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*Research article*

# Vis Tamarind: Assessing the Efficacy of Tamarind (*Tamarindus indica* L.) Seed Extract as an Anti-fogging and Antibacterial Solution for Endoscope Lenses

**Lenjanson Ablaza[1*], Leann Kristel Constantino[1], Lei Dominique Coronado[1], Amirel Gildore[1], Nick Emmanuel Manero[1], Jennifer Andreia Salming[1], Jhanna Kharylle Santos[1], Cleford Jay Bacan[1], and Mark Jobert Ellaga[1]**

[1] Cor Jesu College, Inc., Sacred Heart Avenue, Digos City, Davao del Sur 8002, Philippines
* Correspondence: ablazalenjanson@g.cjc.edu.ph

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**Abstract:** Fogging and bacterial contamination of endoscopic lenses pose risks to patient safety and the success of medical operations. Any flaws in surgery can cause harm to a patient. To mitigate these risks, this research evaluated the efficacy of tamarind (*Tamarindus indica* L.) seed extract as an anti-fogging solution and an antibacterial agent against *Escherichia coli*. Tamarind seeds were gathered, sun-dried, ground into a powder, and soaked in 70% ethanol to obtain the extract. Four concentrations (5%, 10%, 15%, and 100%) were made with distilled water: T1 (1 mL TKP extract + 19 mL distilled water), T2 (2 mL TKP extract + 18 mL distilled water), T3 (3 mL TKP extract + 17 mL distilled water), and T4 (20 mL TKP extract). The lenses applied at each concentration were tested for anti-fogging, optical clarity, and antimicrobial activity three (3) times. Results revealed that all treatments coated with tamarind seed extract effectively prevented lens fogging and maintained excellent optical clarity under humid conditions. Antibacterial testing showed that T4, a 100% extract, exhibited greater inhibitory activity against *E. coli*, producing a 21 mm zone of inhibition. Statistical analysis indicated no significant differences among treatments in fogging duration. However, the findings reveal an operational mismatch: anti-fogging performance was sustained at 5% dilution, whereas meaningful antibacterial activity required the undiluted (100%) extract. Although the raw extract demonstrates dual-action potential, this concentration-dependent trade-off requires formulation optimization before practical application as an eco-friendly and biocompatible alternative to synthetic anti-fogging and antibacterial agents.

**Keywords:** Tamarind seed extract; *Tamarindus indica* L.; anti-fogging; antibacterial; tamarind kernel powder

## 1. Introduction

Ensuring a clear image on the screen is crucial for precise surgical operation because it directly affects patient safety and surgical success. However, challenges persist, such as lens fogging during surgery, which can obscure the image, and bacterial contamination, which may pose a health risk to the patient and reduce the device's effectiveness. These concerns highlight an urgent need for research focused on preventing fogging and effectively disinfecting endoscopic instruments to enhance surgical safety and maintain optimal image clarity. Endoscopic lens issues, such as fogging and bacterial

contamination, have driven the adoption of disposable endoscopes. Human tissues and organs have a high water content and are lined with mucus; consequently, the moist internal environment promotes condensation on lenses, which can obscure the camera's view and thereby affect picture quality [1]. Past research confirms lens fogging severely hinders endoscopic visibility. By definition, lens fogging in laparoscopic surgery is a thermal gradient in which the lens tip temperature is 3.5°C or more lower than the abdominal cavity temperature, which heightens the difficulty of the procedure for the endoscopic surgeon [2]. As these challenges persist, greater challenges in laparoscopic surgeries can be experienced. A significant amount of time is also spent on laparoscopic surgery with a foggy display, which wastes valuable time by requiring lens cleaning [3].

The contamination problem with endoscopic lenses breaches health and safety standards. In the United States, France, China, Germany, the Netherlands, and the United Kingdom, *Klebsiella pneumoniae, Pseudomonas aeruginosa, Escherichia coli,* and *Salmonella enteritidis* contamination outbreaks involving endoscopes, specifically colonoscopy, duodenoscopy, and gastroscopy, were reported [4]. In the US state of Michigan, it was reported that transmission or contamination of *E. coli* through endoscopic procedures was high, even when proper protocols were followed. Specific surveillance studies show the risk may be significantly higher. In particular, a study that conducted microbiological surveillance at an Italian teaching hospital found that 35.7% of reprocessed endoscopes remained contaminated with high-risk indicator organisms, including *E. coli*, *K. pneumoniae, and P. aeruginosa* [5]. This persistent failure directly highlights the inadequacy of current cleaning protocols for internal instrument channels and demonstrates the urgent need for materials with inherent antibacterial properties.

