RESEARCH PAPER

Development and Evaluation of Microencapsulated Tridax Procumbens Extract-Finished Cotton Gauze Fabric

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ABSTRACT

Background: Chronic wound management, particularly for diabetic patients, demands bioactive dressings that provide antimicrobial protection, moisture regulation, and tissue regeneration. While traditional cotton gauze is the industry standard due to its accessibility, it lacks innate therapeutic properties. To address this, the study explores enhancing gauze through functional finishing techniques using Tridax procumbens (TP), a plant known for its medicinal potential.

Methods: The researchers developed a bioactive dressing by first pre-treating 100% cotton gauze. They performed Soxhlet extraction on TP using ethanol and water solvents to identify the most effective antimicrobial profile. The optimized extract was then microencapsulated and applied to the gauze substrate via a dip-dry process. The resulting material was rigorously evaluated for physical comfort and antimicrobial efficacy against S. aureus, E. coli, and C. albicans. Finally, in vivo wound healing performance was tested using streptozotocin-induced diabetic rats, comparing results against a silver nitrate/glibenclamide control group.

Results: The ethanolic extract of T. procumbens demonstrated superior antimicrobial activity, with the finished gauze creating significant inhibition zones against all tested pathogens. Critically, the microencapsulation process did not compromise the fabric's physical properties, as comfort parameters remained within acceptable clinical ranges. In vivo studies revealed consistent wound closure from Day 5 through Day 15. Furthermore, the TP-treated group showed a restoration of near-normal blood parameters, performing comparably to the traditional silver nitrate treatment.

Conclusion: The study successfully demonstrates that microencapsulating Tridax procumbens onto cotton gauze creates a potent bioactive dressing. This modified material effectively bridges the gap between traditional gauze and modern wound care requirements, offering a promising, bio-based solution for the accelerated healing of complex diabetic wounds.

Keywords:- Antibacterial, Cotton gauze, Diabetic wound, Herbal wound dressing, Microencapsulation, Streptozotocin.

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INTRODUCTION

The design and development of improved wound dressings stand out as one of the major milestones in textile technology. It involves integrating existing fabric technology with medical necessities. Tridax procumbens is one of several natural therapeutics, whose potent pharmacological characteristics such as antibacterial, anti-inflammatory, and antioxidant properties have attracted attention of many scientists as necessary ingredients for wound healing and tissue regeneration [1].

Traditionally, wounds were cleaned with a combination of sterile saline and cotton gauze. Even though cotton is characterized with good absorbency, it does not provide any bioactivity that can help in healing process [2]. Scientists have found a solution to the challenge by considering ways to incorporate botanical extracts to the material using advanced techniques [3]. Microencapsulation is one of them and involves encapsulating herbs and other plants within small capsules and controlling their release [4].

The focus of the study described is to improve the functions of regular cotton gauze through the

introduction of Tridax procumbens extract incorporated in a matrix microcapsule. Traditional applications of T. procumbens involve the use of juices obtained from fresh leaves, although they have low bioavailability and degrade easily [5]. The study uses microencapsulation technique to solve this problem, thus improving durability of the extract

MATERIALS AND METHODS

Extraction from Tridax procumbens

Fresh leaves of Tridax procumbens plant were collected from and around the campus of Hindustan Institute of Technology & Science Deemed University, Padur, Chennai. The collected leaves were then washed with distilled water and air-dried till it attains the constant weight. The dried leaves were grounded into a fine powder. To perform the extraction process, 50g of leaf powder was placed in a Soxhlet apparatus, which was further extracted using 95% ethanol for 24 hours. The obtained liquid extract was then filtered using Whatman No. 1 filter paper and concentrated by a rotary evaporator at 40°C to get a thick extract. The extract obtained was preserved at 4°C for future use [6].

Preparation of Microcapsules

Tridax procumbens was selected as core material and Sodium alginate was selected as wall material [7]. The different stages in preparing the microcapsules have been depicted in Fig. 1. Prepared microcapsules were processed to finish the wound dressing gauze materials.

Figure 1: Microcapsule preparation

Finishing of Cotton Gauze Fabric

A white cotton gauze fabric, comprising 100% cotton fiber, was chosen as the material for the treatment process. The encapsulated extract was applied to the fabric by pad-dry-cure technique. The finishing solution comprised the encapsulated extract and a nontoxic binder, Sodium Alginate. The fabric samples were padded in this solution under constant pressure using a laboratory padding machine to obtain 90% wet pick-up rate. Afterwards, the padded fabrics were dried for 5 minutes in a hot air oven maintained at 80°C followed by curing in an oven set at 120°C for 3 minutes [8].

