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ZESTPEN: ASSESSING *CITRUS MICROCARPA* (CALAMANSI) AS A STAIN REMOVER ON OXIDIZABLE, GREASY, AND ENZYMATIC

Kaizer Vaughn J. Escamillan[1], Jose Gabriel P. Clapano[1], Seanne Lalaine San Diego[1], Jean Clariz L. Siglos[1], Wali Abdul Ontawar[1], Jexel Jerkin Pedrosa[2], Justine Ramos[2]

[1]Student, Senior High Student, Colegio de San Juan de Letran-Manila
[2]Faculty Member, Colegio de San Juan de Letran-Manila
Corresponding author. Email: kaizervaughn.escamillan@letran.edu.ph

ABSTRACT

The study evaluated the efficacy of *Citrus Microcarpa*, or calamansi, extract as a natural stain remover for oxidizable, greasy, and enzymatic stains on cotton and polyester fabrics, with the purpose of offering an environmentally friendly alternative solution to commercial chemical cleaners. An experimental design was used, wherein four calamansi-based formulations were tested in a pen-like applicator. Stain removal was quantified through spectrophotometer and digital image analysis, while consistency was checked through standard deviations across replicates. Each solution showed a different level of effectiveness. 75% calamansi formulation was the most consistent for enzymatic stains on both fabrics; 50% formulation performed best for oxidizable stains on cotton, while 100% calamansi did better on polyester; 1:1 calamansi: vinegar performed best for greasy stains. Given this scenario, it has been found that formulations provide good performance. The extract from calamansi is a viable natural stain remover, which can be used in an eco-friendly way, although making it better shall differ depending on the type of stain and fabric. It helps us use fewer harmful chemicals, which matches many consumers' preference for eco-friendly products. However, the study recommends further research on long-term effects and broader applications.

Keywords: *Calamansi, stain remover, oxidizable, greasy, enzymatic, natural cleaning agent, eco-friendly*

INTRODUCTION

Background of the Study

The Philippines processes tons of calamansi yearly. Up to 70% of each fruit's weight becomes waste as peels, seeds, and pulp. This volume strains local landfills and waste systems (Philippine Rural Development Program, 2023). Calamansi acts as a natural solvent due to its high citric acid content. Researchers report 99.86% effectiveness in removing pen ink and other stains (Alarcon et al., 2024).

This study develops a portable stain remover pen from calamansi extract. It converts agricultural waste into a practical product. Users apply it directly to stains on clothes or surfaces. The pen cuts reliance on synthetic chemicals, which harm waterways and soil.

Calamansi *(Citrus Microcarpa)* is a small citrus fruit with green to yellow-orange skin. Farmers cultivate it across the Philippines and in southern China, Taiwan, northern Borneo, and Indonesia. The fruit passes through nine development phases. It reaches commercial maturity in 78 to 84 days from flower opening (Rosillo-Magno & Mapalo, 2018, as cited in Venkatachalam et al., 2023). Calamansi removes stains and adds a fresh scent (Nunez, 2020).

Studies promote citric acid from citrus peels over chemical bleaches. Lemon peel powder works well. A 100-gram dose removes stains from cotton fabric in 2 minutes. It brightens colors without weakening fibers or causing discoloration, unlike bleach (Kamaruzaman, 2024).

Filipino consumers favor sustainable options. A 2023 Pulse Asia survey shows over 80% prefer eco-friendly products. This trend spans urban and rural areas. People seek items that limit pollution in daily use (Pulse Asia, 2023, as cited in Argosino, 2023).

The Tide To Go pen provides the model for this design. It targets fresh stains from food and drinks, such as tomato juice, ketchup, barbecue sauce, grape juice, coffee, wine, tea, and chocolate syrup. Users press the tip and rub gently. Hydrogen peroxide targets stain pigments at the molecular level. Surfactants and detergents lift residues. Water dilutes, and magnesium sulfate stabilizes the formula.

Researchers study citric acid and citrus cleaners. Yet no work tests calamansi extract in a pen applicator. Existing tests use calamansi-vinegar soaks, not quick spot treatments under real conditions (Alarcon et al., 2024). Calamansi gets less attention in the Philippines than imported lemons or oranges. Studies skip tests on repeated use effects on fabrics, soil health, water quality, and non-recyclable packaging.