Advanced scope-cleaning strategies have been developed, such as super-hydrophilic technology using cold plasma to form a thin, protective film [6]. Though effective, this method is limited because it requires intermittent removal of the scope for reapplication and debris clearance, thereby failing to provide the continuous, passive clarity needed during surgery. Other studies also explored natural anti-fogging agents. Seaweed-alizarin has been found to exhibit high antifogging properties, driven by structural interaction between *Gelidium amansii* polysaccharides and nanocrystals (CNCs), confirming the antifogging potential of polysaccharides [7]. In addition, the potential of polysaccharides as an anti-fogging agent was explored, yielding a fog-free glass surface within 10 seconds under specific environmental conditions [8]. Polysaccharides also worked as an anti-fogging agent on glass surfaces [9]. While this approach validates the use of natural materials for functional coatings, the resulting film is not entirely natural because it contains synthetic PVA. Consequently, the documented shortcomings establish a clear need for a novel, biocompatible, and continuously protective material.

Similarly, polysaccharide hydrocolloids have been identified in tamarind seeds, particularly xyloglucan derived from byproducts, further supporting the antifogging ability [10]. These studies have opened the potential of polysaccharides as an anti-fogging agent. Additionally, studies have introduced tamarind as a natural antibacterial agent. Tamarind seeds contain phytochemicals such as xyloglucan within the seed that exhibit antibacterial activity against common pathogens [11]. Tamarind pulp extract demonstrated antibacterial efficacy against both Gram-positive and Gram-negative bacteria such as *E.coli*, *P. aeruginosa, Staphylococcus aureus, and Bacillus cereus,* with the most concentrated solution (100 mg/mL) producing the most preferable zone of inhibition (ZOI) of 21 mm, 22 mm, 25 mm, and 17 mm, respectively [12]. Furthermore, crude ethanolic extract of tamarind produced a significantly larger zone of inhibition when tested against four bacterial strains and one fungal species, indicating high antibacterial potential [13]. In addition, *T. indica* extracts possess significant antibacterial potential against human pathogens, *S. aureus* and *E. coli* [14]. A study also explored the capability of tamarind as an antibacterial agent [15]. The antibacterial potential of *T. indica* leaf extract at different concentrations was evaluated. The results showed that concentrations of 100 mg/mL, 75 mg/mL, and 50 mg/mL exhibited antibacterial activity against Methicillin-Resistant *S. aureus* (MRSA). The extract produced measurable zones of inhibition in a spot test after 24 hours of incubation, supporting the claim that tamarind has potential as an antibacterial agent. These studies support the feasibility of using tamarind extracts as a locally sourced antibacterial component for further formulation development.

Crucially, clinical assessment validates tamarind seed polysaccharide's (TSP) high biocompatibility and moisture-retaining capacity on sensitive tissue, providing strong functional precedent for its use as a dual-action endoscope coating [16]. However, this study is strictly limited to antibacterial testing and fails to

address the optical requirements, such as anti-fogging, necessary for maintaining surgical lens visibility. However, on the other hand, distilled water can affect the antibacterial effects of extracts [17]. Thus, the findings highlight the need to optimize formulation conditions to preserve antibacterial efficacy while meeting the functional requirements of medical coatings. Past studies have explored the antioxidative, antibacterial, and film-forming properties of tamarind, yet its potential anti-fogging capability, especially for endoscopic applications, remains unexamined. Furthermore, while existing literature addresses isolated tamarind seed polysaccharides for topical hydration or standalone antibacterial traits, a clear scientific gap persists regarding how raw crude extract concentrations simultaneously govern both macro-optical performance and microbial resistance under high- humidity surgical parameters. Current anti-fogging solutions primarily use synthetic, alcohol-based chemicals, raising safety and environmental concerns. The use of natural plant-based alternatives, such as tamarind seed extract, is therefore a promising yet underexplored area of study. Recognizing the untapped potential of tamarind seeds, this research aims to address this gap by establishing the exact concentration thresholds where anti-fogging and antibacterial capabilities converge or diverge on optical substrates.

## 2. Materials and Methods

### 2.1 Plant Materials and Extract Preparation

Tamarind seeds were obtained from a local supermarket in Digos City, Davao del Sur. The seeds, with the outer shell intact, were first blended into a fine tamarind kernel powder (TKP). Following the procedures adapted from a study, 50 g of TKP was transferred to a clean beaker, and 1.5 L of 70% ethanol was added [18]. The mixture was refrigerated for 18 hours and stirred occasionally to facilitate the extraction process. Subsequently, the mixture was filtered using No. 40 filter paper, and the resulting filtrate was transferred to a beaker and heated on a hot plate set at 50 °C to evaporate the excess ethanol. The concentrated extract was then distributed into four (4) treatments in different concentrations (specifically 5% for T1, 10% for T2, 15% for T3, and 100% for T4) of the TKP extract using 20 mL of distilled water as the solvent.