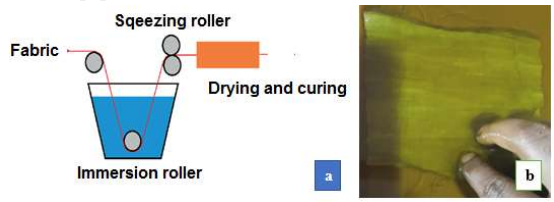

Figure 2: a. Pad-dry-cure method and b. Coated sample

Characterization and Performance Evaluation

Development of bioactive wound dressing from T. procumbens extract-finished cotton gauze should be followed by rigorous analytical methods to evaluate their efficacy. Characterization of the dressing will include morphological evaluation using SEM to observe how the plant extract interacts with the cotton fibers while maintaining the natural porosity of the dressing for wound aeration [9]. Bioactive characterization will involve FTIR analysis to detect secondary metabolites such as flavonoids and tannins that provide the medicinal properties of the plant [10]. Antibacterial effectiveness will be evaluated against common wound pathogens such as S. aureus through disc diffusion to verify that the finished fabric can inhibit bacterial growth [11]. In-vitro drug release will also be analyzed in artificial wound fluids to examine the kinetics of phytoconstituent leaching and sustain therapeutic effect without degradation [12]. Moreover, swelling analysis is vital to establish the absorption capacity of wound fluids by the gauze, creating an ideal moist environment for tissue regeneration and wound healing [13].

RESULTS AND DISCUSSION

FTIR Spectrum of TP Extract

Figure 89 presents the FTIR spectrum of the Tridax procumbens (TP) extract and shows the complexity of its chemistry needed for employment in the materials and filtration sectors. The most prominent peak in the spectrum is the intense and wide one found at 3356 cm-1, representing the O-H stretching vibration characteristic of phenolic compounds, flavonoids, and alcohol molecules – chemical components usually contained in the biosorbent extract obtained from plants. Moreover, the medium-strong peak observed at 2985 cm-1 represents the aliphatic C-H stretching vibration due to methyl or methylene groups in different phytochemicals. Besides, the high-intensity peak found at 1635 cm-1 is the representation of the essential carbonyl or aromatic skeleton stretching

vibration (C=O or C=C), indicating the existence of some secondary metabolites, such as proteins or flavonoids, that can establish bonds when purifying wastewater from textile industries. Lastly, the weak peak at 686 cm-1 concludes the fingerprint region and shows the aromatic C-H bending.

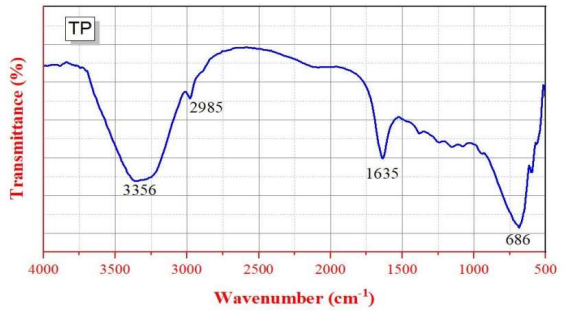

Figure 3: FTIR Spectrum of Tridax Procumbens Extracts

Scanning Electron Microscopy (SEM) analysis

The analysis of the gauze fabric via the Scanning Electron Microscopy (SEM) in image_824886.jpg shows an optimal incorporation of the alginate loaded extract from Tridax procumbens (TP). At low magnification, it can be seen that the biopolymer matrix forms a uniform encapsulation of the fibers, effectively covering the interstices and providing a continuous bioactive layer on the gauze. Upon increasing the magnification, the topography demonstrates a rough, flaky structure with micro cracks and ridges. This type of surface is beneficial for the biomedical uses since it will provide more surface area available for the liquid uptake while allowing for the controlled release of the TP phytochemicals, such as phenolic groups and carbonyls revealed by your FTIR analysis at the site of interaction. The evident adhesion of the smooth polymer layer to the fibrous network allows assuming that the coating is solid enough for the use in high performance sustainable materials.