Objectives of the Study

This study aims to determine the effectiveness of calamansi in removing common stains in a pen-like structure. (1) To assess the effectiveness of calamansi extract in removing different types of common stains (oxidisable, greasy, and enzymatic) from fabric. (2) To determine the consistency of calamansi extract in removing common stains from fabric. (3) To test the effectiveness of calamansi extract at different concentrations and to identify the most efficient formulation for stain removal.

Literature Review

Nature and composition of enzymatic, greasy, and oxidizable stains

Masson and Lushchekina (2022) explain that proteins maintain structure through hydrogen bonds, hydrophobic interactions, electrostatic forces, and disulfide bridges. Heat denatures proteins by breaking these bonds. Unfolded proteins resist water dissolution.

Fazio Cleaners (2025) lists common enzymatic stains as blood, sweat, dairy products, egg, and baby food. Cold water removes these stains. Hot water hardens them permanently.

Jangra et al. (2023), LibreTexts (2022), Thompson (2025), Gadkari (2025), Chemical Safety Facts (2023), and Kipgen et al. (2021) show that different stains require specific treatments. Oil stains need surfactants to emulsify grease. Oxidizable stains like coffee break through oxidation. Enzymatic stains demand targeted enzymes. Apple cider vinegar removes pigment stains. Baking soda-vinegar mixtures handle oxidizable and enzymatic stains among naturals. Commercial detergents outperform all alternatives. Lipids resist water due to hydrophobicity. Cosmetics form waterproof films with polymers and acrylates.

Common stains are substances that react differently with fabrics based on their molecular composition and structural properties. In this study, the researchers focused on the following types of stains: enzymatic stains, greasy stains, and oxidisable stains. The nature and composition of enzymatic, oil, and oxidizable stains significantly influence their behavior on fabrics and their response to cleaning methods. Together, these findings emphasize the need for targeted cleaning strategies that consider stain composition and fabric type to enhance removal effectiveness while minimizing damage to textile materials.

Disadvantages of commercial stain removers in the market

Straits Research (2023) states that commercial removers contain benzene, toluene, formaldehyde, perchloroethylene, and butyl cellosolve. These chemicals cause respiratory problems, skin irritation, neurological damage, blood disorders, and cancer risks.

Scrub n Shine (2022) and Pawar et al. (2025) report that chlorine bleach weakens cellulose fibers in cotton and linen. It causes fraying, holes, yellowing, and color fading. Oxygen bleaches damage delicate textiles. Solvents strip dyes and create brittleness.

Smart Sheep Dryer Balls (2023) and Jaydeep et al. (2025) note that ammonia, phthalates, and trichloroethylene irritate skin and pollute waterways. Enzyme detergents target proteins. Surfactants lift grease. Both degrade fabrics long-term and harm aquatic ecosystems.

Recent sources indicate that while traditional stain removers effectively target specific stains such as proteins and oils, their chemical properties pose risks to both fabric integrity and the environment. Moreover, many conventional stain removers contain hazardous substances like chlorine bleach, ammonia, phthalates, benzene, and formaldehyde. These findings show the need for safer, eco-friendly alternatives as consumer awareness drives the industry toward more sustainable formulation.

Calamansi's chemical composition and applications

Alarcon et al. (2025) identify calamansi juice components as 5.5% citric acid, ascorbic acid, sugars, limonene, and phenolics. Citric acid bleaches mildly and chelates ink, rust, and coffee stains. Ascorbic acid reduces pigments.

Lim and Torres (2025), PMC (2022), and Dela Cruz (2019) find calamansi peel oils containing 65.6% D-limonene and terpenes. These compounds show strong antibacterial activity. Citrus oils deodorize, whiten skin, and fight germs in cleaners. Leaf extracts repel mosquitoes.

Calamansi provides multiple cleaning benefits through citric acid, D-limonene, and other compounds. These natural properties position it as a sustainable replacement for synthetic chemicals in household products.