### 2.1 Evaluation of Antibacterial Efficacy of TKP Extract

For evaluating the antibacterial effect of tamarind seed extract, the Agar Spot Assay Method was adapted [19]. Initially, a colony of *E. coli* was collected using an inoculating loop and transferred to a test tube containing saline solution. A sterile cotton swab was then dipped in the bacterial suspension and pressed against the inner wall of the test tube to remove excess liquid. After that, the swab was carefully distributed evenly all over the Mueller-Hinton agar plate. A drop of the TKP extract solution was then added to the center of the inoculated agar plate. Similarly, a drop of distilled water was added to the center of another inoculated agar plate to serve as the negative control. In contrast, the positive control, the antibiotic levofloxacin, was applied via a sterile paper disk and evaluated using the disk diffusion method. The plates were then incubated at 37 °C for 24 hours. Following incubation, the diameter of the inhibition zones was measured in millimeters using a caliper to quantify the antibacterial effect. This experiment was also performed with the other concentrations (5%, 10%, 15%, and 100%).

### 2.3 Assessment of Anti-Fogging and Optical Clarity Performance of TKP Extract

The procedures for evaluating anti-fogging and optical clarity were adapted [8, 20]. Commercially available double convex lenses with a 1.49 refractive index were utilized as basic surrogates for endoscope optics. Different concentrations of tamarind seed xyloglucan solution were applied to each of the three lenses and allowed to dry at room temperature. To simulate fogging conditions, the treated surfaces were placed in a water bath at 50 °C and maintained at a high humidity level of approximately 90% relative humidity. To determine how quickly the fog formed, transmittance was continuously monitored, and a timer was started as soon as the sample was exposed to steam. Time-to-Fog (TTF) was defined as the elapsed time until either condensation was visibly observed or the transmittance dropped below 80% of the initial T0. These tests were repeated 3 times for each concentration to ensure data reliability. The small sample size (n = 3) was selected due to resource constraints during this exploratory phase. Additionally, the optical clarity was calculated by performing calibration of the light-measuring instrument in a dark, enclosed container with its internal surface painted black to prevent interference from ambient lighting. The light source was located at one end of the enclosure, with the lux meter sensor situated 20- 30 cm from the light source and a lens holder placed 3 cm away. After the light source stabilized for 5 minutes, the baseline light intensity (E0) was measured without a

sample. Each sample was then placed between the light source and the lux meter in the same position, and three readings were taken and averaged to get the transmitted light, E. Finally, the optical clarity was calculated as: (E ÷ E0) × 100%.

### 2.4 Statistical Analysis

The data in this experimental study were analyzed by calculating the mean. The Kruskal–Wallis test was used to determine whether there was a significant difference in anti-fogging and antibacterial performance among the treatment groups, and Dunn's test was used as a follow-up to identify which specific groups differed in relation to the tamarind seed extract treatment.

## 3. Results and Discussion

### 3.1 Level of Fog Formation and Duration on Endoscope Lenses Treated with Tamarind Seed Extract and Controls

The study assessed the effectiveness of tamarind kernel powder (TKP) extract as an anti-fogging agent on endoscope lenses by measuring the time to fog formation under controlled conditions. Four concentrations of TKP extract (1 mL, 2 mL, 3 mL, and 20 mL with distilled water) and a negative control were tested. As shown in Table 1, all lenses treated with TKP extract exhibited complete resistance to fogging throughout the 10-minute observation period (≥600 seconds), with an excellent rating indicating long-lasting, clear vision, which is suitable for high-humidity environments. No variation was observed among replicates, indicating consistent performance across concentrations. In contrast, the negative control showed rapid fogging with a mean time of 6.83 seconds (SD = 0.96), which indicates a poor anti-fogging effectiveness. These findings demonstrated that TKP extract, even at the lowest concentration, effectively prevents fog formation without requiring higher concentrations. Overall, tamarind kernel extract proved to be a stable and highly effective natural anti-fogging agent for endoscopic applications. These results were supported by a study that used polysaccharides and tested their anti-fogging capabilities, yielding a fog-free duration of 10 seconds under specific environmental conditions [8]. Similarly, polysaccharides were confirmed to work as an anti-fogging agent on glass surfaces [9]. Additionally, seaweed-alizarin extracts were shown to possess high antifogging properties [7]. These traits are attributed to the combination of *G. amansii* polysaccharides and cellulose nanocrystals (CNCs), confirming the antifogging potential of polysaccharides.

