

Optimizing Dyeing Parameters Using The Taguchi Experimental Design L9(3³) Method To Evaluate The Antibacterial Activity Of *Solanum Torvum* Fruit Extract Against Pathogenic Bacteria Present In Kitchen Linen

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Abstract

The growing demand for eco-friendly textiles has encouraged the exploration of natural dyes with inherent functional properties. This study investigates the antibacterial potential of *Solanum torvum* (Turkey Berry) fruit extract applied to bamboo–cotton blended fabrics for kitchen linen applications. The plant material was authenticated and extracted using methanol and acetone, with methanol showing superior efficiency in yielding bioactive compounds. Phytochemical, FTIR and HPTLC analysis confirmed alkaloids as the dominant constituents, while cytotoxicity assessment (ISO 10993-5:2009, MTT assay) indicated high cell viability, establishing the safety of the extract. Antibacterial screening revealed strong activity of methanol extracts against *Escherichia coli* (19 mm) and *Staphylococcus aureus* (21 mm). Dyed fabrics with the extract exhibited enhanced antibacterial efficacy, with inhibition zones of 28 mm and 26 mm, respectively. Optimization of dyeing parameters using Taguchi's Experimental design identified the best parameter (10% extract concentration (o.w.f), 50 minutes, 90% pick-up), producing maximum inhibition zones of 30 mm (*E. coli*) and 29 mm (*S. aureus*). Physical property analysis confirmed minor increases in GSM and thickness, without compromising fabric integrity. The results demonstrate that *S. torvum* extract serves as both a natural dye and an effective antibacterial finish, making it a promising sustainable alternative to chemical treatments in home textiles. The integration of medicinal plant extracts with optimized finishing processes provides a pathway for developing safe, durable, and eco-friendly kitchen linen.

Keywords: *Solanum torvum*, Natural dye, Antibacterial activity, Taguchi optimization, Bamboo–cotton fabric, Sustainable textiles, Kitchen linen, FTIR, Phytochemical, HPTLC, Cytotoxicity, Taguchi Experimental Design

1. INTRODUCTION

The home textiles act as a wide range of fabric-based products which are used to improve the comfort, applicability, and visual appeal of living spaces (Carpenter et.al, 2024, Barman et.al, 2023 and Samantha et.al, 2025). Home textiles generally include products like the as bed linens, curtains, rugs, and kitchen textiles and all these products functions significant role in everyday household activities (Lowry et.al, 2024, Farooq et.al, 2021 and Bhat et.al, 2021). Among all these products the kitchen linens are making them highly vulnerable to contamination (Moretro et.al, 2024 and Devi et.al, 2025).

In India, this kitchen linens are generally in explosion to varied environmental conditions and with the repeated use and also having an inconsistent cleaning practice all these contribute to the accumulation of microorganisms (Reynolds et.al, 2022 and Mahendran et.al, 2025). There are several research works which have shown that fabrics used in kitchens frequently harbour bacteria such as *Escherichia coli* and *Staphylococcus aureus*, highlighting the importance of hygiene and safety in these everyday textiles (Moretro et.al, 2022, Mataragka et.al, 2025, Shakir et.al, 2025, Rahamatullah et.al, 2025 and Kim et.al, 2022)

Along with the increasing environmental concerns there is a subsequent consideration into the growing interest of using natural dyes for textile coloration (Che et.al, 2022 and Mamun et.al, 2023). Derived from plants and other renewable sources, natural dyes offer an eco-friendly and biodegradable alternative to synthetic dyes (Kaur et.al, 2023 and Singh et.al, 2021). *Solanum torvum* Sw., commonly known as Turkey Berry, belongs to the order Solanales and the family Solanaceae (Pandey et.al, 2024). It is a perennial shrub valued in traditional medicine for its diverse bioactive compounds, particularly alkaloids, flavonoids, and phenolic constituents, which are reported to exhibit antimicrobial activity. The fruits of *S. torvum* have

been selected in this study as a natural dye source, owing to their medicinal relevance and potential functional applications in textiles (Shah et.al, 2021). Hence, addressing microbial contamination in kitchen linen through sustainable finishing methods has both hygienic and environmental importance (Owen, 2021)

To scientifically establish the bio functional potential of *S. torvum*, its extracts were characterized using multiple analytical techniques. The Fourier Transform Infrared Spectrophotometer (FTIR) is probably the most powerful instrument for determining the sorts of chemical bonds (functional groups) found in compounds. The analysed spectrum shows that the wavelength of light absorbed is indicative of the chemical bond.