Effects of natural acids and enzymes on fabrics

Samanta et al. (2017) and Santiago et al. (2023) demonstrate that citric acid cross-links cellulose through ester bonds. It fixes dyes, provides UV protection, reduces wrinkles, and adds antimicrobial properties. Citric acid improves heat stability.

Wu et al. (2021) and Antunes et al. (2025) show cellulase enzymes biopolish by hydrolyzing surface fibrils. This creates smoother fabrics with better drape and abrasion resistance. Chitosan-citric treatments yield superior antibacterial durability.

Natural acids and enzymes improve fabric performance through chemical bonding and surface modification. These treatments offer sustainable alternatives to harsh chemicals while enhancing durability and functionality.

Vinegar as acid neutralizer and stain remover

GeeksforGeeks (2023) describes vinegar as 4-8% acetic acid with pH 2-3. This acidity neutralizes alkaline stains from soaps and minerals by forming soluble salts.

Sinochem International Corporation (2023) explains that acetic acid dissolves mineral deposits, emulsifies grease, and inhibits bacterial growth on surfaces.

Vinegar effectively neutralizes alkaline residues and breaks down grease through acetic acid's chemical properties. It serves as a safe, accessible cleaning agent for household stains.

Water as stain dissolver

Tsompou and Kocherbitov (2022) found pure water removes hydrophobic films through low ionic strength and roll-up mechanism. Ultrapure water lifts 90% of Vaseline layers. Tap water achieves 75% removal.

Water self-ionizes into H^+ and OH^- ions to adjust pH for water-soluble stains. Polarity disperses both hydrophilic and hydrophobic substances when paired with emulsifiers.

Water's physical and chemical properties enable effective stain loosening without additives. Pure water maximizes removal through reduced surface adhesion and ion interactions.

Research Framework

Theoretical framework

The acid-based stain removal theory. The foundation for using calamansi extract as a stain remover lies in acid-based chemistry and the natural interaction of acids with fabric fibers and staining compounds (Antonio et al., 2024).

Students from GOA Science High School (2025) conducted research titled, "Sustainable Cleaning Alternatives: The Role of Calamansi (Citrofortunella microcarpa) in Stain Removal." According to their findings, the most effective calamansi-vingar formulation ratio for stain removal was the 1:2 ratio—1 part calamansi to 2 parts vinegar—across all the textile types that they chose (cotton, polyester, and terry cloth). Moreover, students from Miriam College High School (2017) conducted a similar research titled, "The Effects of Varying Concentration on the Efficiency of Calamansi and Lemon Juice as a Stain Remover." They concluded that higher concentrations of calamansi juice produce greater efficiency in stain removal.

Conceptual framework

This research assesses the efficiency of calamansi *(Citrus microcarpa)* as a natural stain remover. Firstly, the researchers will extract the calamansi's juice and peels to create different formulations for stain removal. To determine the most effective stain-removal formulation, the researchers will conduct four tests that requires removing specific stains on particular fabrics. The researchers will use the 4 formulations to determine the most consistent and effective formulation for the fabrics and stains and will analyze the stain behavior on fabrics and the solution. Lastly, we will assess the ideal calamansi formulation, measure its efficiency using a spectrophotometer and digital image assessment.

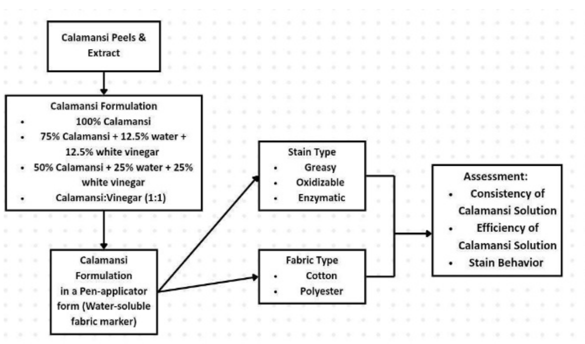

Figure 1. Conceptual framework of the study

Scope and Limitations

The study focuses on the effectiveness of calamansi extract in removing stains on cotton and polyester fabrics. It will test calamansi on three types of stains: enzymatic (chocolate), oxidizable (coffee), and greasy (cosmetic products). Different strengths of calamansi formulation will be prepared to see how concentration affects cleaning. Stains will be applied using a marker pen to keep the amount of stain the same on all fabrics. To avoid color differences affecting the results, only white fabrics will be used. The changes in stain removal will be measured using a spectrometer, a device that checks color changes accurately.