However, a clear ceiling effect was observed in the anti-fogging dataset: all four concentrations (5%, 10%, 15%, and 100%) completely resisted fogging through the entire 10-minute observation window (>600 seconds) with zero variance among the treated groups. This limits the ability to perform a true dose-response analysis or mathematically pinpoint the absolute minimum effect concentration threshold under these parameters. Future studies should extend the observation window beyond 10 minutes or implement repeated fogging cycles to differentiate performance durability across dilution levels.

**Table 1.** Fog Formation Duration on Endoscope Lenses Treated with Tamarind Seed Extract and Controls

| Treatment | Trial Set-up (in seconds) | | | Mean | SD | Interpretation |
|---|---|---|---|---|---|---|
| | S1 | S2 | S3 | | | |
| 1 mL TKP extract with 19 mL distilled water (T1) | ≥600 | ≥600 | ≥600 | ≥600 | — | Excellent |
| 2 mL TKP extract with 18 mL distilled water (T2) | ≥600 | ≥600 | ≥600 | ≥600 | — | Excellent |
| 3 mL TKP extract with 17 mL distilled water (T3) | ≥600 | ≥600 | ≥600 | ≥600 | — | Excellent |
| 20 mL TKP extract (T4) | ≥600 | ≥600 | ≥600 | ≥600 | — | Excellent |
| Negative Control | 7.90 | 6.57 | 6.03 | 6.83 | 0.96 | Poor |

**Note**: TKP = tamarind kernel powder. "≥600 s" indicates that no fogging occurred within the 10-minute observation period. Mean values for treatments with no fogging are reported as the minimum possible time (10 minutes). SD does not apply to these treatments.

### 3.2 Level of Anti-Fogging Effectiveness of Tamarind Seed Extract and Controls on Endoscope Lenses Measured by Light Transmittance

The anti-fogging effectiveness of tamarind kernel powder (TKP) extract on endoscope lenses was evaluated using light transmittance measurements, which reflect lens clarity after exposure to fog-inducing conditions. As shown in Table 2, all TKP-treated lenses exhibited high transmittance values, ranging from 96.60% to 99.39%, with the 1 mL extract in 19 mL distilled water achieving the highest mean of 99.39% (SD = 0.57). The 2 mL, 3 mL, and 20 mL treatments also maintained high transmittance (96.60%–97.46%), all classified as very good, indicating that the TKP coating preserved lens clarity across concentrations. The negative control similarly showed 100% transmittance (SD = 0), reflecting the initial optical clarity of the untreated lens. These findings confirm that TKP extract does not reduce optical quality while effectively maintaining lens transparency. Even at low concentrations, TKP extracts preserved clarity, supporting its potential as a natural, effective anti-fogging agent for endoscopic applications. The anti-fogging effectiveness of tamarind kernel powder (TKP) extract containing polysaccharides on endoscope lenses was evaluated using light transmittance measurements, which reflect lens clarity after exposure to fog-inducing conditions. These findings align with a report that polysaccharide-based films demonstrated significant antifogging performance due to their hydrophilic characteristics [7]. Therefore, this supports the role of polysaccharides in antifogging performance, as their hydrophilic properties help maintain high light transmittance.

**Table 2.** Anti-Fogging Effectiveness of Tamarind Seed Extract and Controls on Endoscope Lenses Measured by Light Transmittance

| Treatment | Trial Set-up (in seconds) | | | Mean | SD | Interpretation |
|---|---|---|---|---|---|---|
| | S1 | S2 | | | | |
| T1 | 100 | 99.64 | 98.90 | 99.39 | 0.57 | Very Good |
| T2 | 97.45 | 96.72 | 95.64 | 96.60 | 0.91 | Very Good |
| T3 | 98.55 | 97.82 | 96 | 97.46 | 1.28 | Very Good |
| T4 | 97.82 | 93.82 | 100 | 97.21 | 3.54 | Very Good |
| Negative Control | 100 | 100 | 100 | 100 | 0 | Very Good |

### 3.3 Level of Zone of Inhibition of Tamarind Seed Extract and Controls Against Escherichia coli on Mueller-Hinton Agar

