Y.-F., & Chen, C.-Y. (2013). Removal of Cu, Pb and Zn by foam fractionation and a soil washing process from contaminated industrial soils using soapberry-derived saponin: A comparative effectiveness assessment. *Chemosphere*, *92*(10). https://doi.org/10.1016/j.chemosphere.2013.04.060

Only 1 Earth. (2022). *Soapberries*. Only 1 Earth. https://www.onlyoneearthaus.com.au/products/soapberries

Rai, S., Acharya-Siwakoti, E., Kafle, A., Devkota, H. P., & Bhattarai, A. (2021). Plant-derived saponins: A review of their surfactant properties and applications. *Sci*, *3*(4), 44. https://doi.org/10.3390/sci3040044

Statista. (2024). *Household cleaners: Market data & analysis*. Statista. https://www.statista.com/study/48841/household-cleaners-market-data-and-analysis/

World Health Organization. (2025). *Exposure to lead: A major public health concern. Preventing disease through healthy environments*. World Health Organization. https://www.who.int/publications/i/item/9789240112384

Yuan, C. L., Xu, Z. Z., Fan, M. X., Liu, H. Y., Xie, Y. H., & Zhu, T. (2014). Study on characteristics and harm of surfactants. *Journal of Chemical and Pharmaceutical Research*, *6*(7), 2233–2237. https://www.jocpr.com/articles/study-on-characteristics-and-harm-of-surfactants.pdf

Yueh, M.-F., & Tukey, R. H. (2016). Triclosan: A widespread environmental toxicant with many biological effects. *Annual Review of Pharmacology and Toxicology*, *56*(1), 251–272. https://doi.org/10.1146/annurev-pharmtox-010715-103417