

THE HORIZON

**The Official Scholarly Journal of
High School Students**

THE HORIZON

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DEVELOPMENT OF A REFLECTIVE PAINT USING EGGSHELL POWDER FOR REDUCING INDOOR TEMPERATURES

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ABSTRACT

This study investigates the development and thermal performance of an eco-friendly reflective paint utilizing eggshell powder as a sustainable, waste-derived pigment to mitigate heat accumulation in roofing materials. Three experimental paint formulations with 15%, 30%, and 50% eggshell concentrations were created and evaluated alongside a commercial reflective paint and an unpainted control roofing sheet. Statistical analysis using a One-Way ANOVA confirmed the overall efficacy of the eggshell coatings: a highly significant difference ($P < 0.001$) was found in the Cooling Differential when comparing all five treatments, demonstrating that the eggshell paint coatings successfully utilized the eggshell's calcium carbonate (CaCO_3) to achieve high Solar Reflectance and significantly outperformed the unpainted control in reducing heat transmission. Crucially, an ANOVA comparing the three eggshell ratios (15%, 30%, 50%) revealed no significant difference in thermal performance ($P = 0.539$), indicating thermal equivalence across the concentrations; this means that increasing the eggshell ratio does not yield a statistically superior cooling effect. Descriptively, the 15% Eggshell Paint formulation recorded the highest mean cooling differential at 6.74°C , confirming its status as the most resource-efficient option. The study concludes that eggshell waste is a viable and effective additive for creating cool coatings. Future research is recommended to shift focus from basic thermal testing to quantifying the international standard Solar Reflectance Index (SRI) and assessing durability, adhesion strength, and rain performance to definitively determine the optimal formulation for long-term use.

Keywords: Eggshell powder, reflective paint, solar reflectance, thermal performance, sustainable materials

INTRODUCTION

Background of the Study

The continued rise in global temperatures and shifting weather patterns driven by climate change have created an urgent need for sustainable cooling solutions for every household. According to the Intergovernmental Panel on Climate Change (IPCC) in 2022, the global average surface temperature rose by about 1.1°C above pre-industrial levels, which in turn has intensified extreme heat events worldwide. In tropical countries like the Philippines, these extreme conditions are further heightened due to the country's climate, which allows heat to accumulate quickly inside homes. The World Health Organization (WHO, 2024) reported that indoor heat not only causes discomfort for many Filipinos but also poses health risks such as stress, fatigue, dehydration, and even heat stroke. Poor urban communities are especially vulnerable due to weak and low-quality housing materials.

Because of this, households and commercial buildings in the Philippines spend a large portion of their income on electricity for cooling appliances such as electric fans and air-conditioning units. During the dry season, residential electricity consumption in Metro Manila increases significantly due to greater use of cooling systems (DOE, 2025). However, this dependence on mechanical cooling also contributes to higher carbon emissions.

Various passive cooling technologies exist to help minimize indoor overheating, such as cool roofs, green walls, and reflective coatings.

Among these, reflective paint stands out as the most economical and practical solution. Reflective paint reduces surface and indoor temperatures by reflecting more of the incoming solar radiation, preventing excessive heat from being absorbed by roofing and wall materials.

Global research demonstrates the effectiveness of reflective coatings in lowering temperatures. A pilot project in Singapore by NTU (2024) showed that applying reflective paint on building facades, rooftops, and even road surfaces resulted in surface and indoor temperatures up to 2°C cooler, with residents reporting that treated areas felt around 1.5°C more comfortable. Laboratory experiments further support these findings. Mishra et al. (2024), for example, created a TiO_2/PDMS reflective paint that achieved 94% solar reflectance, reducing temperatures by about 8°C inside aluminum test boxes coated with the material. These results highlight the strong potential of highly reflective paints to maintain cooler surfaces even under intense sunlight.

Aside from these technological advances, researchers are also exploring sustainable and eco-friendly additives to improve reflectance. One promising material is eggshell, an abundant household waste composed mainly of calcium carbonate (CaCO_3), a naturally white, highly light-scattering mineral. Composite material studies (Kamath & Chandrappa, 2021) emphasize that eggshell powder can enhance mechanical and reflective properties when incorporated into coatings. Tao et al. (2020) further noted that CaCO_3 increases whiteness and light scattering, key characteristics that

enhance reflectance and surface brightness.

With the Philippine context in mind, this research is especially relevant given the robust growth of the poultry subsector, which produced over 185.26 thousand metric tons of eggs in 2023 according to the Philippine Statistics Authority (2023). This high consumption rate generates a massive volume of calcium-rich biowaste that traditionally ends up in municipal dumpsites, contributing to environmental degradation through leachate and greenhouse gas emissions (Baco et al., 2022). Repurposing this waste aligns with the Philippine Green Building Code and the Circular Economy Act, which promote the systemic recovery of resources. Situating this study within the local academic framework addresses a dual challenge: it provides a low-cost, passive cooling solution for "heat-stressed" urban areas while establishing a localized model for converting agricultural by-products into high-value functional coatings.

Despite the proven global effectiveness of reflective paints, many rely on imported or expensive components, limiting their accessibility in developing countries. In the Philippines—where poor insulation, thin roofing, and rising electricity costs intensify heat stress—there remains a lack of affordable reflective solutions made from locally available, sustainable materials. Given that eggshell waste is abundant nationwide, converting it into a reflective paint component offers a practical, eco-conscious approach.

Thus, this study aims to develop and test an innovative reflective paint using eggshell powder as a natural, recycled additive. The research focuses on reflectance and temperature reduction, evaluating how effectively the eggshell-based formulation lowers surface temperatures using infrared measurements. By doing so, the study addresses both the thermal discomfort experienced in many Filipino households and the growing need for sustainable, locally sourced cooling solutions.

Objectives of the study

This study seeks to develop and evaluate a sustainable reflective cooling paint using recycled eggshell waste to address indoor heat stress and promote environmentally responsible innovation.

According to the United States Environmental Protection Agency (2025) and Surface Optics Corporation (2025), among various journals, the secret to minimizing heat absorption is two characteristics: solar reflectance (the capacity to reflect sunlight, both visible and infrared radiation) and thermal emittance (the capacity to emit radiated heat back into the environment). A cool roof with high reflectivity and high emissivity substantially reduces roof and indoor temperatures.

Based on the empirical work of Wongmahasiri et al. (2024), enhancing roof solar reflectance has a significant impact, lowering cooling energy demand by 18–93% and peak cooling demand by 11–27% in air-conditioned buildings. The research also established that cool roofs lower maximum indoor temperatures by 1.2–3.3 °C and thermal discomfort hours by up to 100% in non-air-conditioned buildings.

These results show that high-performance reflective roofing paints provide significant mitigation from tropical urban heat stresses. By reducing roof heat absorption and promoting heat dissipation, reflective paints can lower indoor temperatures, providing not only thermal comfort but also saving in energy consumption. This makes the formulation of environmentally friendly reflective paint a realistic option, specific to the settings of the Philippines

The Role of Infrared Reflection and Direct

Temperature Measurement

Reflective paint has emerged as a crucial passive cooling strategy to minimize heat accumulation in infrastructures and urban surfaces. These paints are composed of special pigments and additives that reflect large amounts of sunlight, particularly the invisible Near-Infrared (NIR) radiation, which accounts for approximately 53% of the total solar energy that causes heat buildup (Development of paints with infrared radiation reflective properties, 2025).

Coatings formulated with special inorganic pigments are designed to reflect the radiation in the NIR spectrum, preventing the coating from absorbing heat and keeping objects cooler than they would be with conventional pigments of the same color (Mansour & Farha, 2025). This mechanism is critical because absorbed sunlight directly increases surface temperature, thereby increasing the need for cooling energy.

While standardized methods rely on laboratory equipment to measure solar reflectance and thermal emittance, a more direct and practical way to evaluate effectiveness is to measure the reduction in Surface Temperature under solar exposure using an infrared (IR) gun. This comparative approach, which measures the temperature differential achieved by painted samples, is a reliable method used in many studies to evaluate a material's practical heat-mitigation performance and to indicate whether a surface is primarily reflecting or absorbing heat. This methodology is directly validated by Wai et al. (2025), who utilised a thermal infrared camera to monitor surface temperature variations, demonstrating that the temperature differential serves as the authoritative performance metric for cool coatings. Furthermore, the relevance of this measurement is confirmed by Wongmahasiri et al. (2024), who showed that the surface temperature reduction achieved by reflective coatings directly translates into improved indoor thermal comfort and reduced cooling energy demand in hot, humid residential environments.

A high-performing coating will exhibit a significantly lower peak surface temperature than conventional materials, with reports indicating that reflective coatings can reduce roof surface temperatures by over 30% (LuminX, 2025). Thus, measuring surface temperature directly provides a reliable and practical measure of the coating's ability to mitigate heat gain.

Differences of Regular and Reflective Paint

Regular paint usually contains primary ingredients such as pigments, binders, solvent, and additives to improve various properties such as durability and drying time. Using these ingredients, the paint assures a long lasting and functional coating particularly in industrial and urban residences. According to Pravin (2024), reflective paints minimize heat absorption of surfaces exposed under direct radiation. While reflective paint shares the same primary ingredients as conventional paints, reflective paint includes special ingredients that make it more reflective.

According to StarShield Smart Paints & Coatings (2025), despite their similarities, reflective paints and regular paints differ in composition, performance, and durability. Common pigments and binders with minimal additives are less heat-resistant, and those are typically used in regular paints, resulting in poorer thermal performance. In contrast, reflective paints have high-tech materials like acrylic elastomeric polymers, ceramic microspheres, and infrared-reflective pigments being able to achieve high heat reduction capabilities, which can reduce roof surface temperatures by more than 30°C

Advanced formulations are utilized in reflective paint production to enhance their ability to minimize heat intake. They are usually made out of epoxy resin or acrylic polymer matrices incorporating solar-reflective nanoparticles. As additives and pigments, the nanoparticles

scatter and reflect solar radiation in the ultraviolet (UV), near-infrared (NIR), and visible spectrums. Due to its high refractive index, TiO₂ is significant in ensuring that solar reflectance is optimized and helps sustain cooler surface temperatures. Additionally, reflective paints contain pigments such as TiO₂ and Calcium Carbonate (CaCO₃) to enhance their reflectance, and specific binders to further improve weather resistance, durability, and adhesion.

Eggshells (CaCO₃) as a Reflective Material

Eggshells are typically regarded as non-reusable waste from homes and the food industry. Murakami et al. (2007), as cited in Aditya et al. (2021) emphasized that 94% of eggshells are composed of calcium carbonate, 1% of which is magnesium carbonate, 1% is calcium phosphate, and 4% is organic material. In which the calcium carbonate contributes significantly to the reflective properties of the eggshells. Calcium carbonate (CaCO₃) is a prevalent inorganic compound and serves as the most extensively utilized filler in polymeric materials, including plastics and rubber (Jahromi et al., 2017, as cited in Tao et al., 2020). Moreover, many studies have found that CaCO₃ has solar reflectivity. Tao et al. (2020) noted that its reflectivity in the visible spectrum is quite high, resulting in significant whiteness. In general, carbonates exhibit higher reflection in ultraviolet light and a shorter wavelength which means they reflect more UV radiation.

The hardness of the eggshells is said to be determined by the calcium carbonate. In paint, eggshells are used to reflect more light than ordinary paint. Roslan et al. (2020) discovered that eggshell-infused composite materials exhibit high strength when fused or bonded to a structure with various boundaries between them. As a result, it's an excellent alternative to synthetic paint composition. Eggshells, made of calcium carbonate polymers, are typically the load-carrying components; the surrounding egg membranes keep them in the proper position and protect them from environmental hazards such as high heat and humidity. (Roslan et al., 2020).

Eggshells can be found in different stores, and even in the comfort of our own homes, making it the easiest and most cost-effective way to minimize the heat in different house environments. Tao et al (2023) said that calcium carbonate (CaCO₃), is known to be affordable, easily accessible, and environmentally safe, making it a sensible option for sustainable applications. Thus, making CaCO₃ a safe addition to a variety of materials, such as reflective coatings. This ensures that the paint's components will not endanger the environment, human health, or animals in any way. Furthermore, CaCO₃ doesn't produce hazardous byproducts, which can help reduce environmental impacts. To add to that, its sustainability supports the rising demand for green materials. When it comes to reflective materials, using CaCO₃ derived from eggshells not only promotes resource efficiency and the 3Rs but also advances the development of sustainable substitutes for traditional reflective agents.

Reflective Paint Effectiveness in the Philippines

In a report prepared for the ASEAN Centre for Energy, Silitonga et al. (2024) noted that as the demand for more sustainable buildings grows, passive reflective techniques are becoming an increasingly viable alternative for cooling and ventilating indoor environments. Passive reflective techniques, unlike mechanical air conditioning systems, require little ventilation and prevent greenhouse gas emissions, reducing energy consumption in buildings by allowing indoor spaces to ventilate sustainably. Using reflective and insulating building materials will maximize the overall cooling efficiency in rural areas, especially in humid countries. The use of passive reflective processes, which employ natural means to regulate a

building's thermal comfort without relying on high-energy-intensity mechanical or electrical systems, provides a relatively solid response to the rising demand for sustainability in building construction applications (European Commission, 2024, as cited in Tayag & Conejos, 2025).

The Philippines is situated in a hot, humid region, and its temperature fluctuations contribute to the extreme heat people experience. Last year, the temperature in Metro Manila reached 38.8 °C, resulting in an extreme heat index of 45 °C due to high humidity (Vera-Ruiz, 2024, as cited in Garcia, 2024). This is the highest record in the Philippines since 1915 and poses a problem, given the potential health risks to the general population. Garcia (2024) emphasized that the Philippines is not dealing with this phenomenon on its own; many Asian nations are facing unpredictable heatwaves, which makes this a more widespread regional emergency that needs strong responses.

Among the passive reflective methods discussed above is reflective paint. Mandal et al. (2020) noted that proponents of passive radiative cooling of buildings suggest that white paints, which are suitable for use on structures and have some radiative-reflective potential, could be improved to create highly effective radiative coolers for worldwide use. This will consistently keep indoor spaces cool, thereby mitigating the health risks posed by heat. Most reflective paints are expensive; therefore, marginalized communities don't have full access to them. Furthermore, its ingredients exacerbate the nation's greenhouse effect, further harming the environment. Recycled eggshells, however, can further lower embodied impacts and material costs; a recent research by Santamouris et al. in 2022 quantifies benefits across different kinds of construction and climates. In addition to comfort enhancements, city programs evaluating cool roofs frequently include the carbon emission releases, which will benefit the areas significantly.

Research Framework

Theoretical Framework

This research is grounded on the concept of Reflection of Light, which describes the behavior of surfaces when dealing with solar radiation. Reflective coatings reduce heat absorption by reflecting a significant percentage of incoming light, thereby lowering surface and indoor temperatures. This concept is reinforced by the Theory of Heat Transfer. According to Jack Holman (2001), as cited by Zu et al. (2021), this theory focuses on the mechanisms of radiation and conduction in controlling thermal energy flow along building surfaces. Additionally, Song et al. (2025) discuss the Albedo Theory (Light Scattering), further explaining how sunlight is scattered and reflected by surfaces.

From a sustainable development approach, the study is based on the Theory of the Circular Economy that advocates for the utilization of recycled and natural materials in a manner that avoids waste and protects resources. This is complementary to the utilization of eggshell waste as a principal reflective material in paint formulation. Wu et al. (2023) also complement this using the Optical Scattering Theory (Light Scattering), which rationalizes the reflectivity of materials. Similarly, the Green Building Theory places this innovation on the right track for sustainable design, focusing on energy efficiency and the reduction of carbon emissions in building processes. And finally, Rathinavel et al. (2023) explore the Thermal Conductivity Theory (Low Thermal Conductivity), which highlights minimizing indoor heat to improve comfort, health, and productivity.

By combining these theories, the current study aims to develop reflective paint as a practical, science-driven innovation that

enhances environmental sustainability and social health.

Conceptual Framework

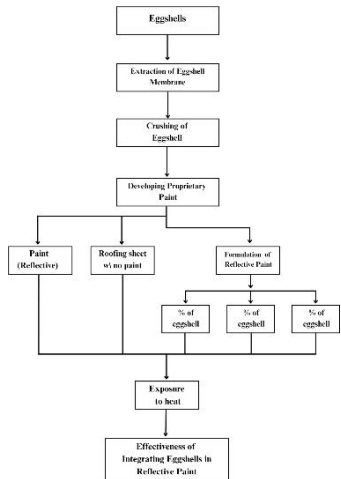


Figure 1. Conceptual Framework of the Study on Eggshell-Based Reflective Paint

The conceptual framework of this study is designed to evaluate the effectiveness of chicken eggshells as an additive in reflective paint. The process starts with the collection of eggshells, removal of the membrane, and crushing into fine particles to ensure consistency. These particles were then incorporated into a formulated reflective paint at three specific concentrations—15%, 30%, and 50%—which serve as the Independent Variable. The formulated paint samples were applied to standardized substrates and compared against a Negative Control (unpainted roofing sheet) and a Positive Control (commercially available reflective paint). All samples were simultaneously subjected to heat exposure. The results were then analyzed by measuring the surface temperature reduction using a non-contact Infrared Thermometer to determine the effectiveness of the eggshell additive in reducing overall heat absorption.

Scope and Limitations

The present study aims to develop and test the thermal performance of the reflective paint made from recycled eggshells. It aims to determine whether the paint effectively reduces surface temperature and, consequently, indoor heat, while remaining eco-friendly. It compared the performance against conventional commercial paint and commercial reflective paint. The experiments examined surface temperature reduction, thermal properties, and physical properties through small-scale application on controlled test substrates using an infrared thermometer (IR gun). The study's ability to measure intrinsic reflectivity is limited to the direct correlation between surface temperature and solar reflection under testing conditions.

The research is limited to small-scale tests on specific substrates and does not extend to large-scale applications on actual buildings or long-term weather exposure. It also does not consider aesthetic aspects like color, finish, or texture. Issues related to industrial production, supply chain, and compliance with manufacturing standards are beyond its scope. Additionally, drying time was only measured under controlled testing conditions and may vary in real-world, full-scale settings. The study also did not evaluate cost efficiency or economic feasibility of the paint.

METHODOLOGY

Research Design

This research will utilize a true experimental design that is quantitative, specifically the post-test-only control group design, to

assess whether an eco-friendly reflective roof paint made from eggshell waste is effective. As J. and D. Creswell (2018) explained in "Research Design: Qualitative, Quantitative, and Mixed Methods Approaches," a true experimental design establishes cause-and-effect relationships through the random assignment of participants to groups, which reduces bias and strengthens internal validity. As opposed to iterative methods involving multiple tests across successive rounds, this research adopts a non-iterative design in which data are gathered once following exposure to the controlled conditions. This is such that the results directly represent the treatment effect, free from interference from repeated testing.

There are two groups in the experimental design: the experimental and control groups. The experimental group consisted of roof panels coated with newly developed reflective paint containing varying concentrations of eggshell-derived calcium carbonate (CaCO_3). The control group consisted of two subgroups: one coated with commercially produced reflective paint and the other left unpainted. Roof panels were randomly assigned to these groups to ensure unbiased distribution and reliable results.

Preparation consists of washing, drying, and grinding eggshells into a powder, then adding them to paint mixtures at various ratios. The same formulation batch was applied evenly to the roof panel samples to ensure reproducibility. Following application and curing under standard conditions, the panels were exposed to natural sunlight or artificial heat lamps in a controlled laboratory setting to replicate outdoor heating.

Thermal regulatory efficacy was measured primarily by the Surface Temperature Reduction achieved by the experimental paints, an established benchmark that assesses a surface's capacity to reflect sunlight and shed absorbed heat. Surface temperature reduction values are directly correlated with a material's ability to remain cool in response to solar radiation, which underpins the Solar Reflectance Index (SRI) as defined by ASTM International. Research by Zahra Jandaghian et al. (2025) validates that the thermal performance of a coating is directly determined by the temperature differential observed under solar exposure. Dark, non-reflective roofs usually exhibit high surface temperatures, whereas highly reflective coatings show significantly lower temperatures. By determining the surface temperature of each panel, the surface temperature reduction is the standardized assessment of the eggshell-based paint's reflective capacity.

The data obtained will be statistically analyzed to ensure that differences in surface temperature reduction are significant between treatments. This method is supported by research, such as that of the U.S. Department of Energy (2025), which shows that high-solar-reflective cool roofs can lower surface temperatures by as much as 28°C compared with standard dark roofs. A rigorous experimental analysis by Wai et al. (2025), which used a thermal infrared camera to monitor surface temperature variations, validates the use of surface temperature differential as a reliable indicator of cooling efficacy in cool roof coatings. Likewise, Wongmahasiri et al. (2024) discuss the role of solar absorption in influencing thermal comfort and energy consumption in homes and thereby advocate for the use of reflective coatings in tropical regions.