Qualitative phytochemical screening confirmed the presence of bioactive compounds such as alkaloids, flavonoids, tannin, terpenoids and phenolics, while High-Performance Thin Layer Chromatography (HPTLC) provided chromatographic evidence of alkaloid dominance in methanol extracts. They are generally non-toxic and can potentially impart additional functional properties, such as antimicrobial activity, to textiles. The integration of natural dyes into kitchen linens thus represents a promising approach that combines sustainability with potential health benefits, making it a focus area for research in home textile applications (Dey et.al, 2025 and Kamboj et.al, 2024). Additionally, cytotoxicity testing was conducted according to ISO 10993-5:2009 using the MTT assay on L-929 fibroblast cells to evaluate the biocompatibility of the extract for textile use. To enhance the efficiency of the dyeing and finishing process, the Taguchi Design of Experiments was adopted. This orthogonal array-based statistical approach reduces the number of experimental runs while providing robust insights into the influence of multiple factors and their interactions, thereby ensuring a reliable optimization strategy (Hisam et al., 2024).

2. REVIEW OF LITERATURE

Experimental design methods have been increasingly applied in textile research to optimize processes and improve functional performance. The Taguchi Design of Experiments (DOE), in particular, is widely recognized for its ability to evaluate multiple parameters simultaneously through orthogonal arrays, thereby reducing the number of experimental runs without compromising statistical accuracy. This approach has proven especially useful in natural dyeing and finishing applications, where factors such as extract concentration, treatment time, and pick-up percentage influence both color yield and antibacterial performance. Studies have highlighted the versatility of the Taguchi method across different disciplines, emphasizing its value in developing sustainable and functional textiles (Hisam et al., 2024; Nikhila, 2025; Pervez et al., 2023).

Kitchen linens such as dish towels, napkins, and aprons are highly susceptible to microbial contamination because of their constant exposure to food residues, moisture, and repeated handling. Research has consistently reported that these textiles harbor pathogenic microorganisms, with *Escherichia coli* and *Staphylococcus aureus* being the most commonly identified species. Their persistence on kitchen fabrics is of particular concern due to their association with foodborne illnesses and potential for cross-contamination in domestic environments. Studies have shown that repeated use and inadequate washing practices contribute to microbial survival and accumulation on these fabrics, underscoring the need for sustainable antibacterial solutions in home textiles (Moretro et al., 2022; Reynolds et al., 2022; Mahendran et al., 2025; Mataragka et al., 2025; Shakir et al., 2025; Kim et al., 2022).

3. Problem Statement

Kitchen linens are among the most contaminated household textiles because of their frequent reuse, contact with food residues, exposure to moisture, and inconsistent washing practices. These conditions create a favourable environment for microbial growth, turning fabrics such as dish towels, napkins, and aprons into reservoirs of pathogenic organisms. Among the wide range of microorganisms detected, *Escherichia coli* and *Staphylococcus aureus* are the most consistently reported pathogens on kitchen fabrics. *E. coli* is often linked to gastrointestinal infections and cross-contamination during food preparation, while *S. aureus* is associated with toxin-mediated food poisoning. Their persistence on household textiles highlights a critical hygiene challenge in domestic environments. Addressing this issue requires sustainable alternatives to conventional chemical finishes, as synthetic treatments may pose health and environmental concerns. Therefore, the present study focuses on assessing the contamination risks posed by *E. coli* and *S. aureus* in kitchen linens and explores the use of plant-based natural extracts of *Solanum torvum* as an eco-friendly solution for antibacterial finishing.