This study has several limitations. The research will only focus on a specific range of fabrics and stains; thus, results may not show the efficiency of calamansi on other types of stains or fabrics. The researchers will also not conduct a study that will measure stains that have been on the fabric longer than 30 minutes or stains that have set into the fabric. The study will not be covering the long-term effects of repeated use of calamansi on fabric quality, such as fading or weakening of fibers. The researchers will also not record the time it took in removing the stains. Tie-dye apparel is excluded from the study because its color processing might interfere with the authenticity of stain removal outcomes and weaken the uniformity of results. The freshness and availability of calamansi utilized in the experiment can also affect its efficacy because variations in acidity and concentration of juice may exist, and its peel. Lastly, this study does not consider the fabric in different kinds of temperatures.

Scientific experiments and procedures will take place in a controlled laboratory setting for convenience, accessibility, and safety. These limitations indicate that calamansi has potential as an environmentally friendly stain remover, but more studies are needed to establish its efficacy on wider fabric types, stain types, and domestic conditions.

METHODOLOGY

Research Design

Our research design will use an experimental design. According to Marcus (2022), experimental design is a research method in which researchers manipulate an independent variable, apply it to subjects, and observe its effects on the dependent variable while controlling other factors. This design fits the study because it aims to assess calamansi extract and juice as a natural stain remover.

The study uses an experimental design with a quantitative approach because it involves measurable data, such as the percentage of stain removed from the fabric and the amount of calamansi extract needed to create the ideal cleaning formulation.

Procedures

The procedure began with the preparation of the calamansi formulation. Fresh calamansi fruits were washed, cut, and juiced using a manual press or citrus juicer. The extracted juice was filtered through cheesecloth to remove seeds and pulp, producing a clear solution. Four different 50 mL formulations were then prepared: 100% calamansi; 75% calamansi with 12.5% distilled water and 12.5% white vinegar; 50% calamansi with 25% distilled water and 25% white vinegar; and a 1:1 ratio of calamansi and white vinegar. Each formulation was measured using graduated cylinders and transferred into labeled pen applicators.

For the preparation of fabric swatches, baseline measurements were first obtained by recording the Lab values of clean, unstained white cotton and white polyester fabrics using a spectrophotometer. The fabrics were then cut into 2 × 2-inch swatches, with three duplicates prepared for each fabric type to ensure reliability of results. Each swatch was labeled according to fabric type, stain type, and formulation to be applied.

In the application of stains, a fixed amount of 2 mL per stain type was applied at the center of each fabric swatch. Three duplicates were also prepared per stain type for each fabric. After application, the stains were allowed to sit for two minutes. Post-staining measurements were then taken using a spectrophotometer to record the initial stain appearance.

For the treatment phase using the Zestpen, the assigned formulation was applied to each stained swatch using the pen applicator and gently rubbed for 10 seconds. Three duplicates were treated for each formulation across all fabric and stain combinations. After treatment and washing, post-treatment measurements were conducted using a spectrophotometer to evaluate stain removal effectiveness.

Finally, observation and recording were carried out through both spectrophotometric and digital image analysis. Absorbance data were recorded at three stages: baseline (clean), stained (before treatment), and post-treatment. At least three readings were taken per swatch and averaged to ensure accuracy. Additionally, high-resolution photographs of each sample were captured and analyzed using ImageJ software. The collected data were tabulated, and stain removal percentages were computed. Statistical measures such as averages and standard deviations were calculated to compare the effectiveness of each formulation.

Statistical Treatment

The statistical treatment of the study incorporated digital image processing using ImageJ, a freely available scientific image analysis software, to objectively quantify stain removal. High-resolution photographs of each fabric sample—clean, stained, and treated—were captured under standardized conditions, specifically using 5500K lighting and a neutral gray background to ensure consistency. All images were saved, properly labeled (e.g., Cotton_Enzymatic_1_Stained), and systematically organized into folders prior to analysis.