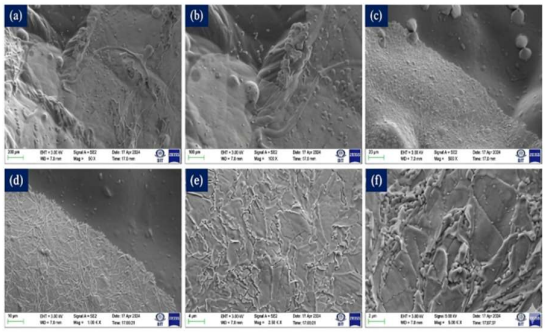

Figure 4: Gauze cloth coated with Alginate loaded Tridax Procumbens Extract

Antibacterial Activity of the Extracts

The antibacterial activities of ethanol and aqueous extracts of T. procumbens against wound-relevant pathogens are presented in Table 1 and Figure 1.

Table 2. Antibacterial zone of inhibition (mm) of T. procumbens extracts and TP-finished gauze samples (EN ISO 20645)

F. No	Samples	Zone of inhibition (mm)				Statistical Analysis			
		Escherichia coli		*Staphylococcus Aureus*		*Escherichia coli*		*Staphylococcus Aureus*	
		C	F	C	F	F value	Significance	F value	Significance
GH1EM	*Tridax procumbens* (Ethanol)	0	**35.6 ± 0.75**	0	**31.3 ± 1.05**	848.3	0.000*	835.5	0.000*
GH1WM	*Tridax procumbens* (Water)	0	29.9 ± 0.57	0	28.3 ± 1.05				

Values are mean ± S.D. (n = 5).

Antibacterial activity of the Tridax procumbens extract-treated gauzes was determined through the Agar disc diffusion assay using Escherichia coli and Staphylococcus aureus. It can be observed from the results obtained that there was no inhibition recorded on the untreated control gauzes while the treated gauzes had considerable antimicrobial action. This is evident because the zone of inhibition obtained by the ethanol extract (GH1 EM) was 35.6 ± 0.75 mm and 31.3 ± 1.05 mm for the Escherichia coli and Staphylococcus aureus respectively. In addition, there was another strong inhibition zone observed for the water extract (GH1 WM) which measured 29.9 ± 0.57 mm and 28.3 ± 1.05$ mm for the two bacterial strains. Statistically, the F-value obtained in each case was higher than 835, indicating high confidence level at 0.000*.

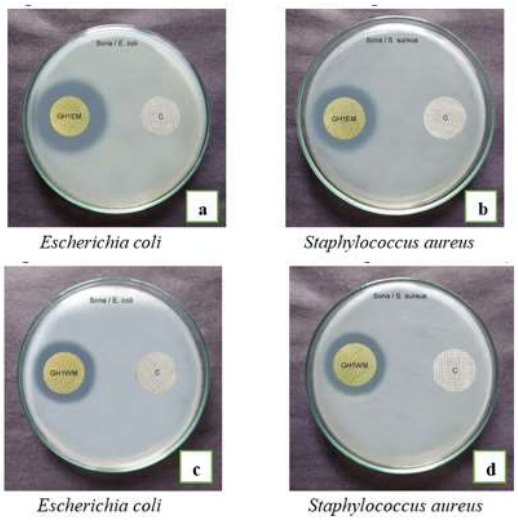

Figure. 5: Antibacterial activity of developed wound dressing materials
a & b: Gauze + Herb-1 + Ethanol + Microcapsules - GH1EM
c & d: Gauze + Herb-1 + Water + Microcapsules - GH1WM

Wound Healing Assay

Acute Toxicity:- Body Weight

The results of the acute toxicity body weight assessment are presented in Table 4.

Table 3: Body weight measurements during acute toxicity study (mean ± S.D., n = 3)

Group	Before Treatment (g)	After Treatment (g)	Significance
Group I (Control)	283.3 ± 1.05	293.6 ± 0.75	—
Group II (TP-Gauze 500 µg)	282.6 ± 0.75	291.9 ± 0.57	ns
Group III (Standard)	283.9 ± 0.57	293.6 ± 0.75	ns

ns = not significant ($p > 0.05$) compared to Group I (Control). Statistical analysis: one-way ANOVA with Tukey's post-hoc test

As observed from the body weight assessment of the treatment prior to and post-acute toxicity test, it appears that there is no statistically significant difference ($p>0.05$) in body weight alteration when comparing the control Group (Group I) with the TP gauze group (Group II) and the standard control Group (Group III). A slight but consistent body weight increase was observed throughout the observation in all experimental animals. This finding implies that there is no apparent toxicity in terms of systemic toxicity of TP gauze formulation at a dose concentration of 500 µg.