4. Scope of the Study

The present study is designed to explore the potential of *Solanum torvum* fruit extracts as a sustainable alternative for developing antibacterial kitchen linens. The research focuses on (i) identifying bioactive compounds in the extract through phytochemical screening, FTIR, and HPTLC analyses, (ii) evaluating the antibacterial activity of the extract against *Escherichia coli* and *Staphylococcus aureus*, two major pathogens commonly associated with contaminated kitchen fabrics, and (iii) assessing the biocompatibility of the extract through cytotoxicity testing. The study further extends to the application of the extract on bamboo-cotton blended fabrics using the pad-dry-cure method, with optimization of dyeing and finishing parameters through the Taguchi Design of Experiments to maximize antibacterial performance. In addition, the antibacterial efficacy and physical properties of treated fabrics are evaluated to ensure functionality without compromising fabric quality. By integrating medicinal plant-based bioactive compounds into household textiles, the study aims to contribute toward eco-friendly solutions that address both public health and environmental concerns.

5. METHODOLOGY

The methodology of the current study was designed to systematically assess the antibacterial efficacy of *Solanum torvum* extracts on bamboo-cotton fabrics and to optimize the finishing process. The following steps were undertaken:

5.1 Plant Taxonomy and Authentication

The fruits of *Solanum torvum* Sw. (Turkey Berry), belonging to the order Solanales and the family Solanaceae, were collected from the area of Sathyamangalam town, Erode district in Tamil Nadu, India. The plant material was authenticated by the Botanical Survey of India (BSI), Tamil Nadu Agricultural University, Coimbatore. The fruits were washed, shade-dried, and stored under controlled conditions until further use.

5.2 Fabric Specification and Pre-treatment

A bamboo-cotton blended fabric (50:50) was woven on a power loom at Pallipalayam, Erode. The warp yarns were bamboo and the weft yarns were cotton, both with a yarn count of 30s. The fabric was constructed in a plain and twill combination weave with 110 ends per inch (EPI) and 85 picks per inch (PPI), with a GSM of 159.4 g/m² and thickness of 0.59 mm. The fabric was desized with hydrochloric acid solution (25 ml/L) at 60 °C for 60 minutes using a material-to-liquor ratio (MLR) of 1:30, followed by washing and drying to remove impurities.

5.3 Preparation of Plant Extract

The dried fruits were powdered and subjected to Soxhlet extraction using methanol and acetone as solvents. The extracts were concentrated and stored at 4 °C in airtight containers. Preliminary antibacterial screening using the agar well diffusion method against *E. coli* and *S. aureus* revealed that methanol extracts showed higher inhibition zones and were selected for further finishing experiments.

5.4 Phytochemical and Analytical Characterization

5.4.1. Qualitative Phytochemical Screening

The methanolic extract was screened for bioactive constituents using standard phytochemical tests. The extract tested positive for alkaloids (Mayer's and Dragendorff's tests), flavonoids (Shinoda test), phenols and tannins (Ferric chloride test) and terpenoids were absent. Alkaloids were found in the highest concentration, correlating with antibacterial potential.

5.4.2. Fourier Transform Infrared Spectroscopy (FTIR)

The small amount of powdered samples were made into pellets using KBr for FTIR analysis and a thin film was prepared by applying pressure. All the samples were analysed in triplicates with plain KBr pellets as blank. The spectral data were compared with a reference to identify the functional groups existing in the sample was then analysed using an FTIR spectroscope (Shimadzu, IR Affinity 1, Japan), which operates with a resolution of cm⁻¹ and a scanning range from 600 to 3600 cm⁻¹.

5.4.3. High-Performance Thin Layer Chromatography (HPTLC)

HPTLC profiling validated alkaloids as the dominant phytochemicals in the methanolic extract. Distinct bands corresponding to alkaloid markers were detected under UV light, confirming the qualitative findings.