Overall, this experimental design provides a valid and reliable method for testing the thermal regulation capability of eggshell-based reflective paint. Through the application of a post-test-only control group design and by measuring performance via surface temperature reduction, the research provides evidence on whether recycled eggshells can be adopted as a sustainable, cost-effective substitute for commercially available reflective paints.

Procedure

The procedure utilizes the following materials: chicken eggshells (CaCO₃), sodium silicate (mNa₂O·nSiO₂·xH₂O), zinc oxide (ZnO), titanium dioxide (TiO₂), iron(III) oxide (Fe₂O₃), sodium hexafluorosilicate (Na₂SiF₆), and water (H₂O). The required equipment includes measuring containers for accurate proportioning, a stirring rod for thorough mixing, a bucket for combining the materials, and a designated curing space to allow the mixture to properly set and achieve the desired properties.

Table 1. Materials and Functions in Reflective Paint Development

Component	Function	Material/Compound
Binder		mNa ₂ O·nSiO ₂ ·xH ₂ O
Solvent		H ₂ O
Filler		CaCO ₃
UV stabilizer		Fe ₂ O ₃
Reflective Pigment		TiO ₂
Pigment and Microbial Resistance		ZnO
Hardener/setting agent		Na ₂ SiF ₆
Additives		—

Table 2. Preparation of Chicken eggshells as an additive

Step	Procedure
1	Collect chicken eggshell waste
2	Boil the eggshells to sanitize and for easy removal of the inner membrane
3	Remove the inner membrane
4	Rinse and allow them to dry completely
5	Crush and grind eggshells into fine powder
6	Pass the ground materials through a sieve for a consistent particle size.

Table 3. Procedure for Formulating Reflective Roof Paint

Step	Procedure
1	Gather all required components: binder(mNa ₂ O·nSiO ₂ ·xH ₂ O) and extender pigments including ZnO, TiO ₂ , Fe ₂ O ₃ , CaCO ₃ , Na ₂ SiF ₆ , and H ₂ O.
2	Mix the extender pigments (ZnO, TiO ₂ , Fe ₂ O ₃ , CaCO ₃ , Na ₂ SiF ₆ , and additives)
3	Stir at room temperature for 20 minutes
4	Combine the extender pigments with mNa ₂ O·nSiO ₂ ·xH ₂ O
5	Stir for another 20 minutes
6	Add water to dissolve the powders, creating a liquid state of paint.

Materials and Experimental Procedure

Both chemical and natural constituents were used in the reflective roof paint. The binder was sodium silicate (mNa₂O·nSiO₂·H₂O), and the solvent was distilled water (H₂O). The fillers included calcium carbonate (CaCO₃) and powdered chicken eggshells, which are expected to provide structural stability to the paint. Iron(III) oxide (Fe₂O₃) served as a UV stabilizer, titanium dioxide (TiO₂) as a reflective pigment, and zinc oxide (ZnO) for color stability and biostatic microbial resistance. The hardener and setting agent was sodium hexafluorosilicate (Na₂SiF₆). All chemicals were of analytical grade, and sourcing from verified suppliers ensured the credibility of the experimental procedure (Le & Lê, 2021). Safety precautions will also be observed during formulation and testing. Since the paint mixture contains both natural and chemical additives, some ingredients may cause allergic reactions upon skin contact or inhalation. Therefore, researchers used protective equipment such as gloves, masks, and lab coats, and ensured proper ventilation throughout the process.

The eggshells were collected from household food waste and local bakeries, ensuring that the study reuses materials that would otherwise contribute to solid waste. After processing (boiling, drying, and grinding), any unusable residues, such as membranes, were disposed of in biodegradable waste bins. Chemical byproducts, if any, were handled in accordance with laboratory waste management protocols to prevent environmental contamination.

The main components of the reflective roof coating included sodium

silicate, zinc oxide, titanium dioxide, calcium carbonate, ferric oxide, and sodium hexafluorosilicate. All chemicals were high-grade and purchased from Merck to ensure consistency and purity.

The experimental process involved preparing an extender pigment mixture with sodium silicate to form a stable coating solution. Initially, the extender pigments (ZnO, TiO₂, Fe₂O₃, CaCO₃, Na₂SiF₆) were measured and added to the sodium silicate solution, followed by continuous stirring at room temperature until a semi-dry mixture was obtained. To achieve uniformity, the resulting powder was refined by ball milling for 1 hour. After milling, the mixtures were left to cure under room temperature conditions for 24 hours to ensure complete hardening before application.

The prepared paint samples were then applied onto identical roofing substrates and allowed to dry for 24–48 hours. Once dried, the samples were exposed to natural sunlight for a 3-day testing period. Temperature readings were taken at three intervals each day—10:00 AM, 12:00 noon, and 2:00 PM—to capture morning, peak, and afternoon heat levels. Surface temperature, indoor temperature, solar reflectance, and thermal absorption were recorded consistently throughout the testing period.

Thermal regulatory efficacy was measured directly via the Surface Temperature Reduction achieved by the experimental paints. Testing was conducted on-site at the residential property (the testing location) by applying the paint samples to standardized substrates (test panels) and exposing them to natural solar radiation.

Surface temperatures were recorded using a non-contact infrared thermometer, model NJYT T600A. This instrument enabled precise, non-invasive capture of instantaneous surface temperatures across all test panels at predetermined intervals throughout the day. The maximum temperature differential achieved between the formulated paints and the control groups was established as the primary measure of effectiveness.

Following the collection of surface temperature data, the results underwent statistical analysis. Specifically, a one-way Analysis of Variance (ANOVA) was employed to determine whether there were statistically significant differences in the average surface temperature reduction (ΔT) among the eggshell-based reflective paint groups (15%, 30%, and 50% concentrations), the commercial reflective paint, and the traditional non-reflective paint groups. This analysis establishes the reliability of the findings, determines the optimal concentration of eggshell powder, and assesses whether there are statistically significant differences among the eggshell-based reflective paint, the commercial reflective paint, and the roofing sheet with no paint groups.

Process of testing the Solar Reflectance and Thermal Absorption of Eggshells-integrated Reflective Roof Paint

The process of testing the solar reflectance and thermal absorption of the eggshell-integrated reflective roof paint began with the preparation of samples. Three paint groups with varying concentrations of eggshell-based reflective paint were prepared and applied to identical metal roof panels in triplicate, ensuring uniform thickness and proper curing under controlled conditions. Following this, the panels were arranged in an outdoor environment with unobstructed exposure to natural sunlight. All samples were positioned adjacent to one another, oriented identically, and inclined at the same angle to ensure equal solar incidence across all test surfaces.

Surface temperature measurements were then obtained using an infrared thermometer (NJTY T600A) at specific time intervals: 10:00 a.m., 12:00 noon, and 3:00 p.m. The maximum temperature differential (ΔT_{\max}) was determined by identifying the largest observed temperature difference between materials, typically recorded during peak solar radiation at midday. In this study, ΔT_{\max} was used to compare the difference between the non-reflective control and the test reflective samples ($\Delta T_{\max} = \text{Non-reflective control} - \text{test reflective sample}$). After data collection, the results were analyzed and compared across all paint groups using the Analysis of Variance (ANOVA) statistical method.

Sampling Method

The researchers used random assignment as the sampling method for this study to ensure objectivity and reduce bias. Roof panels coated with eggshell-based reflective paint, commercial reflective paint, and traditional non-reflective paint were randomly assigned to treatment and control groups. This approach guaranteed that each panel had an equal chance of being assigned to any group, thereby enhancing the validity of the results.

Random assignment is a probability-based technique in which participants or samples are allocated by chance rather than by choice. According to Creswell and Creswell (2018), random assignment strengthens the internal validity of experimental research by ensuring that observed effects can be attributed to the treatment itself rather than to pre-existing differences between groups.

The objective of this research is to test the effectiveness of the eggshell-incorporated reflective paint in reducing surface temperature and indoor temperatures. By randomly assigning roof panels to different paint conditions, the study ensured that any differences observed in surface and indoor temperature reduction and solar reflectivity are the direct result of the paint formulations tested, thereby supporting the study's goal of evaluating the reflective potential of eggshell-based additives.

Research Instrument

The SRI Testing Observation Sheet is designed to record and evaluate the Solar Reflective Index (SRI) results of the formulated eggshell-based cooling paint compared with commercial reflective and non-reflective paints. The SRI is a standard measure that combines both solar reflectance and thermal emittance to indicate how well a surface stays cool when exposed to sunlight. By documenting the surface temperature and SRI values of each paint sample under identical laboratory conditions, this instrument helped assess the experimental paint's thermal regulation effectiveness.

Commercial Paint Samples

The commercial paint samples consisted of two categories used as baseline comparisons in the study. Paint sample 0 served as the control and was identified as a metal panel with no paint applied. Paint sample 1 consisted of a commercially available reflective paint. For both samples, data were collected based on the date of testing, hours of exposure to sunlight, front and back panel temperatures ($^{\circ}\text{C}$), and the computed temperature difference, with corresponding remarks recorded for each trial.

Eggshell Paint Samples

The eggshell-based paint samples were categorized according to varying concentration ratios. Paint sample 2.1 consisted of eggshell paint with a 15% eggshell ratio, sample 2.2 had a 30% ratio, and sample 2.3 had a 50% ratio. Similar to the commercial samples, each was tested under controlled conditions, with data gathered on the date

of testing, duration of sunlight exposure, front and back panel temperatures ($^{\circ}\text{C}$), and the resulting temperature difference. Observations and remarks were also documented for each experimental run to support comparative analysis.

To ensure accuracy in the infrared temperature testing, all roofing sheet samples were prepared and coated under identical conditions. Each panel was exposed to a controlled infrared heat source at a fixed distance to simulate prolonged thermal exposure. An infrared thermometer was used to measure the surface temperature at the front of the panel and the temperature behind the panel to determine heat transfer. All measurements were taken at 4-hour, 6-hour, and 8-hour exposure periods.

Each test will be repeated at least three times to ensure consistency, and the recorded values will be averaged to minimize experimental error. Laboratory personnel conducting the heating and measurement procedures followed standardized protocols, while the researchers independently analyzed the collected data to avoid bias.

Statistical Treatment

The study's thermal data, called the Cooling Differential, was initially analysed using basic figures known as descriptive statistics. The average performance for all developed paint mixes, the commercial reflective paint, and the control panel, which has no paint, were calculated. The standard deviation was also determined. This number showed how consistent the cooling results were during the testing period. These simple calculations summarised the typical performance and reliability of each paint.

To determine whether the differences in cooling performance among the groups are meaningful, an advanced statistical test was used. The One-Way Analysis of Variance (ANOVA) was conducted to compare the average cooling across all paint groups simultaneously. If the ANOVA test shows that an overall difference exists, a second, more detailed test is required: the Tukey's Honestly Significant Difference, or HSD, test. This test involves comparing every single paint mixture against every other one. This direct comparison confirmed which specific paint mixture was statistically superior, allowing the researchers to identify the optimal eco-friendly formulation that performs significantly better than both the commercial paint and the unpainted control.

Ethical Considerations

The study did not involve any human or animal subjects, as it focused solely on paint formulation and thermal testing of inanimate objects, specifically roofing sheets. The preparation of the paint strictly followed standard laboratory safety guidelines to ensure the safe and proper handling of materials. All materials used, especially eggshell waste, were collected and managed responsibly as part of environmental stewardship, promoting upcycling and preventing unnecessary waste or ecological harm.

After formulation, the testing phase was conducted in a real house setting or in a sunlight-exposed environment to accurately assess heat and thermal performance under natural conditions. The procedures were carried out carefully and honestly, with all observations and measurements recorded accurately. All waste materials were disposed of properly in accordance with environmental regulations, ensuring no harm to humans, animals, or the environment. Throughout the study, the researchers upheld transparency and integrity in data collection, ensuring that the results are reliable and that the research contributes responsibly to the field of sustainable materials.

RESULTS AND DISCUSSION

Result for Unpainted Roofing Sheet

The thermal exposure results for the unpainted roofing sheet show clear changes in surface heat and heat transfer across the three testing dates. The temperatures taken every three hours reflect how the bare metal reacted directly to sunlight and the weather.

On 13 November, the front temperature ranged from 40.8°C to 41.8°C, while the back temperature varied from 36.6°C to 39.3°C. The cooling difference was at most 5.2°C, indicating only minimal heat reduction. By 16 November, temperatures rose significantly, with the front reaching 46.8°C and the back 46.7°C, resulting in a negligible cooling difference of 0.1°C. This suggests that nearly all the heat passed through the metal, supporting studies that indicate bare metal roofs transfer heat easily and offer poor insulation (Bansal et al., 2020). On 18 November, a larger temperature difference of 7.5°C was observed in the morning, but during midday and afternoon, the heat reduction remained minimal.

Overall, the unpainted yero absorbed and passed on heat easily. This supports the need for reflective coatings, as past research shows these coatings can help lower heat by reflecting more sunlight (Kim & Kim, 2022; Medina et al., 2021).

Table 4. Unpainted Roofing Sheet Data

Date of Test	Time of Exposure	Front Panel	Behind Panel	Temperature Differential
13-Nov	10:00	40.8	39.3	1.5
	12:00	41.3	38.3	3
	2:00	41.8	36.6	5.2
16-Nov	10:00	43.8	39.3	4.5
	12:00	45.9	45	0.9
	2:00	46.8	46.7	0.1
18-Nov	10:00	39.3	31.8	7.5
	12:00	39.3	39	0.3
	2:00	40.8	40.5	0.3

Result for Commercial Paint

The results for the commercial reflective paint show that it reduced the behind-panel temperature more effectively than an unpainted sheet. Across all testing dates, the cooling differential remained between 2.4°C and 5.7°C, indicating that the coating helped block some of the heat before it reached the back of the panel.

This performance matches what the literature explains about the difference between regular and reflective paint. Regular paints primarily use basic pigments and binders that are not designed to withstand heat. As a result, they allow more heat to pass through (StarShield Smart Paints & Coatings, 2025). In contrast, reflective paints include special ingredients such as ceramic microspheres, infrared-reflective pigments, and acrylic polymers, which make them more effective at reflecting sunlight and reducing heat absorption. These advanced materials can significantly lower surface temperatures, sometimes by more than 30°C (Pravin, 2024; StarShield Smart Paints & Coatings, 2025).

The commercial reflective paint’s consistent cooling effect, as shown in the results, supports this. The higher cooling differential during peak hours, such as 5.7°C at 2:00 PM on November 18, shows how reflective pigments work more effectively when sunlight is strongest. This is also in line with the idea that reflective paints use TiO₂ and CaCO₃ pigments, which help scatter light across UV, NIR, and visible spectrums, keeping the surface cooler.

Table 5. Commercial Paint Data

Date of Test	Time of Exposure	Front Panel	Behind Panel	Temperature Differential
13-Nov	10:00	40.4	37.2	3.2
	12:00	40.9	37.5	3.4
	2:00	42.55	38.1	4.45
16-Nov	10:00	39.4	36.2	3.2
	12:00	42.5	38.7	3.8
	2:00	40.5	38.1	2.4
18-Nov	10:00	39.4	35.8	3.6
	12:00	38.9	36.5	2.4
	2:00	43.5	37.8	5.7

Result for Eggshell Paint (15%)

The analysis of the raw thermal data collected for the Eggshell Paint (15%) formulation, as presented in Table 8, establishes this ratio as the descriptively highest-performing experimental group.

The 15% formulation demonstrated superior heat mitigation, achieving a peak Panel Temperature Difference of 11.0°C when the surface temperature reached 47.0°C. This successful thermal resistance limited the behind-panel temperature to only 36 °C during that peak solar exposure. Furthermore, the overall mean Cooling Differential for the 15 group was the highest among all eggshell formulations at 6.74°C. This performance provides strong empirical evidence that the 15 concentration is highly effective at disrupting the flow of solar heat, directly addressing the research objective of formulating a high-performing reflective paint.

This finding is well-supported by existing literature on sustainable thermal management; studies on reflective coatings in hot climates, such as those by Hernández-Pérez et al. (2021), have reported that light-colored cool roofs achieved a substantial reduction in daily heat gain, resulting in temperature differentials that validate the principle of using high-reflectance materials to interrupt heat transfer and improve indoor thermal comfort. The magnitude of the cooling differential achieved by the 15% eggshell formulation is comparable to, and in some peak instances exceeds, the typical 6% - 8% reductions cited in literature for effective cool coatings in tropical environments by Xian Rong et al, thereby validating the use of the eco-friendly eggshell additive as a viable, sustainable component for passive cooling.

Table 6. Eggshell Paint (15%) Data

Date of Test	Time of Exposure	Front Panel	Behind Panel	Temperature Differential
13-Nov	10:00	39.4	35.2	4.2
	12:00	40.9	35.5	5.4
	2:00	43.2	36.2	7
16-Nov	10:00	42.4	36.2	6.2
	12:00	47	36	11
	2:00	44.9	36.5	8.4
18-Nov	10:00	37.9	31.8	6.1
	12:00	38.9	33.5	5.4
	2:00	43.5	37.8	5.7

Result for Eggshell Paint (30%)

The roofing panel coated with 30% eggshell reflective paint consistently reduced its surface temperature across all trials. The cooling values for the 30% eggshell coating ranged from 4.7°C to 8°C, indicating that the mixture reduced heat on the panel even as sunlight intensity varied throughout the day. The mean drop of 5.88°C indicates steady performance, although this ratio was not the most effective among all mixtures. The largest drop, which reached 8°C at midday, suggests that the coating becomes more responsive as solar radiation increases.

This outcome is supported by previous literature, as Hernández-Pérez (2021) explained that calcium-carbonate-based coatings tend to reflect more solar radiation because the mineral is naturally bright and thermally stable, and this characteristic likely contributes to the behavior observed in the 30% mixture. Additionally, National Science Open (2024) found that mineral fillers can enhance the way reflective paints scatter incoming sunlight, thereby reducing the heat absorbed by coated surfaces. However, the pattern in the present study shows that increasing the amount of additive does not automatically lead to improved thermal performance, which aligns with Lu et al. (2023), who reported that waste-derived reflective additives perform best only at certain concentration levels rather than improving continuously as more material is added.

While the 30% eggshell formulation provided reliable cooling, it did not outperform the other ratios; nevertheless, it still demonstrates

potential as an affordable and environmentally sustainable coating for reducing heat on roofing panels, especially under conditions where solar intensity fluctuates throughout the day.

Table 7. Eggshell Paint (30%) Data

Date of Test	Time of Exposure	Front Panel	Behind Panel	Temperature Differential
13-Nov	10:00	38.4	32.9	5.5
	12:00	40.1	35.4	4.7
	2:00	42	36	6
16-Nov	10:00	41.4	35.9	5.5
	12:00	47	39	8
	2:00	44.1	38.4	5.7
18-Nov	10:00	38.2	31.4	6.8
	12:00	38.1	33.4	4.7
	2:00	41	35	6

Result for Eggshell Paint (50%)

The data presented in Table 10 provide strong evidence for the thermal-regulation capacity of the 50% eggshell paint formulation. The consistent cooling differential, ranging between 5.3 °C and 6.8 °C, demonstrates the paint's reliable ability to reduce heat transfer under various solar conditions.

The highest cooling differential of 6.8°C was recorded twice, both at 10:00 am. This suggests the paint is most effective at reducing heat transfer when the front of the roofing sheet is at a relatively lower temperature, between 39.7°C and 38.2°C. This 50% formulation implies greater efficiency under morning sun conditions or before peak heat. In contrast, the lowest temperature differential of 5.3 °C was recorded multiple times, specifically during peak solar exposure periods. This reduction in cooling performance corresponds to periods of higher front-panel temperatures, suggesting a minimal decrease in the coating's thermal-regulation effectiveness under high solar intensity or elevated ambient heat. Nonetheless, the absolute highest front-panel temperature of 47.6°C yielded a differential of 6.5°C, indicating that the paint can still maintain strong thermal regulation even under peak heat conditions.

Overall, the results demonstrate that the 50% eggshell formulation reliably moderates thermal gain, particularly during morning exposure, and shows strong potential as a passive cooling coating. The mean cooling differential of 6.11 °C supports the limited heat-transfer effectiveness of eggshell powder. This interpretation aligns with the findings of Song et al. (2025), who state that finely ground eggshell powder can enhance solar reflectance in coating systems. Although different materials are used in the present study, the similar outcomes demonstrate the promise of eggshell-based additives as effective cooling components in coating formulations.

Table 8. Eggshell Paint (50%) Data

Date of Test	Time of Exposure	Front Panel	Behind Panel	Temperature Differential
13-Nov	10:00	39.7	32.9	6.8
	12:00	40.7	35.4	5.3
	2:00	42.6	36.7	5.9
16-Nov	10:00	42.7	36.9	5.8
	12:00	47.6	41.1	6.5
	2:00	44.7	39.4	5.3
18-Nov	10:00	38.2	31.4	6.8
	12:00	38.7	33.4	5.3
	2:00	41.6	35.1	6.5

Table 9 then presents the ANOVA results for differences among the five roofing treatments in temperature reduction. To determine if significant differences exist in their thermal performance, the Null hypothesis (H0) states that there is no significant difference in the mean surface temperatures of the roofing sheet across the various paint formulations, while the Alternative hypothesis (H1) states that there is a significant difference in the mean surface temperatures among the different paint formulations.