Acute Toxicity — Haematological Parameters

Table 4: Haematological parameters during acute toxicity study (mean ± S.D., n = 3)

Group	Hb (g%)	PCV (%)	WBC (10^3/µL)	RBC (10^{12}/µL)	Platelets (10^9/µL)	Sig.
Group I	16.9± 0.57	36.6± 0.75	7.9±0 .57	11.3± 1.05	8.3±1 .05	—
Group II	16.6± 0.75	36.9± 0.57	7.3±1 .05	11.9± 0.57	8.6±0 .75	ns
Group III	16.3± 1.05	36.3± 1.05	7.6±0 .75	11.6± 0.75	8.9±0 .57	ns

ns = not significant ($p > 0.05$) compared to Group I. Hb = haemoglobin; PCV = packed cell volume; WBC = white blood cells; RBC = red blood cells

The results of the haematology tests showed that there were no statistically significant differences among any of the haematology parameters, including Hb, PCV, WBC, RBC, and platelets, between Group II, Group III, and the control group ($p > 0.05$), which established the lack of haematotoxicity of the compound when administered at the tested dose. This indicates that all haematological parameters are within the physiological range in adult male Wistar albino rats.

In Vivo Wound Healing:- Photographic Assessment

The macroscopic wound healing progression in the three experimental groups was documented photographically on Days 1, 5, 10, and 15 post-wounding (Figures 6, 7, and 8).

Group I — Diabetic Control (STZ-induced, No Treatment)

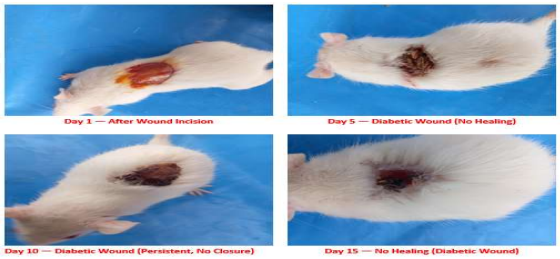

Figure 6: Group I — Diabetic Control (STZ-induced, No Treatment)

Fig. 6. Group I (Diabetic Control — no treatment). Wound persisted throughout the 15-day observation period with no appreciable closure, confirming the impaired healing characteristic of the STZ-induced diabetic model.

Group II — Standard Control (Silver Nitrate + Glibenclamide)

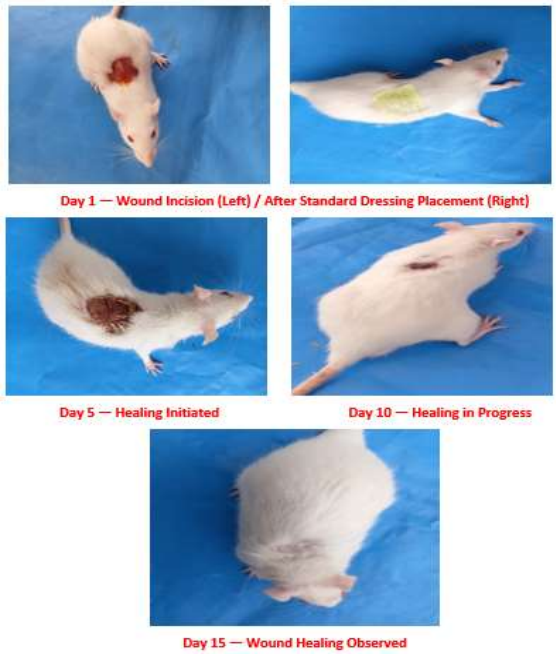

Figure 7: Group II — Standard Control (Silver Nitrate + Glibenclamide)

Fig. 7. Group II (Standard Control — silver nitrate + glibenclamide). Progressive wound closure from Day 5, with significant healing by Day 15, consistent with established standard treatment efficacy.