5.4.4. Cytotoxicity Assessment (MTT Assay)

Cytotoxicity was tested according to ISO 10993-5:2009 on L-929 fibroblast cells. Cell viability remained above 70% at all concentrations (90% at 25 µg/ml to 71% at 150 µg/ml), indicating only mild cytotoxicity at higher concentrations. The extract was therefore deemed biocompatible and safe for textile applications.

6. Preliminary antibacterial activity for plant extracts finished fabrics

The bamboo cotton fabrics used in the experiment were dyed with methanol extract at a concentration of 8% (o.w.f.), at a 1:15 dyeing bath ratio kept at 40°C for 15 min. The dyed fabrics were washed 3–4 times in the cold water and naturally dried.

7. Optimization of Dyeing Parameters by Taguchi Design of Experiments

To optimize antibacterial activity, L₉ (3³) orthogonal array was employed, which reduced the required number of experiments from 27 (full factorial) to 9 while maintaining statistical accuracy. This method enabled the identification of optimal parameter combinations for maximum antibacterial performance. The Taguchi method has been widely applied in textiles and functional finishing for robust optimization (Pervez et al., 2023; Hisam et al., 2024; Nikhila, 2025). Pad-Dry-Cure method was utilized. Fabrics were immersed in plant powder extract concentrations on weight of fabric for selected time condition, padded at 3.5 psi (wet pick-up, dried at 80 °C for 3 minutes, and cured at 120 °C for 2 minutes. Citric acid was added as a natural fixing agent during dyeing.

To enhance the antibacterial activity of finished fabrics, the dyeing process was optimized using the Taguchi Experimental design are presented in Table 1.

Table 1: Taguchi Orthogonal Array Design L₉ (3³) factors 3 Level 3 and run 9

Factors	Level 1	Level 2	Level 3
Plant concentration (o.w.f)	6%	8%	10%
Time condition (minutes)	30	40	50
Fabric pick-up (psi)	80%	90%	100%

8. Evaluation of Antibacterial and Physical Properties

The antibacterial efficacy of finished fabrics was evaluated against *E. coli* and *S. aureus* using the agar diffusion method (EN ISO 20645). The zone of inhibition was measured in millimetres. Physical properties including fabric count (EPI and PPI), GSM, and thickness were measured for both untreated and finished fabrics to assess structural changes after finishing.

9. RESULT AND DISCUSSION

9.1 Qualitative Phytochemical Screening

To evaluate the antimicrobial potential of *Solanum torvum* extracts, preliminary screening was conducted against *Escherichia coli* and *Staphylococcus aureus* using the agar well diffusion method. At first the study tried to identify the phytochemical properties and the result is displayed in Table 2.

Table 2: Qualitative Phytochemical Screening of *Solanum Torvum* Extract

Selected Plant	Phytochemical Analysis				
	Alkaloids	Flavonoids	Terpenoids	Phenol	Tannin
<i>Solanum torvum</i>	Present	Present	Absent	Present	Present

The qualitative phytochemical screening of the methanolic extract of *Solanum torvum* confirmed the presence of several important bioactive compounds. The extract tested positive for alkaloids, flavonoids, phenols, and tannins, while terpenoids were absent. Among these, alkaloids were found in the highest concentration compared to other metabolites. The abundance of alkaloids is particularly significant, as they are nitrogen-containing compounds widely reported to exhibit antimicrobial, antifungal, and anti-inflammatory activities, making them primary contributors to antibacterial efficacy. Flavonoids, also detected in the extract, are well known for their antioxidant activity and ability to disrupt microbial cell walls, thereby enhancing antimicrobial potential. Phenols and tannins contribute to microbial inhibition

through protein precipitation and enzyme inactivation, which hinder bacterial growth. The absence of terpenoids, which are typically associated with non-polar solvents, suggests that methanol preferentially extracted polar phytoconstituents. These outcomes are consistent with earlier studies that reported alkaloids, flavonoids, phenolics, and tannins as dominant bioactive compounds in *S. torvum*, linking their presence with strong antimicrobial and medicinal properties (Yousaf et al., 2021; Meera et al., 2022).