The front-panel temperature indicates no statistically significant

difference among the five treatments ($F = 0.485$, $p = 0.747$). This indicates that, when exposed to direct sunlight, all roof panels absorb the same amount of heat at the surface, regardless of their coating. The temperature behind the panel results indicate a statistically significant difference among treatments ($F = 4.690$, $p = 0.009$). This demonstrates that the five paint types directly affect the amount of heat transferred through the substance. The cooling differential is the most significant metric for assessing reflective performance, as it indicates the actual thermal protection the paint provides. The ANOVA reveals a highly significant difference ($F = 12.067$, $p < 0.001$), suggesting that the treatments' capacities to lessen heat penetration differ significantly.

The result is consistent with research showing that incident solar radiation dominates direct surface heating, such that even reflective coatings would first heat up before exhibiting their cooling effects through reduced heat transfer (Wai et al., 2025). This explains that the actual performance of reflective coatings does not become apparent until heat begins to pass through the material, which accounts for the non-significant result for front-panel temperatures. According to research on CaCO₃ cool-roof technologies by Wongmahasiri et al. (2024), eggshell-based coatings are effective in limiting conductive heat transfer, as evidenced by notable decreases in the p-values for behind-panel temperature and cooling difference.

Table 9. Significance result of Eggshell paints(15%, 30% and 50%) with commercial and unpainted roofing sheets

Variables	F-value	p-value	Decision	Conclusion
front of panel	0.485	0.747	Do not Reject Ho	Not Significant
Behind of panel	4.690	0.009	Reject Ho	Significant
Cooling Differential	12.067	<.001	Reject Ho	Significant

Note: Significant at 5% level

ANOVA result for Eggshell paints(15%, 30% and 50%)

Table 9 shows the ANOVA comparison of the three eggshell paint concentrations 15%, 30%, and 50% to evaluate their thermal performance and the analysis indicates that the differences are non-significant. The front-panel temperature ($p=0.851$), behind-panel temperature ($p=0.845$), and cooling differential ($p=0.539$) all have high p-values. Because each p-value exceeds the 0.05 significance level, the null hypothesis is not rejected.

This result confirms that the different concentrations do not yield a distinct cooling effect, indicating that all three formulations are comparably viable for reducing surface heat. The main cooling mechanism is attributed to the Solar Reflectance of the eggshell's primary component, which is calcium carbonate, which successfully reflects the sun's heat. The successful cooling observed across all eggshell paint samples validates the study's premise of using eggshell as a reflective pigment to reduce roof heat (Tao et al., 2021).

These findings also resonate with the work of Shang et al. (2024), in which composite inorganic coatings applied to walls improved thermal insulation by increasing heat-flux reflectivity. Their study highlights how carefully engineered coating formulations, rather than simply more filler, can drastically enhance reflective performance and reduce heat absorption. This parallels our results, implying that increasing eggshell (CaCO₃) concentration doesn't necessarily yield proportional gains in cooling, and that coating composition and dispersion are arguably more important.

However, the 15% Eggshell Paint formulation achieved the highest mean cooling differential of 6.74 °C. This data point, combined with the ANOVA's finding of statistical equivalence, suggests that 15% concentration is the optimal formulation from a resource-efficiency standpoint.

Table 10. Significant results for Eggshell paints (15%, 30% and 50%)

Variables	F-value	p-value	Decision	Conclusion
Front of panel	0.163	0.851	Do not Reject	Not Significant
			Ho	Significant
Behind of panel	0.170	0.845	Do not Reject	Not Significant
			Ho	Significant
Cooling Differential	0.646	0.539	Do not Reject	Not Significant
			Ho	Significant

Note: Significant at 5% level

ANOVA result of Eggshell paints (15%, 30% and 50%)

The mean cooling differential results show that the 15% eggshell-based reflective paint provides the greatest thermal protection among the three formulations. The results show an average temperature difference of 6.74°C between the front and back of the panel, compared with 6.02°C and 5.88°C for the 50% and 30% eggshell-based paint, respectively. Therefore, indicating that the 15% formulation keeps the back pane cooler than the higher eggshell concentrations under the same solar exposure by preventing more heat from flowing through the roofing sheet.

This pattern implies that there is an ideal eggshell concentration where light scattering and reflectance are maximized without sacrificing the paint matrix's stability. Tao et al. (2020) found that CaCO₃-enhanced reflective films achieved the highest albedo at moderate filler loadings, while excessive CaCO₃ reduced reflectance due to particle crowding.

Moreover, Wu et al. (2023) proved that when the particles are evenly distributed rather than excessively concentrated, eggshell-derived CaCO₃ enhances radiative cooling throughout the day. Thus, this emphasizes that the ideal microstructure and particle behavior are the foundation of the 15% eggshell-based reflective paint's exceptional cooling performance in your study. Eggshell-derived CaCO₃ particles are abundant enough to improve scattering at this concentration, but not dense enough to group together or obstruct the reflecting pathway. Furthermore, particle aggregation and binder insufficiency, observed in both studies, begin to degrade the coating's optical and thermal properties as the concentration increases to 30% and 50%.

Table 11. The Mean Cooling Differential of the 15%, 30%, and 50% Eggshell Paint Formulations

	Group	Mean
Front	1	41.87
	2	41.14
	3	41.83
Behind	1	35.12
	2	35.27
	3	35.81
Difference	1	6.74
	2	5.88
	3	6.02

Note: Significant at 5% level

Interpretation of ANOVA: Comparison of All Treatments

The ANOVA compared all five treatments (This ANOVA compared the thermal performance of all five roofing treatments: the three eggshell concentrations (15%, 30%, 50%), the commercial paint, and the unpainted roofing sheet. For the Front of the panel temperature, the analysis showed no significant difference (F = 0.485, P = 0.747), indicating that all surfaces absorbed heat similarly when directly exposed to the sun. However, a significant difference was found for the Behind of Panel temperature (F = 4.690, P = 0.009). This crucial finding suggests that the various coatings were not equally effective at insulating and reducing heat transfer to the substrate beneath the panels. This disparity was confirmed by the Cooling Differential (Front minus Behind), which showed a highly significant effect (F = 12.067, P < .001), indicating that the treatments differed substantially in their ability to lower the temperature beneath the roofing sheets.

Table 12. ANOVA: Comparison of All Treatments

Variables	F-value	df1	df2	p-value
Front	0.163	2	16.0	0.851
Behind	0.170	2	14.7	0.845
Difference	0.646	2	14.0	0.539

Summary of Findings

The experimental evaluation of the developed reflective paint demonstrated significant cooling efficacy across all tested concentrations. Statistical analysis using a One-Way ANOVA confirmed a highly significant difference (P < .001) in heat reduction when comparing the eggshell-coated roofing sheets to the unpainted control. This confirms that the high concentration of calcium carbonate (CaCO₃) found in eggshells effectively scatters solar radiation and limits heat transmission into the structure.

The following table summarizes the performance of each treatment qualitatively to provide an overview of the thermal trends observed:

Table 13. Summary of Thermal Performance Trends Across Treatments

	Performance Summary	Thermal Result
15% Eggshell Paint	Demonstrated the highest overall reduction in heat transmission among all tested samples.	Optimal Cooling
30% Eggshell Paint	Provided significant cooling that was statistically identical to the 15% formulation.	High Efficacy
50% Eggshell Paint	Maintained a consistent cooling effect comparable to the lower eggshell concentrations.	High Efficacy
Commercial Paint	Successfully reduced heat compared to bare metal but was surpassed by the eggshell formulations.	Moderate Cooling

CONCLUSION

The study successfully achieved its objective of formulating and evaluating the thermal performance of eco-friendly reflective paints using varying concentrations of eggshell powder. Based on the statistical analysis, several key conclusions were drawn. First, the eggshell paint formulations, when considered as a group, were found to be highly effective in mitigating heat transfer. A highly significant difference in cooling differential (F = 12.067, p < 0.001) was observed when comparing all five treatments, including the three eggshell-based paints, the commercial reflective paint, and the unpainted control. This result confirms that the application of paint coatings significantly improved thermal performance compared to the unpainted roofing sheet.

Furthermore, the analysis of the three eggshell concentrations (15%, 30%, and 50%) showed no statistically significant difference in their ability to reduce surface temperature, as indicated by a p-value of 0.539. This suggests that all three formulations provided comparable cooling effects, and increasing the proportion of eggshell powder does not necessarily result in better thermal performance. Lastly, based on descriptive analysis, the 15% eggshell paint formulation emerged as the most resource-efficient option, achieving the highest mean cooling differential of 6.74°C. This makes it the most practical and promising concentration for further development and potential application.

Recommendations

The study recommends that, given the conclusion of thermal equivalence among the tested formulations, future research should move beyond basic temperature differential measurements and instead focus on material performance and durability assessment. The 15% eggshell paint formulation should be established as the baseline for subsequent studies, as it demonstrated the highest mean cooling effect while remaining the most resource-efficient option.

Further investigations should aim to determine the paint's true cooling efficiency by adopting international standards, particularly through the

measurement of solar reflectance and thermal emissivity to compute the Solar Reflectance Index (SRI). In addition, durability and longevity tests are essential to ensure sustained performance over time. These should include evaluations of water resistance to assess performance under rain exposure, adhesion strength to prevent peeling or chipping, and accelerated weathering tests to simulate prolonged ultraviolet exposure and determine any loss in reflectivity.

Moreover, future studies should focus on optimizing the overall coating quality by refining the manufacturing process. This includes examining the ideal eggshell particle size and distribution to achieve better uniformity and surface finish, as well as assessing application properties such as drying time to ensure the paint's practicality and ease of use in real-world conditions.

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SOS WRISTBAND: ARDUINO-BASED EMERGENCY SIGNALING SYSTEM PROTOTYPE

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ABSTRACT

This study focused on the development and assessment of an Arduino-based wristband emergency signaling system designed specifically to support elderly individuals and persons with disabilities who live alone or independently. The project aimed to address risks associated with social isolation, heightened vulnerability, and delayed access to emergency services by creating a wearable device equipped with pulse detection, fall detection, GPS location tracking, and manual alert activation. The system processes physiological and motion data and transmits emergency alerts through email to designated recipients. Utilizing a developmental research design, the study involved the construction of a functional prototype and performance evaluation under controlled conditions. Findings demonstrated acceptable pulse detection accuracy, high fall detection reliability, precise GPS tracking, and timely alert transmission. The results indicate that the device is feasible, functional, and capable of supporting rapid emergency response for at-risk populations.

Keywords: *Emergency signaling system, wearable technology, fall detection, pulse monitoring, GPS tracking*

INTRODUCTION

Background of the Study

The natural process of aging or living with a disability should not equate to social isolation. Yet in the Philippines where family and intergenerational care used to be cultural cornerstones, more and more older adults now find themselves living alone (Russel et al., 2024).

One of the reasons is the shift from mostly egalitarian households where the elderly co-reside with their adult children to nuclearized families with family members scattered around the globe in search of better job opportunities. While options such as hiring caregivers exist for persons with disabilities and for older individuals who are not healthy or mobile, many Filipinos cannot afford this kind of care.

In most cases where all family members are employed and a caregiver is financially out of reach, they are left with no choice but to live alone despite the risks. A study from the Philippines reveals that despite the availability of emergency services, social isolation remains a critical barrier hindering timely care and health service utilization (Buan et al., 2024). Another concerning factor is the lack of specialized Emergency Medical Services (EMS) in the country for those in the minority, such as the deaf community, making emergency response inaccessible (Tannenbaum et al., 2025).

Several modern approaches have emerged, such as wearable devices that gained popularity as personal safety and health technologies. The compact and portable design made them well-suited for daily use, especially for individuals who need continuous monitoring or immediate access to emergency alerts. These were typically in the form of smartwatches such as the well-known Apple Watch with fall-detection and Emergency SOS feature; however, they face inaccuracy

and usability concerns.

The Apple Watch fall detection feature showed a sensitivity of 4.7% and false negative rate of 95.3%. The user's height, impact force, lower limb functioning were some of the factors that played a role in the accuracy of fall detection which are parameters that may influence the ability of Apple Watch to detect falls from wheelchair users (Abou et al., 2021). Wearable devices also come in wristbands; Manasa et al. (2024) investigated an IoT-based smart wristband designed for women's safety through real-time communication and alert functions.

Similarly, Mitro et al. (2023) introduced an AI-enabled wristband that monitors vital signs and stress levels, showing how wrist-worn devices can serve as health monitors and safety tools. These studies highlight the potential of wearable wristbands instead of smartwatches that can integrate personal safety features with real-time physiological and environmental monitoring.

Correlated with social isolation, falls represent a leading cause of fatal unintentional injuries worldwide. For the elderly, it is an increased vulnerability that comes as they age due to the natural decline in muscle strength, proprioception, vision, and vestibular function, making them lose their balance and control. When isolated individuals fall and undergo a long-lie, where a period of more than an hour is spent on the floor after a fall because they are unable to get up or call for help, a 50% increase in mortality rates within six months of the event prevails even if the initial fall was not fatal. (Vellas et al., 1987, as cited in Kubitzka et al., 2023)."

Consequently, older people stand to benefit from non-complex wearable devices as safety innovations, particularly for those living independently who are more prone to delayed medical emergency

response. Wearable devices have been shown to improve older people's lives by continuous health monitoring and rapid emergency response.

Research published in PubMed (2024) emphasizes the importance of devices in providing immediate assistance during emergencies. While studies in MDPI (2022) support that these devices help maintain elderly independence, mitigating risks associated with accidents or sudden health events.

Previous studies have explored many approaches, programs, and tools in creating a security gadget to assist vulnerable individuals during emergencies. Despite this, some limitations in these innovations remain, such as in terms of functionality, design, and usability. For instance, Sultana et al. (2021) were able to design a safety device that is built to aid in safeguarding lives during potentially dangerous situations including sudden abduction, robbery, or sudden illness.

However, it faced the drawback of being too bulky and non-wearable, which limits its practicality and reliability for everyday use. On the other hand, another study attempted to develop a wearable safety system based on GPS and GSM to protect women from being harassed (Dave et al., 2020). Yet its effectiveness was hindered by its strong dependence on user activation, and it requires a manual pressing of a button, which may not always be possible in cases of sudden danger.

In recent years, technological advancements have catalyzed the development of real-time health monitoring solutions such as the IOT-based Patient Health and Fall Monitoring System (Arun et al., 2025). This system integrated an Arduino Uno Microcontroller with several biomedical sensors to ensure a scalable and cost effective design. However, limitations persisted due to some of its components such as the Global System for Mobile (GSM) module which limited the system's functionality due to its heavy reliance on cellular network coverage which may not perform as optimally in signal-poor environments.

Considering the stated gaps, this study aims to fill the gap by developing an Arduino-based emergency signaling system wristband specifically for elderly people and people with disabilities living alone. This device will be able to send alert messages through the e-mail account of the receiver.

In addition, various sensors of this device, such as the pulse sensor and accelerometer sensor, can detect sudden pulse change or sudden movements, which may be caused by risky situations, reducing the need for manual activation by its capability of automatically transmitting signals. Lastly, it is designed to provide user-friendly convenience through its compact and wearable design, allowing users to utilize it for everyday use. This approach ensures that the proposed system will provide a more accessible and practical solution to support timely emergency response for those at risk.

Objectives of the Study

The main objective of this study is to develop an Arduino-based wristband signaling system that ensures reliable and efficient alert communication during emergency situations. Specifically, this study also aims to: (1) Develop an Arduino-based wristband emergency signalling system that has various sensors such as the pulse detection, fall detection, location tracking, and manual button; and, (2) Assess the functionality of the different sensors as well as the effectiveness of the device in sending emergency signals through observation and

testing under controlled conditions.

Literature Review

Technology Foundation: Microcontrollers and IoT in Safety Devices

In order to address the persistent concerns regarding the security of vulnerable people during emergencies, integrating technology in producing safety devices has become one of the significant technological advances. Central to this advancement is the use of different microcontroller chips designed for use in embedded systems and the Internet of Things (IoT).

In 2021, the study of Sultana et al. discusses the development of a safety device for emergencies, focusing on implementing Arduino and GSM Modules. Their model used the Arduino Uno microcontroller which allowed the integration of various sensors such as the pulse detection, GPS, GSM Module, press-push button, and voice command.

They were able to produce a safety device that sends an emergency signal when the recognized voice commands "danger" or "help", when the button is pushed, and when an abnormal heartbeat is detected. According to them, this type of safety device has the potential to provide safety and a supporting hand to vulnerable individuals such as the elderly, women and children amidst the increasing crime rates and health issues.

Aside from Arduino Uno, ESP microcontrollers have also been used to develop safety devices. In an existing study, Jayasudha and Balakrishnamoorthy (2024) were able to develop an emergency alert system using ESP32 microcontroller for patients which aimed to provide assistance for patients through monitoring their health status. The researchers used the ESP32 as the main component of their product innovation, which allowed them to control the components, encode the program as intended and test it. practical and accessible innovations such as this safety device can further help patients, reduce risks, and address critical medical concerns.

The microcontroller that the researchers used also enabled the device to be convenient, user-friendly and wearable for users. Moreover, the devices also proved to have a long-lasting battery life, accurate location tracking, and fast response time in sending alerts. This demonstrates that practical and accessible innovations such as this safety device can further help patients, reduce risks, and address critical medical concerns.

Using the NodeMCU ESP8266, Alabbas (2022) was also able to design an elderly care room-based monitoring system that focused on heat, smoke, and fire detection. The NodeMCU ESP8266 is a low-cost, Arduino-compatible microcontroller with Wi-Fi capability, and hardware based on ESP-12 module. The system allows monitoring of a safe environment for the users by immediately triggering an alert once abnormal environmental conditions are detected. However, despite its effectiveness, the system mainly focused on monitoring environmental conditions. This creates an opportunity for further development of wearable devices that are more compact, user-centered, and focuses more on the personal conditions of its user.

While microcontrollers provide the hardware platform to successfully integrate various sensors and modules in safety devices, its functionality becomes even more effective when combined with Internet of Things (IoT). IoT offers real-time monitoring, automating security, and enhancing the efficiency of operations with the aid of connected devices and a network of sensors (Ghasemi & Babaie, 2024, as cited by Sun, 2025).

A study by Kamalov et al. (2023) emphasized that IoT is now intertwined with various aspects in modern society. Their study indicated how IoT developed its application in various fields, such as theft protection, through its ability to connect directly to the Internet or another component allowing communication between devices and systems.

This existing knowledge shows how microcontroller chips such as Arduino and ESP microcontrollers ensure the smooth integration of different modules and sensors into one single platform while remaining low-cost and effective, and how the Internet of Things provides real-time response, processing of data, and communication between devices, which can be used in various aspects of life, including health and safety.

The functionality and application of microcontroller chips and IoT in developing systems and devices highlights how combining the two could provide a strong foundation for developers and researchers to design innovative safety solutions that are low-cost and efficient in addressing emergencies in high-risk situations or environments.

Wearable Technology: Wristbands and Smart Bracelets

A wristband is commonly known as a fashion or jewellery item nowadays. But some people showed much interest and put much effort into making this happen. Smart wristbands often serve as a clock to check the real time, but these bands are different as these researchers innovate something helpful in tracking your health and keeping you safe.

In the study of Vo et al. (2024), Wearable Biosensors, which are integrated into clothes and accessories or even directly applied to the skin, provide continuous, real-time monitoring of physiological and biochemical parameters such as heart rate, glucose levels, and hydration status. Recent breakthroughs in downsizing, materials science, and wireless communication have greatly improved the functionality, comfort, and accessibility of wearable biosensors.

As stated in the study of Luo & Gao (2021), wearable biosensors are gaining tremendous interest in the clinical and biological medical fields for their potential in providing patients with real-time diagnostic tools, time-sensitive information, and non-invasive measurements of biochemical markers distributed in body fluids throughout the body. These sensors replace part of the equipment that can only be installed in hospitals and become a new choice for assessing human health. Herein, critical perspectives regarding wearable sensors in the future digital health monitoring industry are put forward.

Meanwhile in study of Kulkarni M., et al. (2024), these smart wearable sensors offer an innovative option for evaluating and continuously monitoring human health by incorporating recent advances in technology and engineering that can enhance real time accurate monitoring and point to point care capabilities.

Smart wearable sensors have emerged progressively with multiplexed biosensing, microfluidic sampling, and data acquisition systems incorporated with flexible substrates and bodily attachments for enhanced wearability, portability, and reliability. For comfortable use of the user. In a real-time application, many innovators utilize the number of sensors to put into the SOS Band.

According to the study of Idris S., et al. (2022), to keep up in modern society, healthcare uses technology such as wearable devices and the Internet of Things to dynamically retrieve/access information, which is important for people who require continuous monitoring that

cannot be provided outside of medical facilities.