The antibacterial activity of TKP extract against *E. coli* was examined using the agar spot assay and disk diffusion method, with the zone of inhibition (ZOI) as the indicator of antibacterial effectiveness. As shown in Table 3, antibacterial activity increased with concentration. The 1 mL and 2 mL TKP extract treatments showed no inhibition (0 mm). In contrast, the 3 mL treatment exhibited only slight activity with a mean ZOI of 5.67 mm (SD = 1.7), all classified as resistant, indicating a minimal zone of inhibition and weak or no antibacterial activity. In contrast, the undiluted 20 mL TKP extract demonstrated a strong inhibitory effect with a mean ZOI of 20.33 mm (SD = 0.47), categorized as susceptible, which indicates a large zone of inhibition and strong antibacterial activity. The positive control, levofloxacin, produced a 30 mm inhibition zone, confirming assay reliability, whereas the negative control showed no effect. These results indicate that TKP extract exhibits dose-dependent antibacterial activity, with effectiveness becoming evident only at higher concentrations. Concentrated TKP extract may therefore serve as a potential natural antibacterial agent against *E. coli*, though its efficacy diminishes with dilution. However, not all treatments have shown excellent performance against the Gram-negative bacteria. Only the most concentrated treatment (T4) showed a preferable inhibitory effect against *E.coli.* This aligns with the study in which the most concentrated treatment yielded the most preferable result compared to the positive control [12]. The presence of distilled water affected the effectiveness of the extract to exhibit preferable results against *E. coli* [17]. These findings denote that higher extract concentration is critical to overcome the reduced antibacterial effectiveness caused by dilution factors when targeting gram-negative bacteria.

Crucially, these findings expose a fundamental functional incompatibility between the anti-fogging and antibacterial performance profiles across the tested concentrations. While the macro-structural hydrophilic properties required to prevent lens fogging remain highly effective even at a sparse 5% concentration (T1),

acceptable antibacterial mitigation against *E. coli* is completely absent until the coating reaches an undiluted 100% threshold (T4). This divergence indicates that the two targeted medical properties are not complementary along a uniform dilution gradient. Furthermore, relying on a 100% undiluted crude extract as a direct lens coating presents distinct practical constraints in a clinical setting, specifically regarding film thickness, drying uniformity, and structural stability on the lens substrate. Rather than acting as a simple, direct drop-in dual coating, these data demonstrate that raw tamarind seed extract exhibits a clear operational trade-off. Overcoming this threshold gap will require secondary chemical engineering, such as embedding the extract within a polymer matrix carrier or developing controlled-release stabilization to depress the minimum effective antibacterial concentration to match its highly responsive low-concentration antifogging baseline.

**Table 3.** Zone of Inhibition of Tamarind Seed Extract and Controls Against Escherichia coli on Mueller-Hinton Agar

| Treatments | Result | | | Mean | SD | Description |
|---|---|---|---|---|---|---|
| | R1 | R2 | R3 | | | |
| T1 | 0 | 0 | 0 | 0 | 0 | Resistant |
| T2 | 0 | 0 | 0 | 0 | 0 | Resistant |
| T3 | 5 | 4 | 8 | 5.67 | 1.7 | Resistant |
| T4 | 20 | 21 | 20 | 20.33 | 0.47 | Susceptible |
| Positive Control | 30 | 30 | 30 | 30 | 0 | Susceptible |
| Negative Control | 0 | 0 | 0 | 0 | 0 | Resistant |

### 3.4 Significant Difference in Anti-Fogging Performance Between Tamarind Seed Extract-Treated Surfaces and Untreated Surfaces

The study examined whether significant differences existed in the anti-fogging performance between tamarind kernel powder (TKP) extract-treated and untreated surfaces. Table 4 presents the comparative analysis based on fog formation duration and light transmittance. A normality test using the Shapiro-Wilk method showed that the data significantly deviated from a normal distribution ($W = 0.500$, $p = .000$; $W = 0.879$, $p = .047$), necessitating the use of a nonparametric test. Therefore, the Independent-Samples Kruskal-Wallis Test was applied to determine whether significant differences existed among treatments. The Kruskal–Wallis test for fog formation duration revealed a statistically significant difference among treatments ($H = 13.796$, $df = 4$, $p = .008$), indicating that TKP extract-treated lenses significantly outperformed untreated surfaces in preventing fog formation. Similarly, the test for light transmittance showed a significant difference ($H = 9.970$, $df = 4$, $p = .041$), suggesting slight but consistent variations in clarity among treatments. Lenses treated with lower TKP concentrations, particularly 1 mL extract with 19 mL distilled water, showed the highest mean transmittance (99.39%), nearly equal to the control (100%). Higher concentrations displayed marginally lower values but still maintained very good ratings. These results confirm that TKP extract effectively enhances fog resistance while maintaining excellent optical quality, supporting its use as a natural, efficient anti-fogging agent for endoscopic lenses.