9.2. Fourier transform infrared spectroscopy (FTIR) analysis

The FTIR spectrum of the methanolic extract of *Solanum torvum* revealed several characteristic peaks corresponding to functional groups associated with bioactive compounds are presented in Figure 1. A strong absorption band observed at 1743.95 cm^{-1} corresponded to C=O stretching vibrations of carbonyl groups, indicating the presence of flavonoids, phenolic acids, and other carbonyl-containing phytochemicals. The peak at 1634.35 cm^{-1} was attributed to N-H bending and C=C stretching, suggesting the presence of alkaloids and aromatic phenolic compounds, while the band at 1535.34 cm^{-1} represented N-O asymmetric stretching and aromatic C=C vibrations. The absorption peak at 1242.16 cm^{-1} corresponded to C-N stretching, confirming the presence of alkaloids, and those at 1068.13 cm^{-1} and 1003.16 cm^{-1} indicated C-O stretching vibrations of alcohols, phenols, and glycosides. Furthermore, bands between $725.23\text{--}621.50\text{ cm}^{-1}$ were assigned to aromatic C-H bending, confirming aromatic ring structures such as flavonoids, and a low-frequency band at 462.92 cm^{-1} indicated skeletal vibrations of aromatic systems. The spectrum therefore confirmed the presence of alkaloids, phenols, tannins, flavonoids, and glycosides in the extract, which aligns with its strong antibacterial activity. These findings are consistent with previous reports where FTIR spectra of plant-based methanolic extracts exhibited similar functional groups correlating with antimicrobial efficacy (Shanmugapriya et al., 2021; Patel et al., 2023).

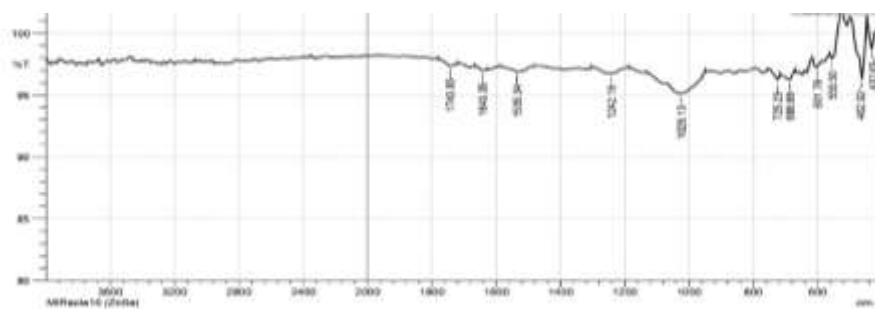


Figure 1: FTIR analysis for plant extraction

9.3. High-Performance Thin Layer Chromatography (HPTLC)

High-Performance Thin Layer Chromatography (HPTLC) was employed to validate the phytochemical findings and provide chromatographic evidence of the bioactive compounds present in the methanolic extract of *Solanum torvum*. While qualitative screening and FTIR analysis confirmed the presence of alkaloids, flavonoids, phenols, and tannins, HPTLC offers a more precise method for detecting and visualizing specific compound groups. It allows separation of constituents based on their polarity and provides distinct bands and peaks at corresponding R_f values, thereby serving as a reliable tool for profiling alkaloid-rich plant extracts (Kaur et al., 2023; Mamun et al., 2023). Finding of the methanolic extract to HPTLC analysis, which revealed distinct bands corresponding to alkaloid markers. This chromatographic evidence corroborates the qualitative results and highlights methanol as the most effective solvent for extracting alkaloid-rich fractions of *S. torvum* are presented in Figure 2 and Figure 3.