For image processing, each file was opened in ImageJ and converted into grayscale through the RGB Stack function to enhance contrast and isolate stain features. For irregular stains, thresholding was applied to automatically identify the region of interest (ROI), representing the stained area. The selection was refined using freehand or polygon tools to ensure accurate boundary tracing. The software's measurement function was then used to obtain quantitative data, including area, mean pixel intensity, minimum and maximum intensity, and perimeter. This process was repeated for all samples, including clean, stained (untreated), and treated fabrics, with at least three trials conducted per condition to ensure reliability.

The stain removal percentage was calculated using the mean intensity values obtained from the images, comparing treated samples against stained and clean baselines. If automatic thresholding did not accurately capture irregular stain regions, manual outlining was employed as an alternative approach. All collected data were tabulated, and statistical measures such as averages and standard deviations were computed to evaluate variability and compare the effectiveness of each treatment formulation. This method provided a quantitative and reproducible basis for assessing stain removal performance across different fabric types and treatment conditions.

Spectrophotometric Analysis

For spectrophotometric data, manual computation was performed. The absorbance values (Abs) were measured using a colorimeter/spectrophotometer for each sample, and descriptive statistics were calculated as follows:

For each solution, stain type, and fabric, absorbance values from three replicate trials were recorded. The mean absorbance was calculated as the arithmetic average of the three trials:

$$\boldsymbol{Mean} = \frac{\sum_{i=1}^{n} Xi}{n}$$

Where Xi is the absorbance value from each trial, and n is the number of trials. The standard deviation (SD) was computed using:

$$\boldsymbol{SD} = \sqrt{\frac{\sum_{i=1}^{n}(Xi - Mean)2}{n-1}}$$

To indicate the variability of absorbance values across trials for each group. All descriptive statistics (mean, median, mode, SD) for each treatment group (defined by stain type, fabric, and solution) were compiled into summary tables to facilitate interpretation and comparison. Statistical calculations were processed with either basic spreadsheet software or manual calculator techniques, ensuring accuracy through independent double-checking by the researchers.

This dual approach—using digital imaging for quantitative assessment and spectrophotometry for quantitative readings—helps reinforce the robustness of the findings

Ethical Considerations

The study on the stain removal efficacy of calamansi extract was conducted in strict adherence to ethical principles to ensure integrity, safety, and responsibility throughout the research process. Honest reporting and accuracy were upheld by carefully performing all experimental procedures and transparently analyzing and presenting the data without fabrication, falsification, or misinterpretation, thereby maintaining scientific credibility. The research also emphasized safety and environmental care by utilizing natural, biodegradable materials such as calamansi juice and vinegar, minimizing potential harm to researchers and reducing environmental impact; all waste materials were properly disposed of, and standard laboratory safety protocols were followed.

Respect for intellectual property was observed through proper citation of related studies, data, and sources, ensuring that all original authors received appropriate credit and that academic integrity was maintained. Furthermore, transparency and reproducibility were ensured by providing detailed documentation of the methodology, including formulations and treatment procedures, allowing other researchers to replicate and validate the findings. Lastly, the study recognized its broader societal responsibility by promoting sustainability and contributing to the development of safer, eco-friendly alternatives to chemical-based cleaning agents, aligning the research with the goal of supporting public health and environmental well-being. Collectively, these ethical considerations guided the study in upholding responsible scientific conduct while advancing green and effective cleaning solutions.

RESULTS AND DISCUSSION

Consistency of the Calamansi Formulation The theme covers the most consistent formulations among our data—formulations that had the lowest standard deviations using both spectrophotometer and digital image processing methods.

Standard Deviation shows the variation of stain-removal results across repeated trials for the same formulation and fabric. Meaning, a low standard deviation reflects that the experiment produced very consistent results. Nearly the same stain removal efficiency was observed every time it was tested for that category.