**Table 4.** Significant Difference in Anti-Fogging Performance Between Tamarind Seed Extract-Treated Surfaces and Untreated Surfaces

| Variables Reviewed | Test Statistic | df | p-value | Decision | Interpretation |
|---|---|---|---|---|---|
| Fog Formation Duration | 13.796 | 4 | .008 | Reject $H_o$ | Significant Difference |
| Light Transmittance | 9.970 | 4 | .041 | Reject $H_o$ | Significant Difference |

#### *3.4.1 Post Hoc Comparisons using Dunn's Test for the Fog Formation Duration*

As presented in Table 5, no statistically significant differences were observed among the TKP-treated groups (T1, T2, T3, and T4), as all pairwise comparisons yielded p-values greater than .05. However, significant differences were found between each TKP-treated group and the control ($p = .033$). This finding indicates that all concentrations of TKP extract were significantly more effective than the untreated control in delaying fog formation on endoscope lenses. The absence of significant differences among the treated groups further suggests that even the lowest concentration of TKP extract provides sufficient anti-fogging protection, and

increasing the extract concentration does not yield additional statistical improvement in performance. To identify which treatment groups differed significantly in terms of light transmittance, a post hoc analysis using Dunn's test was conducted following the Kruskal–Wallis test. As shown in Table 6, the analysis revealed that certain pairwise comparisons were statistically significant. Specifically, T1 and T2 differed significantly (p = .048), while T2 differed significantly from the control (p = .007). Additionally, T3 and the control (p = .048) and T4 and the control (p = .030) also showed significant differences. All other pairwise comparisons did not reach statistical significance (p > .05). These findings indicate that while all TKP-treated surfaces maintained high light transmittance, slight but significant differences were observed between some treatment concentrations and the untreated control. Overall, this suggests that TKP extract preserves lens clarity effectively, with minor variations depending on the specific concentration applied.

**Table 5.** Post Hoc Comparisons using Dunn's Test for the Fog Formation Duration

| | Test Statistic | SE | p | Decision | Interpretation |
|---|---|---|---|---|---|
| Between T1 and T2 | 0.000 | 2.554 | 1.000 | Fail to Reject $H_o$ | Not Significant |
| Between T1 and T3 | 0.000 | 2.554 | 1.000 | Fail to Reject $H_o$ | Not Significant |
| Between T1 and T4 | 0.000 | 2.554 | 1.000 | Fail to Reject $H_o$ | Not Significant |
| Between T1 and Control | 2.936 | 2.554 | .033 | Reject $H_o$ | Significant |
| Between T2 and T3 | 0.000 | 2.554 | 1.000 | Fail to Reject $H_o$ | Not Significant |
| Between T2 and T4 | 0.000 | 2.554 | 1.000 | Fail to Reject $H_o$ | Not Significant |
| Between T2 and Control | 2.936 | 2.554 | .033 | Reject $H_o$ | Significant |
| Between T3 and T4 | 0.000 | 2.554 | 1.000 | Fail to Reject $H_o$ | Not Significant |
| Between T3 and Control | 2.936 | 2.554 | .033 | Reject $H_o$ | Significant |
| Between T4 and Control | 2.936 | 2.554 | .033 | Reject $H_o$ | Significant |

### *3.4.2 Post Hoc Comparisons using Dunn's Test for the Light Transmittance*

To identify which treatment groups differed significantly in terms of light transmittance, a post hoc analysis using Dunn's test was conducted following the Kruskal–Wallis test. As shown in Table 6, the analysis revealed that certain pairwise comparisons were statistically significant. Specifically, T1 and T2 differed significantly (p = .048), while T2 differed significantly from the control (p = .007). Additionally, T3 and the control (p = .048) and T4 and the control (p = .030) also showed significant differences. All other pairwise comparisons did not reach statistical significance (p > .05). These findings indicate that while all TKP-treated surfaces maintained high light transmittance, slight but significant differences were observed between some treatment concentrations and the untreated control. Overall, this suggests that TKP extract preserves lens clarity effectively, with minor variations depending on the specific concentration applied.

**Table 6.** Post Hoc Comparisons using Dunn's Test for the Light Transmittance

| | Test Statistic | SE | p | Decision | Interpretation |
|---|---|---|---|---|---|
| Between T1 and T2 | -7.167 | 3.619 | .048 | Reject $H_o$ | Significant |
| Between T1 and T3 | -4.500 | 3.619 | .214 | Fail to Reject $H_o$ | Not Significant |
| Between T1 and T4 | -5.167 | 3.619 | .153 | Fail to Reject $H_o$ | Not Significant |
| Between T1 and Control | -2.667 | 3.619 | .461 | Fail to Reject $H_o$ | Not Significant |
| Between T2 and T3 | -2.667 | 3.619 | .461 | Fail to Reject $H_o$ | Not Significant |
| Between T2 and T4 | -2.000 | 3.619 | .580 | Fail to Reject $H_o$ | Not Significant |
| Between T2 and Control | -9.833 | 3.619 | .007 | Reject $H_o$ | Significant |
| Between T3 and T4 | -0.667 | 3.619 | 0.854 | Fail to Reject $H_o$ | Not Significant |
| Between T3 and Control | -7.167 | 3.619 | .048 | Reject $H_o$ | Significant |
| Between T4 and Control | 7.833 | 3.619 | .030 | Reject $H_o$ | Significant |