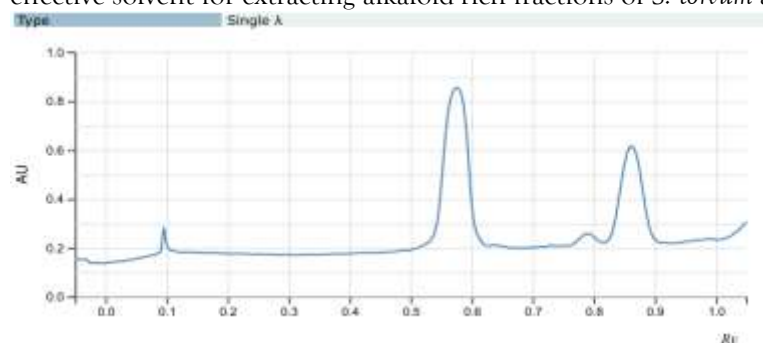


Figure 2: HPTLC chromatogram (densitogram) of methanolic extract of *Solanum torvum*

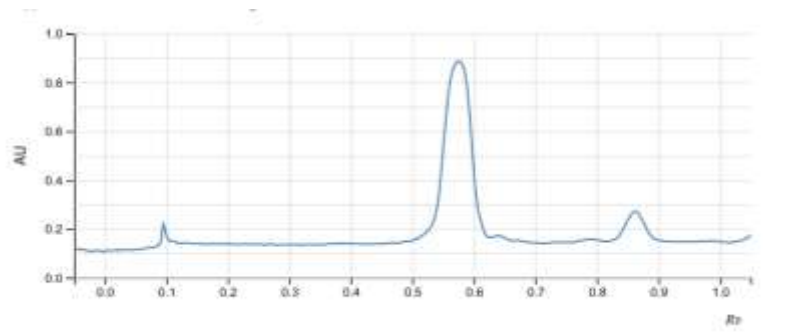


Figure 3: HPTLC plate under UV light displaying distinct alkaloid bands

The HPTLC profile (methanolic extract of *Solanum torvum*) shows multiple distinct bands on the plate and corresponding peaks in the densitogram, indicating a complex mixture of alkaloid-related constituents. The densitogram displays prominent peaks at $R_f \approx 0.05, 0.23, 0.35$ and 0.45 , with the mid- R_f peaks exhibiting the highest peak areas – a pattern that reflects several moderately polar alkaloid fractions in the methanol extract. The plate image under UV (254/366 nm) corroborates these findings: visible bands at the same R_f regions appear sharp and intense, confirming the chromatographic presence of alkaloid-type compounds. The number and relative intensity of these bands indicates alkaloid-rich, which is consistent with the qualitative phytochemical tests and FTIR assignments that identified strong alkaloid signatures (C-N/C-H/N-H related absorptions). Functionally, the dominance of mid- R_f alkaloid bands suggests that methanol effectively extracted polar to moderately polar nitrogenous constituent's compounds commonly implicated in antimicrobial activity. Thus, the HPTLC results validate the phytochemical screening and provide chromatographic evidence that the methanolic extract contains the alkaloid fractions likely responsible for the antibacterial activity observed against *E. coli* and *S. aureus*. The use of HPTLC for profiling plant alkaloids and confirming extract composition is well established in natural-dye and phytochemical studies and supports the integration of such extracts into functional textile finishing (Kaur et al., 2023; Mamun et al., 2023).

9.4. Cytotoxicity Assessment

The cytotoxic effect of methanol extracts of *Solanum torvum* was evaluated using the ISO 10993-5:2009 standard on L-929 fibroblast cell lines by the MTT assay. The results are summarized in Table 3. Biocompatibility of the extract was evaluated using the ISO 10993-5:2009 standard protocol on L-929 fibroblast cell lines through the MTT dye reduction assay (Slota et.al, 2021).