The paper presents a smart health monitoring wristband that uses Arduino Nano 33 IoT with a built-in gyroscope and accelerometer module as the microcontroller, biomedical sensors like temperature sensor, pulse oximeter, heart rate sensor, and GSM/GPRS module. This prototype is developed for all age communities but can be especially useful to the elderly, people with special needs, and those with chronic illnesses.

Moreover, in a study of Karmakar A., et al. (2021), they developed a system involving an EMG sensor and pulse sensor named SafeBand. These bands can send SOS signals after decoding the movement of a muscle caused by hand gestures. SafeBand works on EMG muscle sensor, pulse sensor, Arduino Uno, and ESP8266 Wi-Fi module and is powered by a rechargeable battery.

The unit connects to the user's smartphone, which can send the user's GPS coordinates to the local authorities. The smartphone acts as a gateway to notify users' emergency contacts for help through text, voice, and messages on social media.

Expanding on these safety-oriented applications, Chandak, Chaturvedi, and Dhiraj (2022), citing the work of Khojasteh et al. (2018), underscored the importance of on-wrist fall detection. It demonstrated that rule-based fall detection using wrist-worn accelerometers offers high specificity with low computational cost, making it suitable for embedding in smartphones or wearable devices.

They combined optimised thresholding techniques with machine learning models, such as support vector machines, to further improve performance, enabling accurate fall detection. This demonstrated the feasibility of embedding fall detection features into wearable wristbands and smartphones, reinforcing their role as practical safety devices in emergencies.

Lastly, apart from using wristband devices as a trusted tool for physical health monitoring, a study by Mitro et al. (2023) also showed that these technologies have also significantly contributed to stress detection. The researchers presented an AI-enabled smart wristband capable of real-time monitoring of vital signs and stress detection. Utilizing biosensors such as Photoplethysmography (PPG), oxygen saturation (SpO₂), and pulse rate variability (PRV), their device successfully functioned providing essential biometric data and real-time stress detection with an accuracy score of 91%.

Overall, the studies cited demonstrate the development of a wristband going from basic timepieces or fashion accessories into advanced health-monitoring and safety-enhancing devices. Wearable biosensor technology has developed wristbands into powerful tools that can keep track of important physiological and biochemical parameters in real-time, such as heart rate and blood sugar.

Modern devices are now more portable and reliable because they use modern materials, smaller components and wireless communication technologies which makes them usable outside of a hospital or clinical setting. Smart wristbands now have important safety features, such as fall detection and SOS alert systems, that use biosensors, muscle sensors, pulse sensors, and GPS information to obtain help quickly in an emergency. Throughout history these changes have now established smart wristbands as an essential component of an individual's health monitoring, enhancing emergency response and one's well-being.

Development and Usability Testing of an Emergency Alert Device for Elderly People and People with Disabilities

According to the United Nations' Convention on the Rights of Persons with Disabilities (CRPD, 2006), an individual is regarded as disabled when they have mental or long-term physical impairments that significantly limit their ability to participate fully and effectively in society. Similarly, older adults, who often experience age-related declines in mobility and overall health, are particularly vulnerable to falls, accidents, and medical emergencies, especially when living independently.

Globally, approximately 1.3 billion people live with significant disabilities (World Health Organization, 2023). In the context of an aging population and the persistent challenges faced by persons with disabilities (PWDs), the need for innovative technologies that enhance safety, health, and overall quality of life has become increasingly urgent.

One promising solution lies in integrating Internet of Things (IoT)-based technologies into everyday living environments. These systems can provide real-time monitoring of vital health indicators, support medication adherence, and improve environmental safety within the home.

Equipped with smart sensors, IoT-enabled devices can detect falls and transmit emergency alerts to caregivers or healthcare providers, ensuring rapid response in critical situations (Tariq et al., 2024). Such advancements highlight the potential of wearable and home-based assistive technologies to reduce risks and promote greater independence among elderly individuals and PWDs.

Wearable devices such as wristbands offer greater portability and user comfort than home-based IoT systems. Lersilp et al. (2020) developed and evaluated an emergency alert wristband for elderly individuals and persons with disabilities. The device incorporated two alert mechanisms: a conscious alert, activated when users pressed an SOS button designed with a recessed surface and a two-second delay to avoid accidental triggers, and an unconscious alert, which was automatically activated through continuous monitoring of heart rate (HR) and oxygen saturation (SpO₂).

In both cases, the system transmitted signals to a receiver and relayed them through the Clever Dog application to caregivers' mobile phones. Usability testing demonstrated that the prototype was functional and beneficial, although users recommended refinements regarding display clarity, device size, and comfort to improve.

In a related study, Sultana et al. (2021) proposed a more advanced safety device for old people and persons with disabilities (PWD) that integrated a pulse sensor with a Global Positioning System (GPS) module to monitor users' heart rate and location in real time. Their system supported multiple input methods, including voice commands ("Help" or "Danger"), a push-button for silent alerts, and automatic triggers based on heart rate abnormalities.

Once activated, the device transmitted Short Message Service (SMS) notifications with GPS coordinates to family members, police, or healthcare providers. While including heart rate monitoring and location tracking enhanced emergency response, the system did not incorporate fall detection—a critical feature given the high risk of falls among elderly individuals and persons with disabilities.

Although various emergency alert devices have been developed, many still face usability, design, and functionality limitations. Common issues include poor display readability, bulky form factors,

and limited comfort, which reduce user acceptance. Other systems integrate features such as heart rate monitoring and GPS, but often lack fall detection, depend on input methods like voice commands that may not always be reliable in emergencies, or are not designed in a wearable form.

These shortcomings underscore the need for a more comprehensive and user-centred solution combining fall detection, vital sign monitoring, and location tracking into a wearable device explicitly tailored for older adults and persons with disabilities.

Research Framework

Theoretical framework

According to the Shannon-Weaver Model, communication begins with the sender or information source, who formulates the message. The transmitter or encoder converts this message into signals, which may encounter interference during transmission. The receiver then decodes the signals back into a form understandable to the intended audience.

In the context of the SOS Band, the ESP-32 mini functions as the core platform that integrates sensors and modules to process and transmit signals. Through this system, real-time monitoring and emergency alerts are communicated effectively. When combined with IoT, the device enhances safety by enabling automated security, real-time data sharing, and operational efficiency.

Conceptual framework

The conceptual framework of this study explains the systematic process of the emergency signaling device. Starting with its sensors that is responsible for receiving the signals from the user which are composed of the following: (1) A pulse sensor to measure heart rate, (2) An accelerometer to detect fall, (3) A NEO-6M GPS Module to capture location, (4) A sim card and GSM Module to send the signals, (5) A push button for manual activation, and (6) a CR2032 Battery to serve as power supply. The Arduino pro mini will then act as the processor to detect the location's coordinates, and to command the GSM module to send the SMS/ Call with indicated location if the following conditions are met : (1) abnormality in pulse rate is detected, (2) fall is detected, or (3) manual button is pressed.

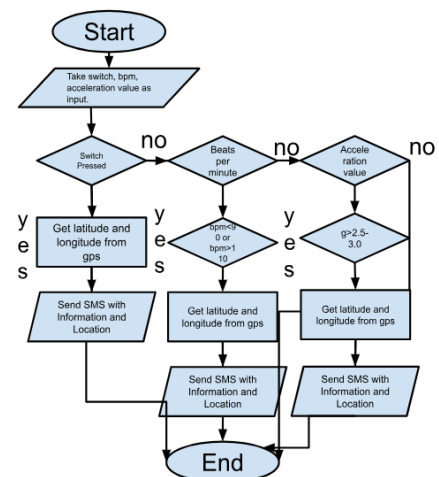


Figure 1. Conceptual framework of the study

Scope and Limitations

This study aims to design and develop an Arduino-based wristband prototype with integrated safety features. The device includes a manual switch button for conscious activation, an automatic trigger for emergencies, a pulse sensor for heart rate monitoring, fall and

motion detection, a GPS module for location tracking. These components enable the system to send emergency notifications and coordinates to designated contacts.

The scope is limited to demonstrating core functions—manual button activation, pulse detection, and fall detection. It will not cover commercialization, advanced health metrics such as blood pressure, unconsciousness without any abnormal pulse or fall event, and blood sugar tracking, or additional features like two-way communication. Long-term durability testing and comparisons with existing devices are also excluded, focusing only on verifying if the prototype works as intended. Lastly, due to the time constraints, the researchers were unable to include offline features to the device.

METHODOLOGY

Research Design

This study will utilize a developmental research design, which involves the process of designing and developing a product, and analyzing its effectiveness in terms of usability (Richey & Klein, 2005, as cited by Yu et al., 2025). The design is non-iterative, meaning it will follow a linear process rather than a continuous cycle of refinement and improvement.

This design will allow the research to undergo the three stages. First, analysis and formulation, where the researchers will review similar existing solutions, and identify the core objectives, target users, and intended functions of the SOS Band. Next, it will undergo the Design and development stage where necessary hardware components and programming will be integrated to construct a single prototype.

Lastly, this research will undergo evaluation, which involves a comprehensive assessment of the pulse detection, fall detection, location detection, and the accuracy of the message transmission to the designated receiver, ensuring that the product performs according to its intended purpose. This aims to demonstrate a linear process of systematically developing the SOS Band, and present its feasibility and performance based on the functionality of its features.

Research Procedure

The study was conducted through a systematic process involving material gathering, system development, fabrication, and testing. The device was developed using an ESP-32 Mini as the central processing unit, integrated with various sensors and modules. These included a pulse sensor for heart rate monitoring, an MPU6050 accelerometer and gyroscope for fall detection, and a NEO-6M GPS module for real-time location tracking. A manual activation switch was also incorporated, while a lithium battery served as the power source. Communication of alerts was facilitated through an email account.

In the system development phase, all necessary components were prepared and assembled. The sensors, GPS module, and switch button were connected to the ESP-32 Mini microcontroller through soldered tin-plated wires. The lithium battery was likewise connected to provide power to the device. The programmed code, developed using the Arduino IDE platform, was uploaded to the microcontroller via a CH340 UART serial converter cable. Once the system integration was complete, all components were enclosed in an acrylic hard-shell casing for durability and protection. The casing was then fitted into a pre-made silicone strap to ensure wearability and user comfort.

For the fabrication of the silicone casing, a mold box was first designed and produced using a 3D printer with PLA filament. The

printed mold was then sanded and finished, followed by the application of a mold release agent to prevent adhesion. Silicone was mixed, poured into the mold, and allowed to cure for 12 to 24 hours before being carefully removed.

Testing and evaluation were conducted through observation-based methods to assess the system's functionality, accuracy, and responsiveness. Pulse detection accuracy was evaluated by comparing readings from the device with those from a reference pulse oximeter. Fall detection performance was tested using controlled and simulated scenarios, with outcomes categorized into true positives, true negatives, false positives, and false negatives to determine sensitivity and false alarm rates. GPS accuracy was assessed by comparing recorded coordinates from known reference locations in both indoor and outdoor environments. Lastly, system responsiveness was measured by conducting multiple trials and calculating the average response time based on recorded timestamps.

Research Instrument

The study utilized a researcher-made data collection instrument designed to evaluate the performance of the SOS Wristband: Arduino Based Emergency Signaling System. The instrument consists of structured tables that measure the device's four primary functions: pulse detection, fall detection, GPS location accuracy, and system responsiveness. These instruments were developed by the researchers to ensure accurate, systematic and consistent recording of experimental data.

Statistical Treatment

The researchers utilized Descriptive Statistics to analyze the recorded data gathered in the testing. Descriptive Statistics synthesizes a data set, providing an organized summarization of data which allows easier comparison for analysis and drawing conclusions (Dong, 2025).

The measure of central tendency: Mean, gives an interpretation of the data by providing and representing the center of the data. It was used in this study for percent errors, accuracy percentage, and response time measurement. The computation follows the formula, where $\sum x$ = sum of the values of the data points and n = total number of data points

$$Mean(x) = \frac{\sum x}{n}$$

Ethical Consideration

Review of Risks and Measures to Mitigate. There were no risks involved in this study because no human participants were included at any stage of the experiment. All procedures were conducted using non-human materials and devices for testing, ensuring that no individuals were exposed to physical, psychological, or environmental harm. As a result, the study fully complies with ethical guidelines regarding the protection of human respondents.

Data Privacy and Protection. Although no personal data from human participants were collected, the researchers ensured that all system-generated data (e.g., sensor readings, GPS coordinates, and test results) were handled securely. Any data transmitted by the device, such as location information sent through email alerts, was limited to designated recipients only. The system was designed to prevent unauthorized access and ensure that sensitive information remains confidential and protected.

Minimization of False Alerts. To address the possible false alarm, this study implemented careful testing and calibration of the sensors

under controlled conditions. Different scenarios were performed to determine actual emergency events from regular activities. Proper threshold values were set for the pulse sensor and accelerometer to ensure that only certain significant changes would trigger an alert. This helps reduce unnecessary notifications and ensures that alerts are only sent during real emergency situations.

Honesty and Integrity. The data gathered from the testing of the device underwent an honest processing and calculations. The researchers made sure to maintain transparency and integrity while conducting the study, with no manipulations on any outcome and/or test conditions.

RESULTS AND DISCUSSION

This chapter presents the findings of the study evaluating the functionality of the device’s sensors and its effectiveness in transmitting emergency signals. The results were obtained through systematic observation and controlled testing. The data gathered from the series of tests are examined in terms of system responsiveness, pulse detection accuracy, fall detection accuracy for both Non-Fall and Fall events, and GPS location tracking accuracy. Collectively, these findings offer insights into the device’s overall performance, reliability, and operational viability.

Table 1. Pulse Detection

Condition	Total % Error	No. of Trials
Normal BPM	16.38%	5
High BPM	24.72%	5
Low BPM	29.76%	5
Mean/Average Percent Error	4.72%	

The performance of the pulse detection component was assessed across three heart rate conditions: normal, high, and low BPM. As shown in Table 1, the system recorded an overall mean percentage error of 4.72% across fifteen trials. A mean percentage error of 5% is typically acceptable for clinical use of heart rate sensors, with some contexts allowing up to 10%. Filguieras et.al. (2025). This indicates that the pulse detection module in the SOS band maintains an acceptable level of accuracy.

A mean percentage error of 3.276%, 4.944%, and 5.952% was recorded for normal, high, and low bpm respectively which shows that the system higher accuracy in normal bpm levels but remains within an acceptable range in high and low bpm levels allowing rapid detection in irregularities despite minor fluctuations.

Similar to what was demonstrated in the study of Karmakar A., et al. (2021) where a pulse sensor was integrated in their emergency signalling system. The outcome of 4.72% mean percentage error for pulse detection further validates its suitability for emergency-response functions.

Table 2. Fall Detection : Fall Event

	Detected		Outcome	
	Yes	No	TP	TN
Frequency	9	1	9	1
Percentage	90%	10%	90%	10%

The fall detection tests for actual fall events yielded a high detection rate, with the device correctly identifying 9 out of 10 induced falls. Only one trial resulted in a non-detection, indicating a potential false negative. These results suggest that while the fall detection system is generally reliable, it may still fail to register certain fall conditions, highlighting the need for further refinement and calibration.

Table 3. Fall Detection : Non-Fall Event

	Detected		Outcome	
	Yes	No	TP	TN
Frequency	0	8	0	8
Percentage	0	100%	0	100%

The accuracy test for non-fall events demonstrated exceptionally strong system performance, indicating that the device is highly capable of differentiating normal daily activities from actual fall incidents. Across all eight trials, which involved sitting, standing, waving, walking, lying down, jumping, dancing, and general movement, the device consistently recorded a “No” detection response. This indicates that the fall detection module did not misinterpret regular body motions as fall events. All outcomes were therefore classified as true negatives, resulting in a 100% accuracy rate for non-fall conditions.

The high level of accuracy in the findings for fall detection in both fall and non-fall events align with the study of Chandak, Chaturvedi, and Dhiraj (2022), citing Khojasteh et al. (2018) expanding on safety-oriented applications that wrist worn accelerometers offers high precision making it suitable for smartwatches and emergency signalling bands like the SOS band.

Table 4. GPS Location Accuracy

	Yes	No
Frequency	10	0
Percentage	100%	0

Table 4 shows that all ten trials, conducted in both outdoor and indoor settings, showed complete correspondence between the actual geographic coordinates and those recorded by the device. Each recorded location matched the reference coordinates exactly, resulting in a 100% accuracy rate with no observed discrepancies.

Similar to the study of Sultana et al. (2021) and Dave et al. (2020) which developed an emergency system integrated with GPS modules, the results of the GPS location accuracy test demonstrate that the device is highly precise in identifying and reporting geographical coordinates across varying environmental conditions.

This signifies that emergency systems with integrated GPS module is reliable and suitable for real-world incidents where precise and accurate location-tracking are critical for proper emergency response in aiding to the user’s safety.

Table 4. GPS Location Accuracy

	Total Response Time	No. of Trials
Fall Event	240.15 sec	5
Manual Press	254.17 sec	5
Mean/Average Response Time	49.432 sec	

Table 5 shows the results the researchers were able to gather to assess the responsiveness of the system. A total of ten (10) trials were conducted for this category — the researchers subjected the device to five (5) simulated fall events and five (5) manual activation of an emergency alert with the use of the switch. The researchers then recorded how long, in seconds, the device was able to respond and send alerts after a person experiences such incidents.

Data shows that on average, the emergency wristband is able to send emergency alerts 49.432 seconds after a risky situation happens to its user.

The researchers used email as a means of communication between the device and the receiver, and it is one of the core components of the broader IoT ecosystem. Therefore, the findings align with emergency the statement of Tariq et al.

(2024) which states that the use of IoT in emergency devices ensures rapid response when transmitting emergency signals.

CONCLUSION

The objective of this study was to develop an Arduino-based wristband emergency signaling system equipped with pulse detection, fall detection, GPS location tracking, and manual activation features, and to assess the functionality and effectiveness of its components under controlled testing conditions. Based on the development process, the researchers successfully designed and assembled a functional wristband prototype that integrates pulse monitoring, fall detection, location tracking, and manual alert activation. This demonstrates that the device was able to fulfill its intended core system features, particularly for elderly individuals and persons with disabilities living independently.

The results of the testing phase showed that the integrated sensors performed accurately under controlled trials. The pulse sensor exhibited an acceptable level of accuracy, while the fall detection system demonstrated high reliability in identifying both fall and non-fall events. Additionally, the GPS module consistently identified and transmitted accurate location data across all testing conditions, confirming the effectiveness of the tracking component.

Furthermore, the evaluation of the alert transmission system revealed that the wristband was capable of sending emergency alerts with an average response time of approximately 49 seconds. This indicates that the device can provide timely emergency signaling and facilitate prompt assistance during critical situations, supporting its potential application as a reliable safety tool.

Recommendations

Considering the findings and the limitations encountered in the study, several recommendations have been identified. These suggestions can help guide future research toward the intended direction of the project. The following outlines the proposed recommendations:

It is recommended to improve the accuracy of the pulse sensor by implementing advanced calibration techniques, applying signal filtering methods, or exploring the use of higher-precision sensors. Enhancing accuracy will reduce measurement errors, particularly for elderly individuals and persons with disabilities, ensuring that the device provides reliable physiological monitoring.

It is recommended to optimize the alert transmission system to reduce response time. This could involve improving the communication algorithm, using faster network connections, or minimizing data packet size, thereby ensuring that emergency signals reach caregivers or authorities as quickly as possible to provide timely assistance.

It is recommended to integrate an application that functions offline to further enhance the reliability and effectiveness of the device.

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

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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 (oxidizable, 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 oxidizable 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.

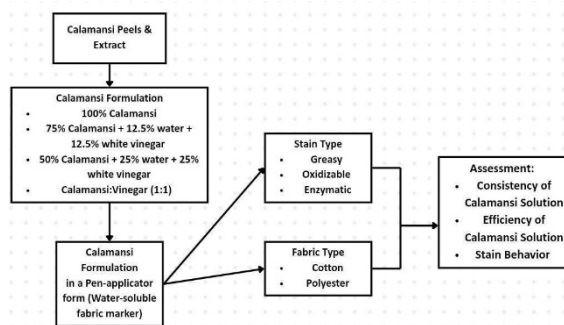


Figure 1. Conceptual framework of the study

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:

$$\text{Mean} = \frac{\sum_{i=1}^n X_i}{n}$$

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

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

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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THE EFFECTIVENESS OF OREGANO AND ALOE VERA EXTRACT CONCENTRATION ON THE ANTIMICROBIAL ACTIVITY OF A BODY-HEAT DISSOLVING DUAL-ACTION SANITIZER-SOAP CAPSULE

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ABSTRACT

This study developed and evaluated a body-heat-dissolving, dual-action sanitizer-soap capsule as an alternative hand-hygiene product. The capsule used a gelatin-glycerin film designed to rupture under body-temperature friction. Three formulations containing castile soap, aloe vera, and diluted oregano essential oil (25%, 50%, and 75%) were prepared. Dissolution tests using heated silicone hands showed that all capsules successfully dissolved, with only minor variations in rupture speed and shell consistency. Antimicrobial activity was assessed with the Kirby-Bauer disk diffusion method against *Staphylococcus aureus*, using ciprofloxacin as a positive control. All formulations indicated measurable antibacterial activity, with the 75% concentration producing the largest inhibition zone, followed by 50% and 25%, while the positive control remained significantly stronger. These findings suggest that the sanitizer-soap capsule has potential as a portable, single-use sanitation option that dissolves under body heat and provides antibacterial effects. Further improvements in gelatin include refining shell making, sealing stability, enhancing formulation consistency, and expanding future testing to additional bacterial strains, standardized neutralization methods, and optimized capsule-forming techniques.