Table 1. Consistency of Stain Removal Across Calamansi Solution Formulations

Category	Formulation	Standard Deviation
Cotton -Enzymatic	75% Calamansi	0.0679
Cotton- Oxidizable	50% Calamansi formulation	0.0370
Cotton - Greasy	Calamansi: Vinegar (1:1)	0.1727
Polyester - Enzymatic	75% Calamansi formulation	0.0660
Polyester - Oxidizable	100% Calamansi	0.0381
Polyester - Greasy	Calamansi: Vinegar (1:1)	0.1372

Note: Spectrophotometer 1.1

Table 1 shows the 100% Calamansi formulation for the Polyester fabric and Oxidizable stains was the most consistent formulation.

Table 2. Consistency of Stain Removal Across Calamansi Solution Formulations

Category	Formulation	Standard Deviation
Cotton - Oxidizable	Calamansi: Vinegar (1:1)	0.18
Polyester - Oxidizable	Calamansi: Vinegar (1:1)	0.63
Cotton - Greasy	50% Calamansi Formulation	0.63
Cotton - Greasy	Calamansi: Vinegar (1:1)	0.71
Polyester - Greasy	50% Calamansi Formulation	0.62

Note: Digital Image Processing 1.1

Table 2 indicates the 1:1 Calamansi: Vinegar formulation was most consistent for oxidizable stains on cotton

Stain removal capacity of Calamansi formulation

Spectrophotometer readings supplied objective mean absorbance values for key fabric stain formulation categories. Lower absorbance numbers reflect greater stain removal, confirming and quantifying visual improvements seen with image analysis.

Stain removal with calamansi is confirmed by both image-analysis and spectrophotometry; the first shows how much stain disappears visibly, and the second measures how much remains chemically.

Table 3. Best Mean Absorbance

Category	Formulation	Standard Deviation
Cotton -Enzymatic	50% Calamansi	1.1847
Cotton - Oxidizable	75% Calamansi formulation	1.0773
Cotton - Greasy	Calamansi: Vinegar (1:1)	1.0917
Polyester - Enzymatic	50% Calamansi Formulation	1.4467
Polyester - Oxidizable	75% Calamansi	0.8597
Polyester - Greasy	Calamansi : Vinegar (1:1)	1.1587

Note: Spectrophotometer 2.1

Table 3 reveals the 75% Calamansi formulation had the lowest absorbance (0.8597) for oxidizable stains on polyester, indicating best spectrophotometric performance.

Table 4. Best Mean Absorbance

Category	Formulation	Standard Deviation
Cotton -Enzymatic	50% Calamansi formulation	68.46
Cotton -Enzymatic	75% Calamansi formulation	57.96
Polyester - Enzymatic	Calamansi: Vinegar (1:1)	43.30
Polyester - Enzymatic	50% Calamansi Formulation	29.90
Cotton - Oxidizable	75% Calamansi	78.96

Note: Digital Image Processing 2.1

Table 4 shows the 75% Calamansi formulation achieved the highest stain removal for oxidizable stains on cotton.

Behavior of stains after applying the Calamansi formulation

Table 5. Behavior of Enzymatic Stains on Cotton and Polyester Fabrics After Applying Calamansi Formulation

Fabric	Formulation	Standard Deviation	Mean
Cotton	100% Calamansi:	0.4135	1.3157
Polyester	100% Calamansi:	0.0971	1.6467
Cotton	75% Calamansi	0.0679	1.2973
Polyester	75% Calamansi	0.0660	1.7207
Cotton	50% Calamansi	0.1074	1.1847
Polyester	50% Calamansi	0.1170	1.4467
Cotton	Calamansi: Vinegar (1:1)	0.2651	1.2863
Polyester	Calamansi: Vinegar (1:1)	0.1452	1.5230

Note: Spectrophotometer 3.1

Table 5. Behavior of Enzymatic Stains on Cotton and Polyester Fabrics After Applying Calamansi Formulation

Fabric	Formulation	Standard Deviation	Mean
Cotton	100% Calamansi:	.2766	68.46
Polyester	100% Calamansi:	.4999	7.39
Cotton	75% Calamansi	.1973	57.96
Polyester	75% Calamansi	.1478	43.30
Cotton	50% Calamansi	3.51	9.83
Polyester	50% Calamansi	1.94	15.43
Cotton	Calamansi: Vinegar (1:1)	2.99	7.76
Polyester	Calamansi: Vinegar (1:1)	6.99	29.50