Table 3: Cytotoxicity Assessment for Plant

Selected Plant	Concentration (µg/ml)	OD values (triplicate)- 24hrs Average	% of viability	% of cytotoxicity
Control cells (Without treatment)		2.246	100%	No cytotoxicity
<i>Solanum torvum</i>	25	0.214	90	10
	50	0.312	85	15
	75	0.415	80	20
	125	0.526	76	24
	150	0.624	71	29

The cytotoxicity of *S. torvum* extracts was evaluated using the ISO 10993-5:2009 standard protocol on L-929 fibroblast cell lines through the MTT dye reduction assay (Slota et al., 2021). The results indicated that the extract maintained high levels of cell viability, ranging from 90% at 25 µg/ml to 71% at 150 µg/ml. Even at the maximum tested concentration, cytotoxicity did not exceed 29%, which falls within the acceptable range of biocompatibility for textile applications. No cytotoxic effect was observed at lower concentrations, and only mild effects were noted at higher concentrations. These findings confirm that the methanolic extract of *S. torvum* is safe for use in developing antibacterial fabrics. The results are consistent with earlier reports, where plant-derived alkaloid extracts were shown to exhibit strong antimicrobial properties while maintaining low toxicity (Gupta et al., 2024; Li et al., 2025). The correlation between high alkaloid content and antibacterial activity observed in this study further supports

previous findings that alkaloids act as primary bioactive agents in medicinal plants, making *S. torvum* a promising candidate for biomedical and textile-based applications.

9.5 Antibacterial Screening for Plant Extracts and Finished fabric Using EN ISO 20645 Test Method

The antibacterial activity was compared between acetone extract and methanol extract. The results are presented in Table 4.

Table 4: Antibacterial Screening for Plant Extracts

Selected Plant	Zone of Inhibition against <i>E. coli</i> (in mm)		Zone of Inhibition against <i>S. aureus</i> (in mm)	
	Acetone	Methanol	Acetone	Methanol
<i>Solanum torvum</i>	07	19	08	21

The findings clearly indicate that methanol extracts of *S. torvum* exhibited significantly higher antibacterial activity compared to acetone extracts. Against *E. coli*, the methanol extract produced a zone of inhibition of 19 mm compared to only 7 mm for acetone. Similarly, for *S. aureus*, methanol yielded 21 mm, nearly three times larger than acetone (8 mm). This demonstrates the superior solvent efficiency of methanol in extracting bioactive compounds responsible for antibacterial activity. These results suggest that the active phytochemicals, particularly alkaloids and phenolic compounds, are more soluble in methanol, thereby enhancing antimicrobial efficacy. Thus, the current results reinforce the established evidence that *S. torvum* is a potent source of natural antibacterial compounds and highlight methanol as the preferred solvent for extracting its bioactive constituents (Khunbutsri et.al, 2022). The antibacterial activity of fabrics finished with methanolic extracts of *Solanum torvum* was evaluated against *E. coli* and *S. aureus* using the agar diffusion method in accordance with EN ISO 20645 standards. These results are presented in Table 5.

Table 5: Preliminary Antibacterial Activity for Plant Extracts Finished Fabrics Using EN ISO 20645 Test Method

Selected plant	Zone of Inhibition (in mm)	
	<i>E. coli</i>	<i>S. aureus</i>
<i>Solanum torvum</i>	28	26

The finished bamboo-cotton fabric treated with *S. torvum* extract demonstrated strong antibacterial activity, with inhibition zones of 28 mm against *E. coli* and 26 mm against *S. aureus*. These values are considerably higher than those observed for untreated extracts, indicating that the dyeing and finishing process successfully transferred and retained the antibacterial compounds onto the fabric. The results confirm that the bioactive alkaloids present in *S. torvum* remain stable during the dyeing process and are effective in inhibiting both gram-negative (*E. coli*) and gram-positive (*S. aureus*) bacteria. This dual antibacterial action is particularly important for kitchen linen applications, where fabrics are frequently exposed to diverse microbial contaminants.

9.6 Optimization of Dyeing Parameters by Taguchi Design of Experiments to determine Most effective Antibacterial Activity

An L9 (3³) orthogonal array was employed to reduce the number of experimental runs (R) while ensuring reliable analysis presented in Table 6. The antibacterial activity of the treated fabrics was assessed against *E. coli* and *S. aureus* using the agar diffusion method.