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

INTRODUCTION

Background of the Study

Nothing in this world is truly devoid of bacteria. Everyday, our hands make contact with objects and surfaces that are prone to bacteria, making our hands one of the most exerted parts of a person's body. As stated in a study conducted in 2020 by Khairnar et al, "Hands are the most common medium for initiation and spread of infection in clinics." For this reason, maintaining cleanliness and bringing portable sanitizers is necessary, taking into consideration that there is not always a water source nearby.

However, instead of always purchasing alcohol bottles or carrying bulky soaps, capsules offer a more portable and convenient solution for hand hygiene. This study aims to assess the effectiveness of capsules containing oregano and aloe vera extract in becoming a dual-action sanitizer-soap.

Oregano (*Origanum vulgare*) is a herb known for its medical and potential antibacterial properties, which is primarily attributed to its essential oil components. According to Tao et al. (2025), oregano essential oils (OEOs) that were extracted from wild and cultivated oregano with white or purple flowers showed strong antibacterial effects.

The study recognizes that carvacrol, an important component of oregano, demonstrates a low MIC value (0.005–0.04 mg/mL) against both Gram-positive and Gram-negative bacteria. Moreover, the study also shows that combining carvacrol with tybocramin had a mutual

effect, indicating that a component in oregano can increase the effectiveness of other antimicrobial agents.

Besides its bacterial effects, Yuan et al. (2023) found that oregano essential oil (OEO) also contains an antifungal action against clinically isolated oral *Candida* strains. It has a strong potential for the prevention and treatment of *Candida*-associated denture stomatitis, which is the most common fungal infection among denture wearers.

As per Arbab et al. (2021), Aloe vera is known to have medicinal attributes. Historically, it has been utilized in the treatments of an extensive range of disorders including light fever, burns and wounds, gastrointestinal infections, diabetes, sexual potency and infertility issues to cancer, immune system modulation, AIDS, and several skin diseases.

Aloe vera (*Aloe barbadensis miller*) belongs to the cactus-like xerophytes family of plants, and around 360 species have been discovered. It is utilized in the treatment of a number of skin conditions (dermatitis, acne and skin irritation, burns, wound) and has also been used to cure exposure of the skin to ultraviolet as well as gamma radiation. A number of studies document the effective utilization of this plant when used topically to heal burns, sunburns, inflammatory dermal diseases, and wounds.

Although Aloe vera and oregano are well known for their antibacterial and skin-soothing qualities, not much is known regarding how well they work together in a dual-action solution.

Additionally, there is only a limited amount of research done on the effective use of body-heat dissolving capsules as a sanitizer-soap product.

Furthermore, there are still a few unanswered problems regarding how stable the body-heat dissolving capsule is, what its dissolution rate is, and how effective it is to release active ingredients so as to use it as a delivery system for hand hygiene products. However, they have not been well investigated yet. In comparison, information on whether such a system could match or surpass the antimicrobial efficacy and user safety of the product. This deficiency emphasizes the necessity of studies that carefully investigate concentration effects, capsule performance, and actual antimicrobial results. This gap highlights the need for the overall effectiveness in practical hand hygiene application.

Objectives of the Study

The researchers aim to determine the effect of varying concentrations of oregano (*Origanum vulgare*) and Aloe vera (*Aloe barbadensis* Miller) extracts on the antimicrobial activity of a body-heat dissolving dual-action sanitizer-soap capsule. The three main objectives for this study are: (1) To develop a dual-action sanitizer-soap capsule with oregano and aloe vera extracts as an alternative hygienic solution. (2) To analyze the effect of different extract concentrations (25%, 50%, 75%) on antimicrobial effectiveness by using the Kirby-Bauer Disk Diffusion Test. (3) To assess the dissolution performance of the capsule body temperature.

Related Literature

Antimicrobial Properties of Oregano (*Origanum vulgare*)

Oregano (*Origanum vulgare*), a common culinary herb, has been recognized as more than just a flavoring agent; it is also valued for its strong antimicrobial properties. Its antibacterial properties come from carvacrol and thymol, which are present in oregano extracts. These compounds can damage the cell walls of bacteria, hinder enzyme activity, and prevent the formation of biofilms, therefore making oregano effective against different types of harmful microbes.

Moghrovyan and Sahakyan (2024) stated that oregano essential oil, which contains thymol and carvacrol demonstrates antibacterial activity by changing membrane permeability, disturbing ion transport, and delaying biofilm growth. These mechanisms were effective against both resistant and non-resistant strains, including *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*. Their study highlights the molecular-level pathways through which oregano compounds weaken bacteria, providing more understanding into its biological activity.

In contrast, Soltani et al. (2021) highlighted the effectiveness of oregano's antimicrobial components. Instead of focusing mainly on molecular pathways, they also showed how oregano extract can also be applied as a natural substitute for chemical-based antimicrobials. Their findings support oregano's role in addressing the growing concern of antimicrobial resistance by demonstrating its constant activity against problematic pathogens such as *Staphylococcus aureus*.

Similarly, Li et al. (2025) provided quantitative evidence by determining low minimum inhibitory concentrations, such as 3.13 $\mu\text{L}/\text{mL}$ for *S. aureus* and 6.25 $\mu\text{L}/\text{mL}$ for *Bacillus cereus*. Using gas chromatography, mass spectrometry, and transcriptomic analysis, they confirmed that oregano compounds could not only damage bacterial cell structures but also interfere with important metabolic

processes. This data-based perspective strengthens the study of oregano's effectiveness even at small concentrations, making it efficient for the formulation of antimicrobial products.

In support of this, Nurzyńska-Wierdak and Walasek-Janusz (2025) pointed out that oregano is rich in thymol and carvacrol, making it very useful not only for antibacterial purposes but also for its anti-inflammatory and therapeutic benefits. Their review spanned on oregano's established role in traditional medicine and how its growing in terms of application in cosmetics, antiseptics, and preservatives. They also noted that thymol and carvacrol can work both individually or together, therefore improving oregano's overall antimicrobial effectiveness.

In summary, oregano has been shown to be a powerful natural antimicrobial agent. While Moghrovyan and Sahakyan (2024) explained the scientific basis of oregano's antibacterial activity, Soltani et al. (2021) shared its applied potential against resistant pathogens, and Li et al. (2025) added quantitative proof of its effectiveness at low concentrations. In similarity to these, Nurzyńska-Wierdak and Walasek-Janusz (2025) emphasized oregano's known therapeutic properties. When taken together as a whole, these findings further support oregano's growing potential as an effective and sustainable alternative to chemical antimicrobials.

Medicinal and Dermatological Applications of Aloe vera (*Aloe barbadensis* Miller)

Aloe vera is commonly known as a green cactus-like plant which can be used for medicinal as well as cosmetic purposes. The gel of the plant has a cooling and healing effect, which is applied to heal burns, cuts, and even rashes on the body. It is beneficial in skin issues such as acne, ulcers, and dermatitis, and it is also employed in the cosmetic industry as a moisturizer, sunscreen and anti-aging substance. Its healing properties are evident from plants' natural healing.

Zhu et al. (2024) stated that Aloe vera (AV) has been recognized for its safety and effectiveness in treating various medical conditions for centuries. Its anti-tumor, anti-diabetes, and immune-boosting properties have been noted, along with significant benefits for skin health, including its bactericidal and anti-inflammatory effects, ability to induce wound healing, and antioxidant benefits.

Based on Mondal et al. (2020), Aloe vera is one of the oldest plants with 200 biologically active ingredients, of which acemannan is the main active ingredient that gives it its medical qualities. Acemannan is a long-chain polysaccharide with strong antibacterial, antifungal, antioxidant, and immunomodulating properties that make it a "healing plant." This study highlights the capabilities and adaptability of health and skin-contact products.

As mentioned by Matei et al. (2025), the Aloe vera plant (*Aloe barbadensis* Miller) contains bioactive compounds that are rich in polysaccharides. This study stated that it is traditionally known for its antimicrobial, anti-inflammatory, antioxidant, and tissue-regenerating properties. The benefits of it are valuable for biomedical applications, skin repair, antiviral applications, and tissue engineering scaffolds.

Sánchez et al. (2024) highlighted that new activities have been explored in Aloe vera and active constituents with a special emphasis on its potent utility as a cytotoxic, antitumoral, anticancer, and antidiabetic compound. It is to be particularly noted that between in vitro studies, there is a great number of studies comparing Aloe vera's protective effects in bone disorders like osteoporosis.

Aloe vera, as noted in the research conducted by Zhu et al. (2024), can cure skin and other diseases as it is anti-diabetes and anti-tumor which can cure skin ulcers, dermatitis, and acne vulgaris by the antibacterial, anti-inflammatory, and antioxidant action.

Soap and Hand Sanitizers in Promoting Proper Hand Hygiene Practices

Hand hygiene is one of the most important practices in order to stop the spread of infectious diseases. The most commonly used products for hand hygiene are soap and alcohol-based hand sanitizers.

These two share the main goal of cleaning and sanitizing, however, they have varying aspects to each other. Soap removes dirt, grease, and a wide range of microbes by using it with a washing action and the help of water. On the other hand, sanitizers provide a fast and convenient alternative whenever water is not available.

Soap and sanitizer use usually depends on the context even if both are trusted for reducing microbial risks, as per Hoffman et al. (2021). In the study, about 70% of respondents considered soap the “most reliable” option because it removed the visible dirt and gave a feeling of complete cleanliness. On the other hand, hand sanitizers were valued for convenience, especially in situations like traveling or when water was unavailable.

However, the study also showed that nearly 40% of participants are worried about skin dryness from continued sanitizer use. The findings suggest that more common habits and accessibility in social environments strongly influence preference, as people were more likely to choose whichever option was most available in their immediate surroundings.

Similarly, Duane et al. (2022) increased this understanding by looking at the sustainability and health implications of soap versus sanitizers. Their study emphasized that even if sanitizers are highly effective against a wide range of pathogens, overuse of this raises concerns regarding chemical exposure.

In addition, Duane et al. also noted the environmental burden of single-use plastic sanitizer bottles and the reliance on chemical production, which may not be sustainable long term. On the other hand, soap was identified as a more environmentally friendly and sustainable option, provided that water is available, since it requires less chemical processing and generates fewer ecological risks.

From these insights, a literature review by Belgis, B. & Algadrie, Z. in 2024 focused on how teenagers are particularly vulnerable during this stage of life due to ongoing physical and emotional development, as well as increased social interactions. While handwashing with soap and water effectively removes germs, hand sanitizers are often used as a more convenient alternative.

The aim of this study was to compare the effectiveness of hand sanitizers and handwashing among teenagers. A literature review was conducted using secondary data from publications between 2007 and 2024, ultimately using eight studies that fit their criteria. The findings were mixed. Three studies indicated that hand sanitizers are more effective than handwashing, while five studies concluded that handwashing is more effective.

The studies favoring handwashing emphasized that hand sanitizers may leave residual germs, do not reach the deeper layers of the skin, and can cause skin dryness and irritation with prolonged use due to their high alcohol content. In conclusion, based on the evidence, teenagers should prioritize handwashing with soap and running water

over the use of hand sanitizers for better hygiene and infection prevention.

Adding further support, Susilaningrum et al. (2021) explained that soap, especially antibacterial soap, is better at cleaning and killing germs on the hands than just using water or hand sanitizer. Liquid soaps are popular because they are easy to use, more hygienic, and better at removing dirt and germs, especially when combined with the scrubbing action of washing.

Compared to hand sanitizers, Susilaningrum et al. (2021) stated that washing hands with soap and water does a better job of removing germs. While hand sanitizer is useful for quick disinfection, washing hands with soap and water is more effective in removing a wider range of microorganisms and dirt, especially viruses, due to its ability to physically dislodge microbes. Hand sanitizer is a convenient option when handwashing facilities are unavailable as it is effective in killing germs and preventing microorganism growth on the skin.

However, using insufficient quantities reduces effectiveness. Soap works by physically loosening and washing away bacteria, while hand sanitizers mainly kill germs with alcohol. If the alcohol level is low, hand sanitizers become less effective. Therefore, washing with soap and water is generally the most effective way to clean hands and keep germs away.

The collective studies highlight that both handwashing with soap and water and the use of hand sanitizers are valuable tools for maintaining hygiene and preventing infection, each offering unique advantages. But, although hand sanitizers offer a convenient and quick alternative, especially when water is unavailable, they may be less effective in eliminating certain microbes and leave residual germs, cause skin dryness, and have environmental and health concerns related to chemical use and sustainability.

In contrast to this, soap is highlighted as a safer, more environmentally friendly option that effectively reduces microbial load, making it preferable for long-term hygiene practices. Therefore, while both methods play roles in infection prevention, prioritizing soap and water is good for optimal hygiene, with hand sanitizers serving as a supplementary option in circumstances where handwashing is not feasible.

Research Framework

Phytochemical Theory

This study adopts the Phytochemical Theory to further investigate the antibacterial effect of oregano and Aloe vera when used in a sanitizer-soap capsule. The theory states that plants produce secondary metabolites (e.g. phenols, flavonoids, terpenoids, and saponins) which are complex organic molecules that can serve as an instrument for its interaction with the environment, including protection and defense for itself (Ashraf et al., 2023). These compounds have been studied for their antimicrobial potential and are often being used in pharmaceutical and hygienic products (Khare et al., 2021).

A study by Hochma et al. (2021) showed that compounds in oregano, specifically carvacrol and thymol, have promising antimicrobial properties.

Similarly, aloe vera possesses healing and antimicrobial effects due to its natural compounds like anthraquinones, saponins, and flavonoids. The study is based on the idea that these natural compounds can be used effectively in hygiene products like a

sanitizer-soap capsule, with their strength varying depending on the concentration used.

Conceptual Framework

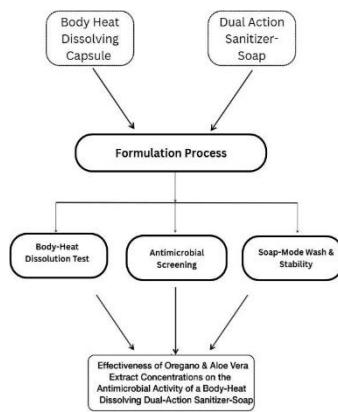


Figure 1. Conceptual framework of the study

This research focuses on developing a Body-Heat Dissolving Capsule Dual-Action Sanitizer-Soap through the concentrational extracts of Oregano and Aloe vera. The framework begins with two main inputs: the body heat dissolving capsule which dissolves when coming in contact with body heat, and the dual-action sanitizer-soap which is designed to function as both a sanitizer and a soap.

These two components will undergo a formulation process to ensure that the product dissolves properly with body heat while maintaining its dual action component. Once the product is formulated, it will undergo three types of tests: (1) First, the heat activated capsules will be tested on a heated silicone hand with a temperature of 36–37 °C and rubbed to simulate hand friction. The researchers will measure the time on how long it will last for the complete dissolution. (2) Then, an antimicrobial activity test will be done. The researchers will undergo different concentrations of oregano and aloe vera extracts (25%, 50%, 75%) that will be tested against *S. aureus*. Methods include measuring inhibition zones and agar well/disk diffusion. These tests will help determine how effective the Oregano and Aloe vera extracts are in fighting against *S. aureus*.

Afterwards, the soap-mode process will be tested by applying the capsule with water to simulate handwashing. This test will compare the effect against *S. aureus* which is to be achieved by the sanitizer-soap with water-only washing.

The final step will be to evaluate the overall effectiveness of the extract concentrations on the antimicrobial activity of the sanitizer-soap. This will show whether the product is truly effective as a natural and dual-purpose hygienic solution.

Scope and Limitations

This study will assess how Aloe vera and oregano will be used as antibacterials and their effectiveness when combined in a dual-action sanitizer-soap capsule that is a solution for hand hygiene. This study will be conducted under laboratory tests that will determine how these extracts fight specific bacteria, without evaluating other antimicrobial agents or formulations. The results will indicate the overall efficacy of Aloe vera compared to usual antibacterial agents and the combined effects of using both extracts to combat bacteria. The study will also explore how body heat activates the sanitizer-soap capsule to enhance the sanitizing process.

However, the research will not consider the long-term stability of the sanitizer-soap capsule or any potential skin irritation for different individuals in actual conditions. It will only focus on the dual-action

sanitizer-soap capsule and the effectiveness of the Aloe and oregano extracts, without testing other natural products. The research does not include how the researchers' sanitizer-soap capsules may affect users with sensitive skin or the effects of long-term use. The research does not include how the researchers' sanitizer-soap capsules may affect users with sensitive skin or the effects of long-term use against sensitive skin. The focus will remain on the antibacterial properties of the extracts and how they contribute to the effectiveness of the sanitizer-soap capsule.

METHODOLOGY

Research Design

This study will adopt a developmental research design, specifically utilizing a non-iterative (single-cycle) approach to test, evaluate, and determine the effect of oregano and aloe vera extract concentration on the antimicrobial activity of dual-action sanitizer soap with body heat capsules. This approach is appropriate for assessing the initial effectiveness of the extracts and avoiding alterations, thus allowing concentrated analysis of their effects at one stage of development by testing the processes created (Maidment, 2020). A design will collect sufficient data on how aloe vera and oregano concentrations affect antimicrobial activity as a dual-action sanitizer-soap.

In line with recent laboratory practices, the study will utilize silicone hand models as controlled testing surfaces for antimicrobial evaluation. Silicone replicas are recognized as practical substitutes for human skin because they offer thermal stability, safety, and consistent conditions suitable for product testing (Althumayri et al., 2024). Although they do not replicate full skin features, their ability to maintain body-like temperature and provide a reproducible testing surface makes them appropriate for this developmental research design.

This study aims to give us knowledge about the effectiveness of plants as sanitizer soap and how body heat capsules make your life easier as portable sanitizer, and this research intends to provide useful information that can help future researchers.

Furthermore, having body heat-activated capsules in the soap formulation provides an additional unique method for longer preservation and steady antimicrobial action. This quality of the product illustrates its convenience in sanitizing product, on-the-go sanitizing solution, and the primary needs for such a product are the unavailability of standard sanitizers and washing facilities.

The scope of this study is to evaluate the combination of plant-derived antimicrobial ingredients with contemporary personal care products to find out whether such products will serve as substitutes to synthetic chemical sanitizers. The findings will also demonstrate the practical feasibility of the product idea and are expected to assist other researchers and product designers working on natural active ingredients for personal care and health safety in the hygiene products domain.

Procedure

The materials used in this study include unflavored gelatin (10 g), distilled water (20 mL), vegetable glycerin (3 mL), Castile soap base, aloe vera extract, oregano essential oil (as a substitute for oregano extract), ethanol, xanthan gum, Mueller-Hinton Agar (MHA) plates, blank discs, ciprofloxacin discs, and parchment paper. The equipment utilized consists of a digital scale, beakers and labeled containers, a hot plate, stirring rod, measuring dropper, silicone molds, pH meter or strips, incubator set at 37 °C, autoclave, vernier caliper, and silicone hands.

To prepare the capsule shell, 10 g of gelatin was first sprinkled over 20 mL of cold distilled water and allowed to bloom for 5–10 minutes until fully swollen. The bloomed gelatin was then heated in a water bath at 50–60 °C and stirred until completely dissolved. Afterward, 3 mL of vegetable glycerin was added and mixed thoroughly until a uniform solution was achieved. The warm mixture was poured onto parchment paper and spread into a thin film. This film was left to dry until it became firm, flexible, and non-sticky, after which it was carefully peeled off.

For the capsule core, three labeled beakers corresponding to 25%, 50%, and 75% concentrations were prepared. Each beaker contained 7.5 mL of Castile soap, 3 mL of aloe vera extract, and 0.6 mL of vegetable glycerin. Since oregano extract was unavailable, oregano essential oil was diluted in ethanol to create the antimicrobial solution. The diluted oregano solution was then added to each beaker according to the designated concentration levels, with 25% as the least, 50% as moderate, and 75% as the highest concentration. If the mixtures appeared too runny, a small amount of pre-dissolved xanthan gum in warm water was added to slightly thicken the solution, followed by continuous stirring until smooth.

For capsule assembly and sealing, the dried gelatin film was cut into uniform circular pieces and gently pressed into molds to form capsule halves. Approximately 0.5 mL of the prepared core mixture was dispensed into each capsule half using a dropper. Another gelatin piece was placed on top, and a heated cutter mold was used to seal the edges by slightly melting the gelatin, ensuring the capsule was securely closed without burning it. The sealed capsules were then allowed to dry at room temperature and stored in a clean, covered container until further testing.