Note: Spectrophotometer 3.1

Enzymatic stains (Tables 5 and 6), primarily composed of proteins, are affected by acidity and enzymatic action. Cotton showed lower absorbance (1.1847 with 50% formulation) than polyester (1.4467) due to cellulose's hydrophilic nature facilitating protein denaturation, while polyester's hydrophobic polymers resisted acid penetration (Samanta et al., 2017). The 50% and 75% formulations outperformed 100% calamansi (1.3157 on cotton) because dilution with water and vinegar reduced excessive acidity that could cause protein coagulation, optimizing pH for enzymatic breakdown (Masson & Lushchekina, 2022).

Table 7. Behavior of Oxidizable Stains on Cotton and Polyester Fabrics After Applying Calamansi Formulation

Fabric	Formulation	Standard Deviation	Mean
Cotton	100% Calamansi:	0.0535	1.3657
Polyester	100% Calamansi:	0.0381	1.1607
Cotton	75% Calamansi	0.0440	1.0773
Polyester	75% Calamansi	0.5863	0.8597
Cotton	50% Calamansi	0.0370	1.2270
Polyester	50% Calamansi	0.6361	1.3357
Cotton	Calamansi: Vinegar (1:1)	0.1217	1.3397
Polyester	Calamansi: Vinegar (1:1)	0.1296	1.0980

Note: Spectrophotometer 3.2

Table 8. Behavior of Oxidizable Stains on Cotton and Polyester Fabrics After Applying Calamansi Formulation

Fabric	Formulation	Standard Deviation	Mean
Cotton	100% Calamansi:	.5756	78.96
Polyester	100% Calamansi:	.0113	11.76
Cotton	75% Calamansi	.0179	7.94
Polyester	75% Calamansi	.0113	13.64
Cotton	50% Calamansi	.0120	6.27
Polyester	50% Calamansi	.0134	9.54
Cotton	Calamansi: Vinegar (1:1)	.0018	4.56
Polyester	Calamansi: Vinegar (1:1)	.0063	12.46

Note: Digital Image Processing 3.2

Oxidizable stains (Tables 7 and 8), such as coffee and tea tannins, bind differently due to their molecular interactions. Cotton's hydrophilic cellulose allows better uptake of acidic solutions like the 75% calamansi formula, enabling effective oxidation and stain breakdown. Polyester's hydrophobic surface repels water-based treatments but can benefit from limonene's solvent action present in calamansi oil, which helps dissolve stain molecules despite lower absorbency (Jangra et al., 2023; Alarcon et al., 2025).

Polyester achieved lower absorbance (0.8597 with 75% formulation) than cotton (1.0773) as its smooth synthetic surface enabled better tannin oxidation contact, whereas cotton's absorbency diluted oxidizing agents (Jangra et al., 2023). Diluted formulations (75%, 50%) surpassed 100% calamansi by balancing citric acid concentration to prevent over-oxidation that precipitates tannins, with vinegar enhancing chelation (Kamaruzaman, 2024).

Table 9. Behavior of Greasy Stains on Cotton and Polyester Fabrics After Applying Calamansi Formulation

Fabric	Formulation	Standard Deviation	Mean
Cotton	100% Calamansi:	0.1861	1.1523
Polyester	100% Calamansi:	0.2949	1.3973
Cotton	75% Calamansi	0.3222	1.2437
Polyester	75% Calamansi	0.5423	1.2073
Cotton	50% Calamansi	0.3350	1.1777
Polyester	50% Calamansi	0.6336	1.8413
Cotton	Calamansi: Vinegar (1:1)	0.1727	1.0917
Polyester	Calamansi: Vinegar (1:1)	0.1372	1.1587

Note: Spectrophotometer 3.3

Table 10. Behavior of Greasy Stains on Cotton and Polyester Fabrics After Applying Calamansi Formulation