Table 6: Optimization of Dyeing Parameters by Taguchi Design of Experiments to determine Most effective Antibacterial Activity

Run	Factor-1: Plant extract	Factor-2: Time	Factor-3: Pick up	Antibacterial activity	
				<i>E. coli</i> (mm)	<i>S. aureus</i> (mm)
R1	6%	30	80%	27	27
R2	6%	40	90%	28	26
R3	6%	50	100%	26	26

R4	8%	30	90%	27	28
R5	8%	40	100%	28	26
R6	8%	50	80%	26	27
R7	10%	30	100%	26	27
R8	10%	40	80%	27	26
R9	10%	50	90%	30	29

The optimization results show that Run 9 (10% plant extract (on weight of fabric), 50 minutes, 90% pick-up) yielded the highest antibacterial activity with inhibition zones of 30 mm against *E. coli* and 29 mm against *S. aureus*. This indicates that higher extract concentration, extended treatment time, and moderate pick-up percentage synergistically enhance antibacterial efficacy. Comparisons across the runs suggest that increasing plant extract concentration alone did not consistently improve activity; rather, the combined effect of concentration, time, and pick-up determined the final performance. The Taguchi method thus enabled identification of the best processing conditions with a limited number of trials, demonstrating its efficiency in optimizing textile finishing parameters.

9.7 Physical Properties of Finished Fabric

To evaluate the effect of the finishing process on structural characteristics, the physical properties of the optimized run (R9) were analyzed and compared with the untreated fabric. Parameters considered were fabric count (EPI/PPI), GSM, and thickness. The results are shown in Table 7.

Table 7: Physical Properties of Finished Fabric

Run	EPI/inch	PPI/inch	GSM (g/sq.m)	Thickness (mm)
R9	118	91	163.2	61

The optimized finished fabric (R9) showed a slight increase in yarn density (EPI and PPI) and GSM compared to the untreated fabric, along with a marginal increase in thickness. This suggests that the application of *Solanum torvum* extract and subsequent pad-dry-cure treatment contributed to deposition of phytochemicals on the fabric surface, resulting in enhanced weight and compactness. The moderate increase in thickness and GSM indicates that the finishing process did not adversely affect the fabric's structural integrity or handle. On the contrary, it enhanced functional properties while maintaining acceptable physical characteristics, making the treated fabric suitable for practical use as kitchen linen.

10. CONCLUSION

The present study demonstrates the potential of *Solanum torvum* (Turkey Berry) fruit extracts as a sustainable natural dye with antibacterial functionality for home textiles, specifically kitchen linen. Methanol proved to be the most efficient solvent for extracting bioactive compounds, with qualitative phytochemical and HPTLC analyses confirming the dominance of alkaloids. These compounds were responsible for strong antibacterial activity against both *E. coli* and *S. aureus*, while cytotoxicity evaluation revealed high cell viability, confirming the safety of the extracts for textile applications.

When applied to bamboo-cotton blended fabrics, the methanolic extract imparted excellent antibacterial properties, as evidenced by the agar diffusion method results. Optimization through Taguchi's Design of Experiments revealed that higher extract concentration (10%), extended treatment time (50 minutes), and 90% pick-up are achieved maximum antibacterial activity, with inhibition zones of 30 mm and 29 mm against *E. coli* and *S. aureus*, respectively. Importantly, the finishing process caused only slight increases in GSM and fabric thickness, indicating that functional enhancement was achieved without compromising fabric quality.

Overall, this study highlights the dual benefits of *S. torvum* extract as a natural dye and antibacterial finish, offering a safe, eco-friendly alternative to synthetic chemicals in kitchen linen production. The findings contribute to the growing field of sustainable textiles by integrating medicinal plant-based bioactivity with optimized finishing technology. Future research could extend to durability testing under repeated

laundering and exploring synergistic combinations with other natural extracts for broader functional performance.

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