To evaluate antimicrobial properties, the Kirby-Bauer disk diffusion test was conducted using *Staphylococcus aureus* as the test organism. Mueller-Hinton Agar plates were prepared, and blank discs were soaked with the 25%, 50%, and 75% capsule core solutions, with three discs per concentration. The agar plates were streaked with the bacterial culture, and the soaked discs, along with ciprofloxacin discs as the control, were placed evenly on the agar surface. The plates were incubated at 37 °C for 24 hours. After incubation, the zones of inhibition were measured in centimeters using a vernier caliper, and the results were recorded.

For the body heat dissolution test, silicone hands were placed on a hot plate and adjusted to approximate human body temperature. A capsule was placed on the warmed surface, and a timer was started while gently rubbing the capsule. Observations were made on the time required for the capsule to rupture and spread. This procedure was repeated at least three times to ensure accuracy and consistency.

Lastly, for soap mode testing, the silicone hands were again heated to body temperature. A capsule was placed on the surface and rubbed with water using a handwashing motion. The dissolution time, residue, and visual cleanliness were recorded. This process was repeated at least three times for comparison and reliability of results.

Research Instrument

This observation sheet will document the results from the antimicrobial efficacy test and the capsule's ability to dissolve with body heat. It will provide sections for recording data from the Kirby-Bauer Disk Diffusion Test, and Soap-mode Test with Water, ensuring consistent measurement of bacterial reduction, inhibition zones, and cleaning effectiveness under controlled conditions. By utilizing this, the researchers can guarantee that the data is organized efficiently, providing an easier way to check accuracy and track the overall performance of the antimicrobial body-heat dissolving capsule and its components.

Statistical Treatment

In the study, descriptive statistical methods were used to process and analyze the data gathered from the Body-Heat Dissolution Test, the Kirby-Bauer Disk Diffusion Test, and the Soap-Mode Wash Test. The measures computed included the mean to determine the average performance of each concentration, the standard deviation to describe the variability of the results, and the kurtosis to identify the distribution pattern of each set of values. All statistical computations were carried out using Jamovi, which provided an organized and accurate summary of the recorded data. These descriptive measures were applied to support the interpretation of the outcomes presented in the Results section.

Ethical Considerations

During the making of the product, the researchers are guided by the following ethical considerations:

No Human and Animal Testing. The researcher made sure that no humans or animals were used in testing the sanitizer soap capsule. Instead of real hands, silicone fake hands were used to simulate (the testing) to avoid biological risk. With this, it protects the living subjects while ensuring accurate and safe experimentation.

Accountability with Results. All data collected while doing the experiment were recorded accurately and reported directly. This ensures the reliability of this research regarding the findings on the antimicrobial activity and aloe vera extract concentration.

Sustainable Material Use. The study prioritizes the use of sustainable materials, including the natural extracts of oregano and aloe vera. To reduce waste, laboratory equipment was carefully selected and used effectively. This dedication supports sustainability throughout the research process.

Safety During Work. Proper laboratory safety protocols were strictly followed during the experiment to prevent any accidents or contamination that might occur. The researchers wore protective equipment and maintained a controlled workspace to ensure a safe environment where the researcher developed and tested the sanitizer-soap capsule.

RESULTS AND DISCUSSION

Dissolution with Body Heat Test (Sanitizer Mode)

In the Body Heat Dissolution Test, proving that the formulation was both practical and sensitive to standard skin heat. Compared to the 25% and 75% concentrations, the 50% concentration revealed the most stable dissolving performance, with a mean dissolution time of 25.67 seconds and the lowest standard deviation (4.93). This means that the capsule's most stable structural balance might have been achieved at the 50% concentration. The 75% concentration showed more variability, which indicates that both lower and higher extract levels may have an effect on the capsule's physical behavior, even if the 25% concentration dissolved a little more slowly and inconsistently.

The formulation of the plant extracts may be the reason for the differences. While oregano has concentrated bioactive components like carvacrol and thymol, aloe vera contains polysaccharides like acemannan, which are recognized for their gel-like and moisture-retaining qualities. Aloe vera has a variety of physiologically active compounds that support healing, antibacterial activity, and viscosity, according to Mondal et al. (2020) and Matei et al. (2025). These components may make the capsule mixture denser or thicker at higher concentrations, which could account for the 75%

concentration's less consistent dissolution even if it was effective. As a result, the ideal balanced effect between heat sensitivity and capsule stability could be considered found at the 50% concentration.

Table 1. Body Heat Dissolution Test

Observation No.	25%	50%	75%
1	22s	29s	24s
2	19s	20s	45s
3	48s	28s	21s
Mean	29.67s	25.67s	30.00s
SD	15.95	4.93	13.08
Kurtosis	-1.50	-1.50	-1.50

Kirby Bauer Disk Diffusion Test

The 75% concentration indicated the best antibacterial activity against *Staphylococcus aureus* among the experimental groups, indicated to the Kirby-Bauer Disk Diffusion Test results. It consistently provided the most significant mean zones of inhibition in both trials, even somewhat surpassing the ciprofloxacin control in Trial 1. This indicates that the product's antibacterial potential was improved by adding more oregano and Aloe vera extract.

Oregano essential oil indicates antibacterial activity by interfering with ion transport, changing bacterial membrane permeability, and slowing biofilm formation, according to Moghrovyan and Sahakyan (2024). Oregano is effective against bacteria like *Staphylococcus aureus* because these mechanisms inhibit bacterial survival and reproduction. In the same manner, Li et al. (2025) discovered oregano compounds can disrupt vital bacterial metabolic processes and are effective even at low concentrations. Higher concentrations most likely contained more of these active antimicrobial substances, which helps explain why the 75% concentration in the current analysis exhibited the biggest antimicrobial zones.

Additionally, Aloe vera is shown to have antibacterial, anti-inflammatory, antioxidant, and wound-healing qualities, which makes it ideal for skin-contact hygiene products (Zhu et al., 2024). The antibacterial and antifungal properties of Aloe vera are also attributed to acemannan, one of the plant's primary bioactive chemicals, according to Mondal et al. (2020). This indicates the barrier against *S. aureus*. The antibacterial efficacy of the capsule may have been improved by the combination effect of oregano and Aloe vera extracts.

In both experiments, the 50% concentration exhibited the weakest zones of inhibition while the 75% concentration exhibited the strongest antibacterial activity. It indicates that higher levels in concentration does not always result in a perfectly linear enhanced efficiency in performance under every circumstance. The diffusion rate of active chemicals into the agar, rather than only their actual antibacterial power, may have been shaped by the interaction between the two plant extracts and the capsule medium. To put it another way, even if a sample contains potent antibacterial chemicals, the inhibition zone may still be smaller if the compounds are not as effective in spreading through the test medium. This illustrates how crucial it is to interpret disk diffusion results as indicators of compound dispersion and release behavior in addition to its efficacy.

Table 2. Disk Diffusion Test (Trial 1)

Observation No.	CIP	25%	50%	75%
1	3.575cm	2.985cm	2.340cm	3.525cm
2	3.250cm	3.165cm	1.970cm	3.000cm
3	3.175cm	2.850cm	1.465cm	3.460cm
Mean	3.34cm	3.10cm	1.92cm	3.47cm
SD	0.16	0.18	0.38	0.36
Kurtosis	-1.23	-1.46	-1.53	-1.13

Table 3. Disk Diffusion Test (Trial 2)

Observation No.	CIP	25%	50%	75%
1	3.475cm	3.00cm	2.390cm	3.710cm
2	3.325cm	3.310cm	1.645cm	3.140cm
3	3.210cm	3.290cm	1.690cm	3.980cm
Mean	3.34cm	3.10cm	1.92cm	3.47cm
SD	0.16	0.18	0.38	0.36
Kurtosis	-1.23	-1.46	-1.53	-1.13

Dissolution with Water (Soap Mode)

All concentrations properly cleaned the silicone hand model in the Soap Mode Wash Test, but higher concentrations showed better performance. The 75% concentration had the shortest mean wash duration (7.00 seconds), followed by 50% (9.00 seconds) and 25% (13.33 seconds). Qualitative observations further showed that the 25% solution produced weaker foam and less surface coverage, while the 50% and 75% concentrations generated more lather and left minimal residue.

These findings align with existing research. Susilaningrum et al. (2021) noted that soap effectively removes dirt, oils, and microbes, while Hoffman et al. (2021) found that users perceive soap as more reliable due to its visible cleaning action. Similarly, the dual-action capsule combined sanitizer convenience with the mechanical benefits of soap, particularly at higher concentrations. The results also support the potential of plant-based formulations, as oregano has recognized antimicrobial properties (Soltani et al., 2021), and aloe vera provides anti-inflammatory and skin-soothing benefits, enhancing safety and user acceptance (Duane et al., 2022).

Overall, concentration had an influence on different aspects of performance. The 50% formulation demonstrated the most consistent dissolution, suggesting better physical stability, while the 75% concentration showed the highest antibacterial and cleansing efficacy. This indicates that the optimal concentration depends on the intended priority—balanced performance or maximum effectiveness. In conclusion, concentration plays a critical role in enhancing the performance of dual-action sanitizer-soap capsules, and the successful incorporation of oregano and aloe vera supports the viability of plant-based alternatives in hygiene product development.

Table 4. Soap Mode Wash Test (Wash Duration)

Observation No.	25%	50%	75%
1	14s	3s	2s
2	10s	12s	9s
3	16s	12s	10s
Mean	13.33s	9.00s	7.00s
SD	3.06	5.20	4.36
Kurtosis	-1.50	-1.50	-1.50

CONCLUSION

The results of the study demonstrate that the dual-action body-heat dissolving sanitizer-soap capsule successfully met the research objectives. The product dissolved effectively at body temperature, exhibited measurable antibacterial activity, and showed functional cleansing performance across all concentrations tested. In the two trials, the 75% concentration displayed the strongest antibacterial efficacy, while the 50% concentration proved to have the most consistent and reliable dissolution results. Though all formulations were usable, the Soap-Mode Wash Test revealed that the 25% concentration presented drawbacks, that includes weak lather formation and a sticky residue. Overall, the medium to high concentrations (50%–75%) produced the best balance between dissolution, cleansing ability, and antimicrobial effectiveness, with higher concentrations delivering superior antibacterial action

This research demonstrates the practical potential of combining plant-based extracts specifically oregano and aloe vera with a body-heat dissolving way. At a time when hygiene, accessibility, and sustainable alternatives to chemical sanitizers are increasingly important, this study offers a promising natural solution that can function both as a sanitizer and a soap. The findings contribute to the growing body of evidence supporting herbal antimicrobial agents and introduce a capsule that may benefit communities with limited access to traditional hygiene products.

However, the study is not without limitations. It did not test long-term product stability or performance under real-world environmental conditions, nor did it evaluate possible skin reactions over extended use. These aspects provide valuable directions for future research.

Lastly, the dual-action sanitizer-soap capsule offers a practical, creative, and eco-friendly method of maintaining personal hygiene. This study presents a workable solution with significant promise by fusing the natural antibacterial qualities of oregano and aloe vera with a dissolving capsule technology, one that demonstrates both scientific creativity and a dedication to enhancing routine health practices.

Recommendations

Based on the findings and limitations observed in the study, several recommendations are proposed for future researchers to improve the accuracy, reliability, and overall performance of similar studies. These suggestions aim to enhance testing procedures, strengthen product formulation, and ensure more consistent and valid results. Future studies are encouraged to include testing on additional bacterial strains, such as *Escherichia coli*, to further validate antimicrobial effectiveness. Evaluating the capsule against both Gram-positive and Gram-negative bacteria will provide a more comprehensive assessment of its antimicrobial properties. In addition, the use of manual capsule-filling devices is recommended to improve consistency in capsule shape, minimize sealing issues, and prevent deformation or leakage, thereby increasing production efficiency compared to manual gelatin capsule formation.

Furthermore, improvements in the gelatin formulation are suggested to produce stronger and more stable capsule shells. Refining the gelatin-to-glycerin ratio or incorporating stabilizing agents may help reduce stickiness and enhance capsule hardness, allowing the capsules to better maintain their form during handling and dissolution testing. It is also recommended that future experiments utilize standardized temperature-control methods, such as infrared thermometers or regulated heating devices, to ensure consistent testing conditions during dissolution trials. This approach will help increase accuracy and minimize variability caused by fluctuations in temperature.

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FEAR OF MISSING OUT (FOMO) AS A PREDICTOR OF ONLINE IMPULSIVE BUYING BEHAVIOR AMONG COLLEGE STUDENTS IN LETRAN MANILA

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ABSTRACT

This study examined the influence of Fear of Missing Out (FOMO) on online impulsive buying behavior among college students of Colegio de San Juan de Letran–Manila. Guided by Social Comparison Theory and the Stimulus–Organism–Response (S-O-R) model, the study aimed to determine students’ levels of FOMO, assess their online purchasing behavior, and analyze the predictive relationship between these variables. A quantitative, predictive correlational design was employed, involving 104 college students aged 18 and above who actively use online shopping platforms such as Shopee, Lazada, and TikTok Shop. The results showed a moderate level of FOMO, with urgency and social comparison emerging as the most prominent dimensions. Students also demonstrated moderate levels of impulsive buying, purchase immediacy, and purchase frequency, with online recommendations and limited-time offers strongly influencing purchase decisions. Regression analysis revealed that FOMO significantly predicts impulsive buying and purchase immediacy, while its effect on purchase frequency was less evident. Overall, the findings indicate that although Letran Manila students generally exercise control over their online purchasing decisions, urgency- and socially driven aspects of FOMO still play a meaningful role in shaping impulsive and immediate buying behaviors.

Keywords: *Fear of Missing Out, Online Impulsive Buying, Social Comparison*

INTRODUCTION

Among Filipino students, social media has become a dominant platform that plays a significant role in shaping online habits and purchasing behavior. In 2025, over 5.41 billion people—approximately 68.5% of the global population—use platforms such as Facebook, WhatsApp, YouTube, Instagram, and TikTok, with individuals aged 16–24 accessing an average of 7.71 platforms per month (Team B, 2025). In the Philippine context, this widespread exposure means that students, including those from Colegio de San Juan de Letran Manila, are constantly encountering advertisements, influencer content, and promotional trends, which can influence their purchasing decisions (Neha & Walia, 2025).

One key psychological factor driving this behavior is Fear of Missing Out (FOMO), defined as the anxiety associated with missing experiences or opportunities others are enjoying (Gupta & Sharma, 2021). Studies suggest that FOMO encourages impulsive online buying, particularly when scarcity cues, exclusive deals, and social validation are present (Ayyasy et al., 2025; Santoso, 2024).

However, despite existing research on FOMO and online shopping, many studies focus on general emotional responses and rely on descriptive or simple correlational approaches. There remains a lack of empirical studies that specifically examine how FOMO influences online purchasing behavior among Filipino students, particularly within local institutional context such as Letran Manila. This gap highlights the need for a focused investigation on how FOMO relates to impulsive buying tendencies and exposure to online marketing strategies among Letran Manila students.

Objectives of the Study

This study aims to determine the level of Fear of Missing Out (FOMO) among Letran Manila students in terms of anxiety, urgency, social comparison, and desire to belong. It also seeks to measure the online purchase behavior of the students, specifically in relation to impulsive buying, purchase immediacy, and purchase frequency.

Furthermore, the study intends to determine the extent to which Fear of Missing Out (FOMO), particularly its dimensions of anxiety, urgency, social comparison, and desire to belong, predicts the online purchase behavior of Letran Manila students in terms of impulsive buying, purchase immediacy, and purchase frequency.

Literature Review

Online Impulse Buying

With the rise of social media and digital marketing, consumers are increasingly exposed to stimuli that encourage spontaneous online purchases. Du (2020) found that interactive features such as live chats, instant reactions, and visible peer engagement heighten emotional excitement and create a sense of Fear of Missing Out (FOMO), pushing consumers to make faster, unplanned purchases. Limited-time offers and social visibility further amplify this pressure, reducing self-control and prompting immediate spending. Similarly, Rodrigues et al. (2021) reported that perceptions of exclusivity or scarcity in online offers intensify FOMO, encouraging impulsive rather than deliberate decisions. While both studies highlight urgency as a key factor, Du (2020) emphasizes social interaction, whereas Rodrigues et al. (2021) focus on promotional scarcity cues.

Online shopping platforms are increasingly designed to influence consumer behavior through technological and social features. Zhang and Shi (2022) showed that social presence—such as interactivity, vividness, and peer activity—can trigger FOMO, leading to quicker purchases with less deliberation. Pal (2025) further demonstrated that personalized advertisements and one-click purchase options increase urgency and perceived scarcity, resulting in faster and less reflective buying behavior. Although Zhang and Shi (2022) emphasize the psychological effects of social presence, Pal (2025) highlights the role of convenience and personalization. Together, these studies suggest that both social engagement and platform design work together to encourage impulsive online purchases.

Despite these consistent findings, most studies focus on general consumer populations rather than students. They also rely heavily on survey-based methods and descriptive analyses, which limit deeper understanding of how impulsive buying develops over time. Moreover, while platform features are widely discussed, fewer studies examine how individual psychological traits, such as FOMO, specifically influence impulsive buying behavior among young consumers in academic settings.

Overall, the literature indicates that online impulse buying is shaped by a combination of social interaction, platform design, and promotional strategies that heighten urgency and emotional arousal. However, there remains a lack of student-focused and locally grounded research, particularly in Southeast Asian contexts. This highlights the need for studies that examine how FOMO-driven impulsive buying manifests among Filipino students who frequently engage with online shopping platforms such as Shopee, Lazada, and TikTok Shop.

Psychology of FOMO

The reviewed studies consistently identify Fear of Missing Out (FoMO) as a significant psychological factor influencing consumer behavior in digital environments. Tresna (2025) explains that FoMO emerges through social comparison, peer influence, and continuous exposure to online content, often resulting in rushed decision-making and impulsive purchases. This theoretical perspective provides a foundation for understanding how emotional and social pressures shape consumer behavior, especially in online settings where individuals are constantly exposed to curated lifestyles and trending products.

Supporting this, Widiastuti et al. (2025), focusing on Generation Z in Indonesia, found that social media advertising amplifies FoMO and encourages impulsive buying of trending products such as iPhones. Their findings highlight how FoMO is particularly strong among young consumers in Southeast Asia, where social media plays a central role in daily life. Similarly, Pane et al. (2024) reported that promotional content and influencer endorsements intensify feelings of urgency and social pressure, leading to emotionally driven purchasing decisions.

Santoso (2024) further emphasized that FoMO functions as an emotional trigger that reduces rational evaluation and increases the desire for social inclusion. While Tresna (2025) focuses on the psychological origins of FoMO, the other studies demonstrate its real-world behavioral effects. However, most of these studies focus on specific products or general consumer trends rather than broader online purchasing behavior among students in academic institutions.

Collectively, the literature suggests that FOMO is a powerful psychological driver that influences online buying through urgency,

social comparison, and the need to belong. Southeast Asian studies, in particular, show that students and young consumers are highly susceptible to FOMO due to their heavy social media use. Nevertheless, there is limited research that directly examines how FOMO relates to different aspects of online purchase behavior—such as impulsive buying, immediacy, and frequency—among Filipino university students, indicating a clear gap that the present study aims to address.

Research Framework

Theoretical framework

The theoretical framework of this study is grounded in Social Comparison Theory and the Stimulus–Organism–Response (S-O-R) model, which explain how psychological processes and environmental stimuli influence online consumer behavior. Social Comparison Theory suggests individuals evaluate themselves relative to others, leading to emotional responses such as anxiety and urgency when they perceive they are missing out on experiences or opportunities that others enjoy, which underpins the Fear of Missing Out (FOMO) construct. The S-O-R model further explains that external cues on social media and e-commerce platforms (stimuli) trigger internal psychological states (organism) such as FOMO, which then influence behavioral outcomes like impulsive buying, purchase immediacy, and purchase frequency (response). Empirical research shows that FOMO—amplified by social interactions and platform features—significantly influences online impulse buying behavior, indicating that psychological responses to social comparison and digital stimuli are central to understanding online purchase decisions (Neha & Walia, 2025).

Conceptual framework

The conceptual framework of this study presents Fear of Missing Out (FOMO) as the independent variable and online purchase behavior as the dependent variable among Letran Manila students. FOMO is measured through indicators such as anxiety, urgency, social comparison, and the desire to belong, as these capture the emotional and social factors that drive the fear of missing out. Online purchase behavior is measured through impulsive buying, purchase immediacy, and purchase frequency, which reflect students' typical responses to online shopping. These indicators will be operationalized using Likert-scale survey items to quantify how strongly students experience FOMO and how frequently they engage in online purchasing. The framework focuses on analyzing the influence of FOMO on online purchase behavior, providing a basis for quantitative analysis without assuming causal effects.