Fabric	Formulation	Standard Deviation	Mean
Cotton	100% Calamansi:	.0459	9.80
Polyester	100% Calamansi:	.0150	15.50
Cotton	75% Calamansi	.0239	6.55
Polyester	75% Calamansi	.0076	17.33
Cotton	50% Calamansi	.0063	6.20
Polyester	50% Calamansi	.0062	15.25
Cotton	Calamansi: Vinegar (1:1)	.0071	6.62
Polyester	Calamansi: Vinegar (1:1)	.0076	16.08

Note: Spectrophotometer 3.3

For greasy stains (Tables 9 and 10), the presence of D-limonene, a natural solvent in calamansi, plays a significant role. Limonene's lipid-dissolving properties penetrate the oily deposits more efficiently on polyester because its nonpolar, hydrophobic nature aligns better with greasy substances, allowing higher stain removal percentages. In contrast, cotton's porous structure tends to absorb both the stain and the cleaning solution, which can reduce the direct solvent effect on grease (Thomas Thompson, 2025; LibreTexts, 2022).

Polyester demonstrated higher removal (15.50%-17.33%) than cotton (6.20%-9.80%) because its nonpolar surface allowed lipid solvents to emulsify cosmetic oils effectively, while cotton trapped grease within fibers (Thompson, 2025; LibreTexts, 2022). The 1:1 calamansi:vinegar ratio exceeded 100% calamansi as acetic acid synergized with D-limonene to lower surface tension, improving grease penetration over pure citrus oil's limited solvency (Sinochem International Corporation, 2023).

Pure 100% calamansi exhibited higher variability (SD 0.4135, Table 5) due to inconsistent acid strength causing fabric saturation. Water-vinegar dilution optimized viscosity for pen application, stabilized pH to prevent stain re-precipitation, and enhanced surfactant action through acetic-citric acid synergy, reducing absorbance across all stain-fabric combinations (Alarcon et. al., 2025).

CONCLUSION

This study aims to investigate the efficacy of different calamansi extract formulations in remediating oxidizable, greasy, and enzymatic stains on cotton and polyester fabrics. This research endeavors to establish whether calamansi serves as a viable alternative natural stain remover and determines the optimal formulation ratio for various types of stains. Experimental results showed that calamansi-based solutions exhibit different efficacies based on solution composition and stain and fabric substrate types.

Three types of stains—enzymatic, oxidizable, and greasy—were tested with four different calamansi solution formulations: 100% calamansi, 75% calamansi + water + vinegar, 50% calamansi + water + vinegar, and 1:1 calamansi:vinegar. In these tests, certain solution–stain–fabric combinations exhibited lower mean absorbance values and higher consistency of results, suggesting that formulation design might be optimized for specific cleaning scenarios.

Stain behavior on calamansi solutions is consistent with the underlying theory that the principal acidic compounds in calamansi, namely citric acid and ascorbic acid, along with D-limonene, interact with the stain molecules differently with respect to their chemistry. Results from this study indicate that calamansi-based formulations provide a viable method for removing stains; however, the mechanism and efficiency are highly dependent upon several factors such as solution ratio, stain composition, and type of fiber used.

The current research opens up opportunities for further studies on natural cleaning alternatives that address the concerns of environmental sustainability and customer preference. Further work may solidify how these laboratory results would translate into real-world household conditions and long-term fabric safety.

Recommendations

Considering the patterns observed in stain response and the objectives of this research, further investigation into the application and effectiveness of calamansi-based formulations on a greater range of stains and fabrics would be useful.

Further testing of such variables as stain age, colored textiles, and everyday usage environments can yield more specific insights into practical applications and the limitations that exist for natural stain removers developed from calamansi.

Focus more research into the long-term effects of repeated calamansi solution use on fabric quality and scalability/accessibility of production may provide further clarification on broader impacts. The results so far suggest different formulations and usage conditions are worth considering in real-world settings, particularly as part of efforts to offer safer and more sustainable household cleaning options.

Conduct comparative studies between calamansi based formulations and conventional chemical stain removers regarding effectiveness, safety, and cost to better position natural alternatives in the market.

Explore blends with other essential oils. This adds value by improving product appeal and user satisfaction while retaining natural and sustainable qualities.

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