### 3.5 Significant Difference in the Zone of Inhibition of Tamarind Seed Extract and Controls Against Escherichia coli on Mueller-Hinton Agar

The study examined whether significant differences existed in the antibacterial activity of tamarind kernel powder (TKP) extract at varying concentrations compared to the controls. Table 7 presents the comparative analysis of the zone of inhibition against *E. coli* using the experimental groups (different TKP concentrations) and control groups (levofloxacin and distilled water). A normality test using the Shapiro-Wilk method indicated a significant deviation from normal distribution ($W = 0.793$, $p = .003$), suggesting that the data did not meet the assumptions for parametric testing. Consequently, the Independent-Samples Kruskal–Wallis Test was employed to determine whether significant differences existed among the treatments. As shown in Table 7, the Kruskal–Wallis test indicated a test statistic of 16.859 with 5 degrees of freedom and a p-value of .005, which is less than the .05 significance level. Therefore, the null hypothesis was rejected, indicating a statistically significant difference in the antibacterial activity among the treatments. This finding suggests that the concentration of TKP extract significantly influenced its inhibitory effect against *E. coli*, with higher concentrations producing greater antibacterial activity compared to the lower concentrations and the negative control.

**Table 7.** Significant Difference in the Zone of Inhibition of Tamarind Seed Extract and Controls Against Escherichia coli on Mueller-Hinton Agar

| Variables Reviewed | Test Statistic | df | p-value | Decision | Interpretation |
|---|---|---|---|---|---|
| Zone of Inhibition | 16.859 | 5 | .005 | Reject $H_o$ | Significant Difference |

#### *3.5.1 Post Hoc Comparisons using Dunn's Test for Zone of Inhibition Between Treatments*

Dunn's test for pairwise comparisons in Table 8 identified the 20 mL TKP extract (T4) as the most effective treatment. T4 showed significantly greater inhibition than T1, T2, and the negative control (all $p = .027$), while performing similarly to the positive control ($p > .05$). This indicates that substantial antibacterial efficacy against *E. coli* requires higher TKP concentrations. These data confirm that the antibacterial efficacy of the extract against Gram-negative isolates is strictly dosage-dependent, conforming to traditional minimum inhibitory concentration thresholds found in crude botanical extracts. Statistical analysis using Dunn's Test revealed significant variance among the treatment groups, with T4 emerging as the most potent concentration. This highest concentration demonstrated antibacterial activity significantly exceeding that of T1 and exhibited an inhibitory performance comparable to the positive control, levofloxacin. Such findings validate previous research, which reported that peak concentrations of tamarind extract produced a notable 21 mm zone of inhibition (ZOI) against *E. coli* [12]. In contrast, no statistically significant differences were observed between T1, T2, and T3, suggesting that lower concentrations yield relatively uniform antibacterial effects. Ultimately, these data indicate that the antibacterial efficacy of the extract is dosage-dependent, with substantial potency gains occurring at higher concentration levels.

### 3.6 Study Limitations and Clinical Constraints

While this study demonstrates the functional potential of tamarind seed extract as an anti-fogging and antibacterial coating, several methodological limitations should be considered before extrapolating the findings to clinical applications. First, the study employed standard double-convex lenses (refractive index = 1.49) as surrogate optical substrates, which provide only a structural approximation of clinical endoscope lenses. Actual endoscopic systems are manufactured from precision optical materials, such as borosilicate glass or specialized high-refractive-index material (approximately 1.52-1.90), and incorporate anti-reflective or hydrophobic coatings with specialized curvature optimized for visualization within narrow luminal spaces. Consequently, the surface chemistry, wettability, thermal properties, and coating behavior of the surrogates may differ substantially from those of clinical endoscopes. Moreover, coating the entire lens surface does not accurately replicate the distal tip environment of an endoscope, where performance is influenced by confined geometry and continuous exposure to biological fluids. In addition, the fogging simulation utilized a 50°C water bath at 90% relative humidity, representing an accelerated thermal challenge rather than a clinically

validated environment. Endoscopic lens fogging primarily occurs when a room-temperature scope encounters the warm, humid intra-abdominal environment, creating a localized thermal gradient [2]. Therefore, the experimental conditions likely induced condensation more rapidly than would typically occur during clinical procedures.