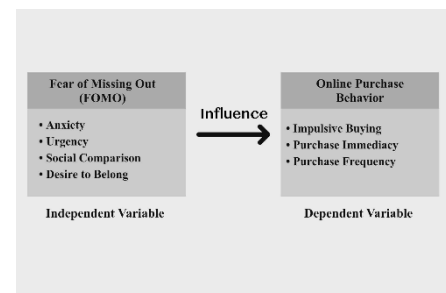


Figure 1. Conceptual framework of the study

Scope and Limitations

This study focuses on examining the influence of Fear of Missing Out (FOMO) on online purchase behavior among Letran Manila college students. Specifically, it aims to determine the level of FOMO experienced by students and measure their online purchasing

behavior, as well as assess how variations in FOMO are associated with differences in students' online purchasing behavior. The data will be collected during the third quarter of School Year 2025–2026 over a period of approximately one month. The study is limited to students who actively engage in online shopping, particularly on popular platforms such as Shopee, Lazada, and TikTok Shop, as their experiences are directly relevant to the objectives of the research.

Several limitations are acknowledged in this study. First, the data are based on self-reported responses, which may be influenced by respondents' honesty, self-perception, or recall bias. Second, the study is confined to Letran Manila college students, which may limit the generalizability of the findings to students from other institutions or to different populations. Third, the study focuses only on Fear of Missing Out as a psychological factor influencing online purchase behavior, and other possible influences are not examined. Fourth, the use of purposive sampling may result in sampling bias, as only students who actively engage in online shopping are included. Lastly, due to the correlational research design, the study can identify associations between variables but cannot establish causal conclusions.

METHODOLOGY

Research Design

This study employed a quantitative non-experimental, predictive correlational research design to examine how Fear of Missing Out (FOMO) predicted the online purchase behavior of Letran Manila college students. A structured survey with Likert-scale items was utilized to measure the key indicators of FOMO and online purchasing behavior, generating quantifiable data for multiple regression analysis. This design was appropriate because it analyzed naturally occurring psychological factors and their influence on consumer behavior without manipulating variables, while allowing the study to determine the predictive influence of FOMO on students' online purchasing tendencies.

Research Instrument

The study employed a self-administered survey questionnaire developed by the researchers to measure the level of Fear of Missing Out (FOMO) and online purchase behavior of the respondents. The instrument consisted of structured statements rated using a 5-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), to capture respondents' attitudes and behavioral tendencies. To ensure validity, the questionnaire underwent expert review to assess content validity, clarity, and alignment with the research objectives, and a pilot testing was conducted to identify and refine any ambiguous items.

The internal consistency reliability of the instrument was assessed using Cronbach's alpha, and all constructs yielded reliability coefficients above 0.70, indicating acceptable to good internal consistency. According to George and Mallery (2003), Cronbach's alpha values of $\alpha \geq 0.90$ are considered excellent, $\alpha \geq 0.80$ good, $\alpha \geq 0.70$ acceptable, $\alpha \geq 0.60$ questionable, $\alpha \geq 0.50$ poor, and $\alpha < 0.50$ unacceptable; thus, the instrument used in this study was deemed reliable for data analysis.

Table 1. Scale Reliability Statistics

Variable	Cronbach's α	Interpretation
Anxiety	0.86	Good
Urgency	0.92	Excellent
Social Comparison	0.91	Excellent
Desire to Belong	0.91	Excellent
Impulsive Buying	0.89	Good

Respondents

The participants of this study were college students of Colegio de San Juan de Letran Manila who were 18 years old and above. A purposive sampling method was applied to select students who actively used social media and online shopping platforms such as Shopee, Lazada, TikTok Shop, or similar applications. College students were considered appropriate and credible respondents in consumer behavior research because they were highly engaged in digital environments, frequently interacted with online commerce platforms, and demonstrated active purchasing decision-making behaviors. Recent studies in consumer and social commerce research have consistently utilized college students as valid samples due to their familiarity with online technologies and their relevance to studies examining psychological and behavioral factors influencing online consumption (Sun & Wang, 2020). This sampling approach ensured that participants possessed direct experience with online shopping, allowing the data collected to be closely aligned with the objectives of the study.

The study managed to include 104 participants. According to Buckley (2024), in quantitative research involving common statistical techniques such as correlation and regression analysis, a sample size of at least 100 respondents was generally sufficient to achieve adequate statistical power when the research model was not overly complex. To minimize potential sampling bias, participants were selected based on clearly defined inclusion criteria, and consistent recruitment procedures were applied to all prospective respondents. This ensured that all participants met the study requirements and were capable of providing relevant and reliable data, thereby enhancing the credibility and validity of the study's findings.

Statistical Treatment

The collected data were analyzed using descriptive statistics to address the first and second objectives. Mean and standard deviation were employed to determine the average level and variability of Fear of Missing Out (FOMO) and online purchase behavior based on the Likert-scale responses. Additionally, percentage distribution was applied to describe the respondents' profiles, with online purchase frequency specifically illustrated through pie charts to highlight the distribution of behaviors among Letran Manila college students.

Prior to inferential analysis, reliability testing using Cronbach's Alpha was conducted to ensure the internal consistency of the FOMO and online purchase behavior scales, as both variables were measured using multiple indicators. Multiple regression analysis was then employed to examine how the key indicators of FOMO—namely anxiety, urgency, social comparison, and desire to belong—predicted online purchase behavior in terms of impulsive buying, purchase immediacy, and purchase frequency. This method was appropriate for determining the extent to which FOMO components influenced students' online purchasing tendencies, with the significance level set at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Table 2. Respondent's level of FOMO

Terms	Mean	SD	Interpretation
Anxiety	2.58	1.02	Disagree
Urgency	3.05	1.01	Neutral
Social Comparison	3.11	0.94	Neutral
Desire to Belong	2.85	0.99	Neutral
Overall	2.90	0.86	Neutral

Note: Legend: 1.00 - 1.79 Strongly Disagree; 1.80 - 2.59 Disagree; 2.60 - 3.39 Neutral; 3.40 - 4.19 Agree; 4.20 - 5.00 Strongly Agree

The findings in Table 2 show that respondents exhibit a moderate level of FOMO, as indicated by the overall mean score of 2.90, which falls within the Neutral range. Among the dimensions, Social Comparison (M = 3.11) and Urgency (M = 3.05) scored slightly higher, suggesting that respondents moderately compare themselves to others and feel a mild sense of urgency to stay involved in activities or trends. Desire to Belong also reflected a neutral tendency (M = 2.85), indicating a moderate interest in social inclusion, while Anxiety scored the lowest (M = 2.58), showing that respondents generally do not feel strongly anxious about missing out. The standard deviations, ranging from 0.86 to 1.02, indicate some variation in responses, suggesting that while most respondents share similar experiences, individual differences still exist across the dimension of FOMO.

Table 3. Respondent's level of impulse buying behavior.

Statements	Mean	SD	Interpretation
I often buy products online without planning in advance.	3.04	1.34	Neutral
I make spontaneous purchases when I see something appealing online.	3.16	1.23	Neutral
I usually feel satisfied with the impulsive purchases I make online	3.11	1.17	Neutral
I get attracted to items because of online recommendations.	3.49	1.00	Agree
I tend to make unplanned purchases when browsing shopping apps.	3.11	1.16	Neutral
Overall	3.22	0.94	Neutral

Note: Legend: 1.00 - 1.79 Strongly Disagree; 1.80 - 2.59 Disagree; 2.60 - 3.39 Neutral; 3.40 - 4.19 Agree; 4.20 - 5.00 Strongly Agree

The findings in Table 3 show that respondents generally exhibit a moderate level of impulse buying behavior, as indicated by the overall mean score of 3.22, which falls within the Neutral range. Among the items, being attracted due to online recommendations scored the highest (M = 3.49, Agree), suggesting that this factor has the strongest influence on respondents' online purchasing decisions. The other statements, including buying products without planning (M = 3.04), making spontaneous purchases when something is appealing (M = 3.16), feeling satisfied with impulsive purchases (M = 3.11), and making unplanned purchases while browsing apps (M = 3.11), all fall within the Neutral range, indicating moderate impulsive tendencies. The standard deviations, ranging from 1.00 to 1.34, reflect noticeable variation in responses, showing that while some respondents frequently engage in impulse buying, others do so less often, resulting in diverse experiences across the sample.

Table 4. Respondent's level of purchase immediacy behavior.

Statements	Mean	SD	Interpretation
Once I decide to buy a product online, I complete the purchase without delaying.	3.25	1.20	Neutral
I usually finalize my online purchases in one session.	3.13	1.14	Neutral
When I plan to buy something, I make the purchase as soon as I can.	3.18	1.11	Neutral
I rarely postpone online purchases after deciding to buy.	3.06	1.09	Agree
I respond quickly to limited-time offers or discounts for products I already intended to buy.	3.29	1.17	Neutral
Overall	3.16	0.89	Neutral

Note: Legend: 1.00 - 1.79 Strongly Disagree; 1.80 - 2.59 Disagree; 2.60 - 3.39 Neutral; 3.40 - 4.19 Agree; 4.20 - 5.00 Strongly Agree

The findings in Table 4 show that respondents demonstrated a moderate level of purchase immediacy behavior, as indicated by the overall mean score of 3.16, which falls within the Neutral range.

Among the items, responding quickly to limited-time offers or discounts obtain the highest mean (M = 3.29), suggesting that respondents are somewhat inclined to act promptly when incentives are present. The other statements, including completing purchases without delay (M = 3.25), finalizing purchases in one session (M = 3.13), buying as soon as planned (M = 3.18), and rarely postponing purchases (M = 3.06), all fall within the Neutral range, indicating moderate immediacy in purchasing behavior. The standard deviations, ranging from 1.09 to 1.20, reflect noticeable variation in responses, showing that while some respondents act quickly when making online purchases, others tend to delay their purchases, resulting in diverse behaviors across the sample.

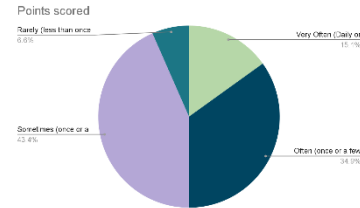


Figure 2. Purchase frequency pie chart

The results on perceived purchase frequency show that respondents engage in online purchasing with varying regularity. Most respondents reported purchasing sometimes (once or a few times a month), accounting for 43.40% of the sample, followed by those who purchase often (once or a few times a week) at 34.90%. A smaller portion of respondents indicated buying very often (daily or almost daily) at 15.10%, while only 6.60% reported purchasing rarely (less than once a month). These findings suggest that the majority of respondents engage in online shopping on a moderate basis, with a smaller segment showing very frequent or infrequent purchasing behaviors.

Hypothesis

Null Hypothesis (H₀):

Fear of Missing Out (FOMO) does not significantly predict the online purchase behavior of Letran Manila students in terms of impulsive buying, purchase immediacy, and purchase frequency.

Alternative Hypothesis (H₁):

Fear of Missing Out (FOMO) significantly predicts the online purchase behavior of Letran Manila students in terms of impulsive buying, purchase immediacy, and purchase frequency.

Table 5. Regression analysis between FOMO and online purchase behavior in terms of impulsive buying

Predictor	Estimate	t	p-value	Decision	Interpretation
Anxiety	-0.095	-1.000	0.320	Fail to Reject H ₀	Not Significant
Urgency	0.272	2.759	0.007	Reject H ₀	Significant
Social Comparison	0.141	1.083	0.281	Fail to Reject H ₀	Not Significant
Desire to Belong	0.380	2.828	0.006	Reject H ₀	Significant

The regression results indicate that urgency and desire to belong are significant predictors of impulsive buying among the FOMO dimensions. Urgency (β = 0.272, p = 0.007) positively influences impulsive buying, suggesting that time pressure increases the likelihood of making unplanned online purchases. Similarly, desire to belong (β = 0.380, p = 0.006) shows a strong positive effect, indicating that the need for social acceptance encourages impulsive purchasing behavior. In contrast, anxiety (β = -0.095, p = 0.320) and social comparison (β = 0.141, p = 0.281) were not significant

predictors. Among the variables, desire to belong emerged as the strongest predictor of impulsive buying.

Table 6. Regression analysis between FOMO and online purchase behavior in terms of purchase immediacy

Predictor	Estimate	t	p-value	Decision	Interpretation
Anxiety	-0.004	-0.040	0.968	Fail to Reject Ho	Not Significant
Urgency	0.274	2.617	0.010	Reject Ho	Significant
Social Comparison	-0.202	-1.468	0.145	Fail to Reject Ho	Not Significant
Desire to Belong	0.448	3.133	0.002	Reject Ho	Significant

For purchase immediacy, the results also show that urgency and desire to belong are significant predictors. Urgency ($\beta = 0.274$, $p = 0.010$) has a positive impact on purchase immediacy, confirming that the time pressure brought by FOMO could speed up consumers' purchase process. Desire to belong ($\beta = 0.448$, $p = 0.002$) possesses an even greater positive influence, which indicates that consumers who want to establish social connection and be accepted in the society are more likely to purchase online instantly. However, anxiety ($\beta = -0.004$, $p = 0.968$) and social comparison ($\beta = -0.202$, $p = 0.145$) are not significant predictors. In summary, these results demonstrate that desire to belong exerts the most significant effect on purchase immediacy, revealing that social motivations overwhelmingly drive consumers to make an immediate purchase.

Table 7. Regression analysis between FOMO and online purchase behavior in terms of purchase frequency

Predictor	Estimate	t	p-value	Decision	Interpretation
Anxiety	-0.030	-0.280	0.780	Fail to Reject Ho	Not Significant
Urgency	0.287	2.619	0.010	Reject Ho	Significant
Social Comparison	-0.156	-1.080	0.283	Fail to Reject Ho	Not Significant
Desire to Belong	0.189	1.263	0.210	Fail to Reject Ho	Not Significant

For purchase frequency, urgency is the only significant predictor according to the regression analysis results ($\beta = 0.287$, $p = 0.010$). This means that a high sense of urgency related to FOMO amongst consumers leads to them making more online purchases. Anxiety ($\beta = -0.030$, $p = 0.780$), social comparison ($\beta = -0.156$, $p = 0.283$), and desire to belong ($\beta = 0.189$, $p = 0.210$) are not significant predictors of online purchase frequency. As urgency is the only statistically significant influencer, it also has the highest impact on purchasing frequency, restating the importance of the time pressure stimulus as driver for repeat online buying.

CONCLUSION

This study aims to examine how the feeling of missing out influences the online buying behavior of Letran Manila students. It focuses on identifying the level of Fear of Missing Out through factors such as anxiety, urgency, social comparison, and the desire to belong. The study also explores students' online purchasing habits, including impulsive buying, purchase speed, and shopping frequency, to determine how these behaviors are affected by the feeling of missing out.

Influence of Social Comparison on Awareness

In terms of anxiety, Letran Manila students generally do not feel strongly uneasy or worried about missing out, suggesting that this dimension has little effect on their decisions. respond quickly or remain engaged in activities, but this does not consistently influence

their behavior. Social comparison has some effect, as students sometimes observe and compare themselves to peers or online figures, which may spark interest or curiosity without dominating their choices. The desire to belong is also moderate, showing that students consider social inclusion when making decisions, but it does not strongly drive their actions. Overall, the assessment of these dimensions reveals that FOMO among Letran Manila students exists at a moderate level, with urgency and social comparison having some influence, while anxiety and the desire to belong have a limited role in shaping their behavior.

Controlled Impulsive Buying Tendencies

Regarding impulsive buying, Letran Manila students show a moderate tendency to make unplanned purchases, especially when influenced by online recommendations, while other impulsive behaviors occur only occasionally. Purchase immediacy is also moderate, as students sometimes complete transactions quickly or respond to limited-time offers, though many take more time before finalizing their purchases. For purchase frequency, most students shop online occasionally, typically once or a few times a month, while smaller groups buy more or less frequently. Overall, the evaluation of these aspects indicates that students approach online purchasing in a balanced manner. Impulsive buying, immediacy, and frequency influence behavior to some degree, but none dominate decision-making, suggesting that Letran Manila students generally make thoughtful and controlled choices when shopping online.

FOMO as a Trigger for Impulsive Buying

Fear of Missing Out influences the online purchasing decisions of Letran Manila students in several ways. Students are more likely to make impulsive purchases when they feel a sense of urgency or a need to belong, with the desire to be accepted socially having the strongest effect. These same factors also affect how quickly students complete their purchases, showing that social motivations and time pressure encourage faster buying. Anxiety and social comparison, however, do not have a significant impact on either impulsive buying or purchase immediacy. Regarding how often students shop online, urgency is the only factor that makes a noticeable difference, suggesting that feeling rushed can lead to more frequent purchases. Overall, FOMO shapes students' online buying mainly through social needs and urgency, while other dimensions have little influence on their decisions.

In conclusion, this study helps to understand how Fear of Missing Out, or FOMO, affects the online buying behavior of Letran Manila students. It looked at different factors like anxiety, urgency, social comparison, and the desire to belong, and found that FOMO is present at a moderate level. The study also showed that FOMO makes students more likely to buy impulsively and act quickly, but it does not really affect how often they shop online. Even though students are constantly exposed to social media, trends, and online promotions, they are generally able to control their decisions and shop carefully. By focusing on students from Letran Manila, this study gives new insights into how social influence and personal feelings of missing out shape online shopping habits among Filipino students.

Recommendations

The researchers further assessed the findings of the study to develop several recommendations. Students are encouraged to practice mindful shopping behavior by becoming more aware of how Fear of Missing Out (FOMO) influences their purchasing decisions. By exercising discipline and carefully evaluating purchases, they can reduce impulsive buying and make more rational financial choices.

In addition, educational institutions are advised to implement support

systems such as programs, seminars, or counseling services that promote responsible spending and emotional awareness. These initiatives can help students better manage the psychological triggers associated with digital marketplaces. Online shopping platforms are also encouraged to adopt ethical marketing strategies that avoid placing excessive pressure on consumers, fostering a more sustainable and responsible relationship with users. Lastly, future researchers are recommended to expand the scope of study by examining other psychological and social factors that may influence online purchasing behavior, in order to gain a deeper understanding of the topic and its long-term effects on student well-being.

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The Influence Of Countdown Timer On Purchase Urgency And Cart Abandonment In Flash Deals Promotions

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ABSTRACT

The growth of e-commerce has led online retailers to use flash deal promotions with countdown timers to create urgency and influence consumer behavior in online shopping. This study examines the influence of countdown timers on consumers' purchase urgency and cart abandonment behavior during flash deal promotions. Data were collected through an online survey administered to consumers aged 18 and above who have experience with flash deal promotions. Using descriptive statistics, the intensity of countdown timers, purchase urgency, and cart abandonment behaviors of consumers were analyzed. Meanwhile, linear regression was used to determine the influence of countdown timers on consumers' purchase urgency and cart abandonment during flash deal promotions. The findings indicate that countdown timers make consumers more engaged and are effective in creating time pressure during promotions, significantly increasing purchase urgency and reducing cart abandonment, with a stronger effect on purchase urgency than on cart abandonment. This study concludes that countdown timers can influence purchase urgency, while their effect on preventing cart abandonment varies among consumers, providing practical insights for online retailers to strategically integrate time-sensitive campaigns, encourage faster checkout, and implement measures such as reminders and streamlined processes to reduce cart abandonment.

Keywords: *Fear of Missing Out, Online Impulsive Buying, Social Comparison*

INTRODUCTION

Background of the Study

The rapid growth of e-commerce has significantly affected individuals' day-to-day lives, as more people rely on online platforms to purchase goods and services electronically. According to Montano and Mercado (2023), the COVID-19 pandemic further increased the demand for online shopping as people worked and studied from home. Since buying products has become part of individuals' lives, e-commerce plays an essential role in fulfilling their needs and necessities while ensuring their safety and health.

With this growth, online retailers are forced to adopt various promotional strategies to remain competitive in the e-commerce industry, aiming to attract and retain more customers. Based on the study of Dsilva & N, (2021), one such tactic includes flash deals—online promotions that offer highly discounted prices for a short period of time, also known as daily sales or private sales. Flash deals often use countdown timers—a display of the time remaining before a promotion expires. These enhance purchase urgency by motivating consumers to make quicker decisions and increasing the perceived value of time-limited offers (Suvarna & Malagi, 2025).

Despite the effectiveness of countdown timers in increasing urgency, online retailers still face high rates of cart abandonment. As stated by Jiang et al., (2021) Some items placed in consumers' shopping carts are purchased, while others remain unpurchased; this is known as cart discard (abandonment), broadly referred to as Internet Abandoned Cart Syndrome (IACS). Cart abandonment remains high even during flash deals, indicating that countdown timers may not always lead to completed purchases.

While existing literature studies the effect of countdown timers on consumers' purchase urgency, there is limited research examining the relationship among countdown timers, purchase urgency, and cart abandonment simultaneously during flash deal sales, as well as their influence on actual customer purchasing behavior.

Furthermore, few studies have examined current customer behavior during the flash offer process, such as whether countdown timers effectively increase checkout completion or unintentionally lead to cart abandonment.

This study aims to address these gaps by analyzing the effects of countdown timers on customers' purchase urgency, purchasing behavior, and cart abandonment in flash deal sales, in line with the study's objectives of measuring these relationships, understanding customer behavior, and evaluating the influence of countdown timers on purchase decisions.

Objectives of the Study

To analyze the effects of countdown timer of customers' purchase urgency and cart abandonment, during flash deals sales. (1) To perceive the intensity of countdown timer used in flash deals promotions. (2) To investigate the degree of consumer's purchase urgency and cart abandonment in flash deals promotions, with countdown timer. (3) To determine the influence of a countdown timer on customers' purchase urgency and cart abandonment during flash deals promotions.

Literature Review

Use of countdown timers in online shopping

In the study of Su et al. (2025), it was stated that marketers are increasingly using countdown timers in online video advertising to capture consumer attention and improve advertising effectiveness. By employing eye-tracking methods, the study revealed that countdown timers enhance viewers' visual attention, memory, and advertisement recall, particularly for experience-oriented advertisements. Similarly, e-commerce platforms strategically utilize micro-moment marketing to influence consumer purchase decisions by presenting urgency cues, real-time prompts, and personalized messages during critical decision-making moments (Basir, 2025). These strategies encourage consumers to act quickly by reducing cognitive deliberation and increasing the perceived relevance of offers. However, as mentioned by the study of Tiemessen (2022), it explained that while countdown timers can significantly increase purchase urgency and transaction completion, the use of deceptive time pressure cues negatively affects consumer trust, satisfaction, and perceived fairness once consumers recognize the manipulation.

In the study of Kim and Gupta (2023), they examined that countdown timers used in online shopping significantly increase consumers' perceived urgency and purchase intention by featuring limited availability and time scarcity. The study showed that when online consumers are exposed to countdown timers, they tend to make quicker purchasing decisions and are less inclined to compare other products or research more about them. It states that in the study, countdown timers shift consumers' focus from careful evaluation to immediate decision-making, leading to impulsive buying behavior. Furthermore, it emphasized that countdown timers are mostly effective in the e-commerce environment because they create a sense of competition among online retailers and consumers and increase the fear of missing out (FOMO), making the offers more valuable. However, the researchers in the study also showed that the continuous and repeated use of countdown timers may lead to a decline in consumers' trust and weaken the credibility of the platform, resulting in negatively affected long-term customer relationships.

Purchase urgency in time limited online promotions

According to Oberoi (2024), businesses are continuously searching for inventive approaches to retain clients and compete in today's competitive industry, often providing transient discounts that compel customers to buy limited available products, known as time-limited discounts. Moreover, time-limited discounts are found to foster brand loyalty. Businesses exploit the fear of missing out (FOMO), which instinctively makes customers act impulsively and may lead to post-purchase dissatisfaction. Some customers have an irresistible urge to buy due to their enormous desire to purchase and satisfy themselves (Meena, 2018, as cited in Rodrigues & Varela, 2021). Because of this, limited-time offers influence customers to buy within a specific period, affecting consumer behavior and increasing sales (Oberoi, 2024). Supporting this, in the recent study of Suvama and Malagi (2025) found that limited-time discounts significantly increase consumers' sense of urgency and accelerate purchase decisions, often reducing careful evaluation of alternatives. Similarly, it was found that online promotional strategies, including time-limited offers, heighten emotional arousal and impulsive buying intentions, leading to unplanned purchases Luo et al. (2021). Lastly, the psychological triggers such as scarcity and urgency play a crucial role in shaping consumer buying behavior in online shopping environments, as these triggers intensify perceived value and prompt immediate purchasing actions emphasized by the study of Luo et al. (2021)

Cart abandonment in online shopping

Recent quantitative findings from 2025 indicate that shopping cart abandonment remains a significant challenge for e-commerce, with global rates averaging approximately 70.22%. This behavior is increasingly driven by the "pseudo-wishlisting" trend, where consumers use carts to store items while awaiting further price drops or promotions. To reduce this, retailers employ temporal scarcity cues such as countdown timers to induce purchase urgency. However, research suggests that the effectiveness of these timers is non-linear; while they can successfully "nudge" shoppers toward completion, excessive or perceived inauthentic time pressure can trigger consumer reactance, leading to an immediate exit from the site as a defense mechanism against psychological stress.

Online shopping cart abandonment is influenced not only by technical issues or high costs but also by underlying psychological factors. As studied by Adnan (2025) on why consumers leave their online carts without purchasing, using interviews with online shoppers in the e-commerce industry. The study found that feelings such as hesitation, uncertainty, fear of risk, lack of trust, and mental tiredness strongly influence the decision to abandon a cart. The study used the Theory of Planned Behavior (Ajzen, 1991) and the Trust–Risk Framework (Pavlou, 2003; Kim et al., 2008) to explain how attitudes, social influence, sense of control, trust, and perceived risk affect online buying decisions. It also explained that leaving a shopping cart is often a rational decision made when consumers feel uncertain, fear making the wrong choice, or believe that the online platform does not meet their expectations.

Research Framework

Theoretical framework

Countdown timers in flash deal promotions may result in various calls to action from customers. According to Rook (1997), as stated in Oberoi (2024), consumers make sudden, unplanned purchases that are triggered by certain situations, which result in customers immediately buying a product as they see it as an opportunity to get it at a much lower price. On the other hand, too much pressure due to the countdown timer may result in cart abandonment, as people sometimes avoid decisions when the cost of choosing outweighs its benefits, especially when decision-making becomes too complex or emotionally uncomfortable for some individuals (Anderson, 2003, as stated in Mittal, 2023). With this, customer actions may vary in how they generally react to countdown timers during flash deal promotions, whether they act impulsively or simply avoid the purchase.

Conceptual framework

The conceptual framework illustrates how a Flash Deal Countdown Timer directly influences consumer behavior. When shoppers see the time running out, it creates Purchase Urgency by making them feel they must act quickly to save money, but it can also lead to Cart Abandonment if the pressure causes them to hesitate or feel overwhelmed. These two reactions determine the Purchasing Behavioral Responses, showing whether the timer successfully leads to a completed sale or causes the customer to leave.



Figure 1. Conceptual framework

Scope and Limitations

The research study investigates the influence of countdown timers used in flash deal promotions on customers’ purchase urgency and cart abandonment in online shops that offer this promotional strategy. The scope of the study is defined to measure the relationship between flash deal countdown timers and customer purchasing behavior during time-limited flash deals using a quantitative approach. Other promotional strategies, platforms, and external factors that may affect purchasing decisions, such as social media advertising, email marketing, influencer endorsements, pricing strategies, online marketing websites, and offline promotions, are excluded and set outside the scope to maintain focus and clarity in the data analysis. A quantitative research design is employed, utilizing a structured survey questionnaire to collect measurable data on customers’ perceptions and behaviors during flash deals. The defined scope enables a structured investigation within the study time frame and available resources.

The respondents of the study consist of online shoppers aged 18 and above who have experienced flash deal promotions. All information provided by the respondents will remain confidential and will be used solely for research purposes; only data relevant to the study findings will be included to ensure participants’ privacy and safety.

METHODOLOGY

Research Design

The study utilizes a Predictive Correlational Design. This design allows the researchers to examine the correlation among the variables in the study, such as countdown timers, purchase urgency, and cart abandonment, and determine whether they influence one another. According to Devi et al. (2022), correlational studies examine the relationship between variables without the researchers controlling or manipulating them. With this, the study will be able to identify and describe whether countdown timers have a significant influence on customers’ purchasing behavior—specifically cart abandonment and purchase urgency—and predict how these variables are affected.

Research Instrument

The research will analyze data collected by means of a structured survey questionnaire. The main objective of the survey is to obtain quantitative data for use in the study of how countdown timers affect consumers’ purchase urgency and cart abandonment. Respondents will be asked to rate their level of agreement with several statements concerning the variables of interest on a range from 1–5 using a five-point Likert scale, where 1 indicates Strongly Disagree and 5 indicates Strongly Agree. The development of the questionnaire was guided by a comprehensive review of existing literature and related studies to ensure relevance and alignment with the research objectives. To ensure the validity and reliability of the instrument, the questionnaire will undergo a validation process. It will be reviewed by experts in the field, such as research advisers or subject teachers, to assess content validity, clarity, and appropriateness of the items.

The survey begins with information about the respondents’ demographics; this will be used to provide a better understanding of the demographic makeup of all survey respondents. The remaining parts of the survey will focus on each of the major topics of the research: countdown timer, purchase urgency, and cart abandonment. Items related to the countdown timer category examine how respondents perceive time pressure and urgency with regard to flash sale offers. Purchase urgency items examine how countdown timers create feelings of urgency and influence customers to make quicker decisions or impulse purchases. Finally, the cart abandonment section

examines whether countdown timers have caused respondents to abandon goods before completing their purchases due to stress, pressure, or hesitation.

The Likert scale provides a structured approach that ensures consistency and objectivity for researchers to analyze trends or relationships among countdown timers, urgency to buy, and cart abandonment through statistical analysis. This is also consistent with the predictive correlational design of the study.

Sampling Method

This study employs a non-probability purposive sampling method to select respondents who are relevant to the research objectives. This approach is suitable for the predictive correlational design, as it allows the intentional selection of online shoppers who have experienced flash deal promotions with countdown timers.

The purposive sampling method involves selecting participants based on their relevance to the study and their ability to provide meaningful insights. Although it has limitations, it remains effective for obtaining context-specific and accurate data (Tajik, Golzar, & Noor, 2025). The target population includes online shoppers aged 18 years and above—students and staff at Letran Manila—who have encountered flash deal promotions with countdown timers. Respondents must have added at least one item to their online shopping cart during a flash deal, whether the purchase was completed or abandoned.

Respondent distribution will be described using frequency and percentage analysis. Demographic variables such as age, gender, and respondent category (student or staff) will be summarized to provide a clear profile of the participants. This distribution helps in understanding the composition of the sample and ensures that the data interpretation is grounded in the characteristics of the respondents.

Statistical Treatment

The research will analyze its data using both descriptive and inferential statistics. Using descriptive statistics, the researchers will address the first and second objectives by calculating the mean and standard deviation, allowing the study to describe and summarize current trends and patterns, providing reliable insights. On the other hand, the third objective will be analyzed using inferential statistics, specifically linear regression, to examine the relationship, effects, and influence of flash deals’ countdown timers on customers’ purchase urgency and cart abandonment. Moreover, the analysis will be conducted using statistical software, with the significance level set at $\alpha = 0.05$, providing a deeper understanding of how flash deals’ countdown timers affect the purchasing behavior of students and faculty at Letran Manila.

RESULTS AND DISCUSSION

Table 1. Perceived Intensity of Countdown Timers

Statement	Mean	SD	Interpretation
I feel that countdown timers help me become more aware of the limited time in flash deals.	4.19	0.86	Agree
I believe that countdown timers make flash deal promotions feel more engaging.	4.25	0.89	Strongly Agree
I clearly notice the remaining time when a countdown timer is displayed, that somehow gives me pressure.	4.18	1.03	Agree
I prefer countdown timers during flash deals, since it feels more dynamic, compared to regular promotions.	4.09	0.99	Agree
Overall	4.12	0.98	Agree

The findings from Table 1 show that participants generally agreed that countdown timers intensify their engagement and excitement while shopping in flash sales, with an overall mean of 4.12. The highest-rated statement indicates strong agreement that countdown timers make flash deal promotions appear more engaging (mean = 4.25, SD = 0.89), showing that respondents are positively oriented in this regard. The other statements also fall within the “Agree” range, with averages ranging from 4.09 to 4.19, suggesting that countdown timers are also associated with creating hype and time pressure during promotions. The standard deviations, ranging from 0.86 to 1.03, indicate moderate variation in responses; most respondents think alike, but there are some differing opinions and feelings toward countdown timers.

To further support our findings, according to AnnCode Solutions (2025), when consumers see a ticking clock, it pushes their sense of urgency to buy a product. Due to a mere psychological phenomenon called FOMO or the fear of missing out. A powerful motivator in e-commerce. This is supported by a study of Tan and Chen (2023) in the Service Business Journal, revealing that flash sale environments create psychological pressure that affects consumer decision-making and increases purchase intention under time constraints. This supports the present study’s results, where participants generally agreed that countdown timers increase engagement, excitement, and perceived time pressure during flash sales.

Table 2. Purchase Urgency

Statement	Mean	SD	Interpretation
I feel like countdown timers help me decide more quickly whether to buy a product.	3.98	1.05	Agree
I feel motivated to secure the deal immediately, whenever I see a countdown timer during flash deals.	4.04	1.04	Agree
I believe the discount offered in a flash deal is a unique opportunity that may not be available again soon.	4.07	1.03	Agree
I feel encouraged to make faster purchase decisions when a countdown timer is present.	4.13	1.01	Agree
5. I feel that countdown timers make flash deal offers feel more time-sensitive and important.	4.07	1.04	Agree
Overall	4.06	1.03	Agree

Note: Legend: 1.00 - 1.79 Strongly Disagree; 1.80 - 2.59 Disagree; 2.60 - 3.39 Neutral; 3.40 - 4.19 Agree; 4.20 - 5.00 Strongly Agree

As shown in Table 2, the respondents tend to agree that countdown timers generate a strong sense of purchase urgency, with an overall mean of 4.06 and a standard deviation of 1.03. Therefore, it can be inferred that respondents are motivated to shop for more items or at least feel urged to make faster purchasing decisions when countdown timers are present, though there is some divergence in the intensity of this urgency. The item means range from 3.98 to 4.13, indicating agreement that the countdown timer promotes immediate action, draws attention to the limited-time nature of the offer, and affects decision-making in flash sales. The item-level standard deviations, which are close to the overall SD, further suggest that while most respondents feel more urgency, some feel less due to individual shopping styles and sensitivity to time pressure. Overall, the moderate SD supports the idea that countdown timers induce purchase urgency among participants to a certain degree. According to Cybertek (2024), the flash sales taps into a consumer’s fear of missing out, which consequently results in purchase urgency. Making people sometimes tend to buy products without thinking. This is further supported by the study of Sun et al. (2023), which found that time pressure in online shopping environments significantly increases impulsive buying behavior and leads consumers to make faster purchasing decisions due to heightened urgency during limited-time conditions.

Table 3. Cart Abandonment

Statement	Mean	SD	Interpretation
I believe countdown timers help me stay engaged throughout the checkout process.	4.22	0.88	Strongly Agree
I feel like countdown timers positively influence me to complete a purchase rather than leave items in my cart.	4.18	0.93	Agree
I prefer the presence of a countdown timer that motivates me to finalize my order.	4.11	0.95	Agree
I believe countdown timers reduce my tendency to leave items unpurchased in my cart.	4.00	1.08	Agree
I am confident that countdown timers influence me positively, to purchase rather than abandon my cart.	4.11	1.06	Agree
Overall	4.12	0.98	Agree

Note: Legend: 1.00 - 1.79 Strongly Disagree; 1.80 - 2.59 Disagree; 2.60 - 3.39 Neutral; 3.40 - 4.19 Agree; 4.20 - 5.00 Strongly Agree

The findings in Table 2.2 reveal that respondents agree that countdown timers are perceived to affect cart abandonment, with an overall mean of 4.12. The overall standard deviation of 0.98 indicates moderate variation in responses. This means that although respondents perceive countdown timers as useful for keeping them on-task and motivating purchase completion, the intensity of this effect varies among individuals. Item means range from 4.00 to 4.22, with sustained engagement during checkout being the strongest predictor. However, this moderate variability indicates that not all consumers are affected equally; some are more influenced by countdown timers than others. In general, the results imply that countdown timers have the potential to decrease cart abandonment for a large group of shoppers, though this influence is not universal among all participants in the study. Furthermore, according to Baymard Institute (2024), one of the main factors influencing cart abandonment is the design itself, being too infuriating or confusing for some consumers, leading to them not completing the purchase. Additionally, in the study of Li, Zhang, and Wang (2022), they found that perceived effort and checkout friction in online shopping environments significantly increase the likelihood of cart abandonment, as consumers are more likely to abandon purchases when the process feels time-consuming or mentally demanding.

Hypothesis

Null Hypothesis (H₀): Countdown timers used during flash deal promotions have no significant influence on customers' purchase urgency or cart abandonment rates.

Alternative Hypothesis (H₁): Countdown timers used during flash deal promotions have a significant influence on customers' purchase urgency and cart abandonment rates.

Table 4. Influence of countdown timer intensity on purchase urgency and cart abandonment

Variables	Estimate	p-value	Decision	Interpretation
Countdown Timer				
Purchase Urgency	0.755	<0.001	Reject H ₀	Significant
Cart Abandonment	0.665	<0.001	Reject H ₀	Significant

Based on the regression analysis results in Table 4, the intensity of the countdown timer had a statistically significant influence on both purchase urgency and cart abandonment (p-value < 0.001 for both dependent variables), indicating that the null hypothesis was rejected for both outcomes. The effect of countdown timer intensity on purchase urgency (Estimate = 0.755) is greater than on cart abandonment (Estimate = 0.665), suggesting that countdown timers have a stronger influence on making consumers feel time pressure and make faster buying decisions than on directly preventing cart abandonment. This indicates that while countdown timers significantly increase urgency and help maintain commitment throughout the checkout process, their effect in fully aligning

motivation through the entire checkout is somewhat weaker. Strengthening this finding, according to Oberoi (2023), limited offers allow consumers to feel pressured and immediately purchase a product. However, with the findings not all are fully committed throughout the checkout process, since according to Baynard Institute (2025), factors like how the flash deals promotions and countdown timers work makes someone feel annoyed, it hinders them for completing the payment, resulting in leaving it in anger. This pattern is further supported by Huang and Zhang (2021), who found that time pressure in online shopping environments significantly increases purchase urgency but does not always guarantee purchase completion, as consumers may still abandon their carts when cognitive load or checkout effort becomes too high.

CONCLUSION

The study concludes that countdown timers are highly effective in making flash deals feel more exciting and urgent for shoppers. Most participants agreed that seeing a timer increases their awareness of limited time and encourages faster buying decisions. These timers successfully shift the customer's focus toward immediate action, demonstrating that time pressure is a strong motivator in online sales. Additionally, the results show that countdown timers significantly help reduce cart abandonment by keeping shoppers engaged until they complete their purchase. While the timers have a stronger effect on creating initial urgency than on preventing cart abandonment, they still play a key role in helping customers follow through with their orders. Overall, the use of countdown timers is a successful strategy for online stores to convert interest into actual sales by providing customers with the extra push needed to checkout.

Recommendations

The conclusions of this research lead to the following recommendations. Online platforms should consistently enhance the user experience during flash sales by improving transaction processes, reducing page loading times, and streamlining checkout steps. Furthermore, it is recommended that consumer feedback and shopping patterns be monitored. This will help assess the influence of countdown timers and determine whether they positively motivate or negatively pressure consumers. Such insights will enable businesses to adjust urgency-based strategies while maintaining customer satisfaction.

Online retailers should also consider optimizing the design and placement of countdown timers. The goal is to clearly inform customers about time constraints without causing them to feel overwhelmed. Countdown timers should be easily visible to create a sense of urgency but should not distract from the purchase process. Regular testing of timer placement and duration can ensure they effectively encourage faster decisions and increase the likelihood of completed purchases.

Finally, online platforms should support countdown timers with a smooth and efficient checkout process. Minimizing unnecessary steps and preventing technical delays during flash sales can help reduce cart abandonment and increase completed transactions. Enhancing checkout efficiency alongside urgency cues can improve the overall shopping experience and contribute to higher conversion rates.

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Guide to Contributors

The Horizon is the official academic journal of the high school students of Colegio de San Juan de Letran, Intramuros, Manila

The editors recommend that manuscripts conform to the following guidelines:

1. Manuscripts should be endorsed by their respective research advisers together with the consent from the student researchers.
2. Authors should submit two versions of the manuscript. One file (“file not for review”) should include the names of the authors (adviser and student/s), their contact information (e-mail addresses), and current affiliation (program/area and college). The other file (“file for review”) should remove any information that would identify the authors.
3. The paper should include keywords and an abstract of 100 – 200 words.
4. The article should contain approximately 6000 – 7000 words (including abstract, tables/figures, and references) and should be typed in a 12-point font, Garamond, double-spaced, with one-inch margin on all sides.
5. Tables/figures and references should follow the APA format style. Table titles are placed above while figure titles are placed below.
6. Reference should follow the APA format style.
7. The editors prefer to have the file in Microsoft Office Word 97-2003 Document (.doc) format and should be sent to thehorizon@letran.edu.ph
8. Manuscripts that are already published or in the process of publication in other journals will not be considered in the Letran Business and Economic Review.

Review Process

1. The editor screens the submitted manuscripts and selects those deemed suitable for peer reviewing. Selected articles then undergo a rigorous double-blind refereeing.
2. Once accepted, a Copyright Agreement will have to be sought from the student researchers and their research adviser.
3. Attached with the letter of acceptance are the comments and suggestions from the members of the editorial board. Revisions should be incorporated and returned to the Center within 2 weeks.
4. The editor makes the final decision on the publication of the revised articles.

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