**Table 8.** Post Hoc Comparison

| | Test Statistic | SE | p | Decision | Interpretation |
|---|---|---|---|---|---|
| Between T1 and T2 | 0.000 | 4.068 | 1.000 | Fail to Reject $H_o$ | Not Significant |
| Between T1 and T3 | -6.000 | 4.068 | .140 | Fail to Reject $H_o$ | Not Significant |
| Between T1 and T4 | -9.000 | 4.068 | .027 | Reject $H_o$ | Significant |
| Between T1 and Positive Control | -12.000 | 4.068 | .003 | Reject $H_o$ | Significant |
| Between T1 and Negative Control | 0.000 | 4.068 | 1.000 | Fail to Reject $H_o$ | Not Significant |
| Between T2 and T3 | -6.000 | 4.068 | .140 | Fail to Reject $H_o$ | Not Significant |
| Between T2 and T4 | -9.000 | 4.068 | 0.027 | Reject $H_o$ | Significant |
| Between T2 and Positive Control | -12.000 | 4.068 | 0.003 | Reject $H_o$ | Significant |
| Between T2 and Negative Control | 0.000 | 4.068 | 1.000 | Fail to Reject $H_o$ | Not Significant |
| Between T3 and T4 | -3.000 | 4.068 | .461 | Fail to Reject $H_o$ | Not Significant |
| Between T3 and Positive Control | -6.000 | 4.068 | .140 | Fail to Reject $H_o$ | Not Significant |
| Between T3 and Negative Control | -6.000 | 4.068 | .140 | Fail to Reject $H_o$ | Not Significant |
| Between T4 and Positive Control | -3.000 | 4.068 | .461 | Fail to Reject $H_o$ | Not Significant |
| Between T4 and Negative Control | -9.000 | 4.068 | .027 | Reject $H_o$ | Significant |
| Between Positive Control and Negative Control | -12.000 | 4.068 | .003 | Reject $H_o$ | Significant |

s using Dunn's Test for Zone of Inhibition Between Treatments

Another important limitation concerns the evaluation of antibacterial activity using the agar spot assay, which measures the diffusion of free liquid extract through a hydrated agar matrix. In practical medical device applications, the coating would exist as a dried, polymerized film immobilized on the optical surface. Consequently, the present assay does not determine whether a fully cured xyloglucan-based coating would retain comparable antibacterial activity or contact-killing efficacy. Future studies should therefore incorporate standardized surface-contact antimicrobial testing, such as ISO 22196, to better simulate clinical use conditions. Furthermore, all experiments were conducted using an exploratory sample size of three (n = 3) without a formal statistical power analysis. The relatively large standard deviations observed in certain treatment groups indicate biological and experimental variability that cannot be adequately characterized with such a limited sample size. Increasing the sample size to at least five or six replicates in future validation studies would improve statistical robustness and confidence in the observed effects. Finally, the study did not include phytochemical characterization of the tamarind seed extract. Although the observed functional properties are hypothesized to arise from naturally occurring xyloglucans, tannins, and organic acids, analyses of xyloglucans, tannins, and organic acids, such as total polysaccharide quantification, high-performance liquid chromatography (HPLC), and Fourier-transform infrared spectroscopy (FTIR), were not performed. As a result, the specific bioactive constituents responsible for the observed performance remain unverifiable, and batch-to-batch compositional consistency cannot be established.

## 4. Conclusions

This study evaluated the anti-fogging and antibacterial properties of *T. indica* seed extract while maintaining lens clarity. All concentrations showed high anti-fogging activity compared to the control, reducing fog and maintaining a fog-free state for over 10 minutes (≥600 seconds). Optical clarity, measured by light transmittance, ranged from 96% to 99%. In the clarity test, T1 (1 mL TKP extract with 19 mL distilled

water) had the highest mean percentage at 99.39%, followed by T2 (2 mL TKP extract with 18 mL distilled water) at 96.60%, T3 (3 mL TKP extract with 17 mL distilled water) at 97.46%, and T4 (20 mL TKP extract) at 97.21%. For antibacterial activity against *E. coli*, only T4 showed the highest mean ZOI of 20.33 mm, while T3 was lower at 5.67 mm, and T1 and T2 showed no activity. No significant differences were found among all treatments (p=1.000) for anti-fogging duration, but a definitive performance mismatch was identified between the functional thresholds of each property. While low dilutions (5%) optimize lens clarity and anti-fogging, antibacterial defense requires an undiluted (100%) matrix. Consequently, raw tamarind kernel extract cannot currently be deployed as a uniform dual-action coating without further formulation processing to reconcile this critical functional gap. Furthermore, given the limitations regarding basic lens surrogates, extreme fogging simulation temperatures, and liquid agar spot testing methods, these findings serve as an initial proof-of-concept rather than a direct claim of immediate clinical readiness.

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