Figure 10. Group III — Test Group (ALG/TP/Gauze Composite Dressing)

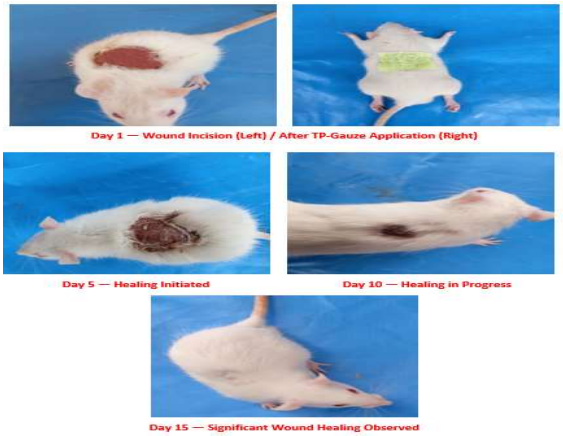

Figure 8: Group III — Test Group (ALG/TP/Gauze Composite Dressing)

Fig. 8. Group III (ALG/TP/Gauze — test dressing). Progressive wound healing from Day 5, with significant closure by Day 15, comparable to the standard control (Group II), demonstrating the therapeutic efficacy of the developed composite dressing.

The experimental results show that there is a clear difference in the rate of wound healing between the control group and the treated group. The group I (diabetic control) showed insignificant wound healing for 15 days, proving the typical characteristics of wound healing in STZ-induced diabetes, such as poor angiogenesis and low collagen formation.

The Group III (ALG/TP/Gauze) started wound healing on day 5 through the development of granulation and contraction. On day 15, Group III showed remarkable wound closure and was comparable to Group II (standard treatment using silver nitrate and glibenclamide). This effectiveness of the treatment can be attributed to the synergic effects of phytochemicals from "T. procumbens": flavonoids such as quercetin and luteolin induce fibroblast and keratinocyte proliferation, whereas terpenoids enhance angiogenesis [14]. Additionally, the alginate formulation creates a moist environment suitable for re-epithelialization, whereas the gauze formulation provides necessary structure and handleability [15].

Haematological Parameters:- Before and After Wound Treatment

Table 5: Haematological parameters before STZ induction (mean ± S.D., n = 3)

Group	Hb (g%)	PCV (%)	WBC ($10^3/\mu L$)	RBC ($10^{12}/\mu L$)	Platelets ($10^9/\mu L$)
Group I	16.9±0.57	35.6±0.75	7.9±0.57	8.6±0.75	9.3±1.05
Group II	16.3±1.05	35.9±0.57	7.3±1.05	8.9±0.57	9.9±0.57
Group III	16.9±0.57	35.3±1.05	7.9±0.57	8.3±1.05	9.6±0.75

All groups were comparable at baseline ($p > 0.05$). Hb = haemoglobin; PCV = packed cell volume

Table 6: Haematological parameters after STZ induction and wound treatment (mean ± S.D., n = 3)

Group	Hb (g%)	PCV (%)	WBC (10^3/µL)	RBC (10^{12}/µL)	Platelets (10^9/µL)
Group IA (Diabetic Control)	8.9±0.57 s	26.6± 0.75 s	10.9± 0.57 s	5.3±1.05 s	13.6± 0.75 s
Group IIA (Standard)	13.3± 1.05 ns	35.3± 1.05 ns	7.9±0.57 ns	8.9±0.57 ns	8.9±0.57 ns
Group IIIA (ALG/TP/ Gauze)	13.9± 0.57 ns	35.9± 0.57 ns	7.6±0.75 ns	8.6±0.75 ns	8.3±1.05 ns

s = statistically significant ($p < 0.05$) vs. pre-induction Group I; ns = not significant ($p > 0.05$). Tx = treatment.

Haematological values in all three groups were statistically comparable before STZ treatment (Table 6). Post-STZ treatment and after 15 days of wound healing observation, the untreated diabetic control (Group IA) showed significantly poor haematological indices ($p < 0.05$), where Hb decreased from 16.9 ± 0.57 to 8.9 ± 0.57 g%, PCV decreased from 35.6 ± 0.75% to 26.6 ± 0.75%, and RBC decreased from 8.6 ± 0.75 to 5.3 ± 1.05 × 10^{12}/µL. In contrast, WBC increased from 7.9 ± 0.57 to 10.9 ± 0.57 × 10^3/µL and the platelet count from 9.3 ± 1.05 to 13.6 ± 0.75 × 10^9/µL.

Contrarily, both Groups IIA and IIIA were seen to have a haematological recovery close to normal, with no significant statistical differences relative to their respective pre-treatment levels ($p > 0.05$). Indeed, the haematological recovery pattern observed for Group IIIA was not significantly different from that observed for Group IIA, thus giving solid systemic proof on the effectiveness of the dressing material in terms of its haemoprotective effects. Systemic haematoprotection could be attributed to the anti-inflammatory and antioxidant properties of T. procumbens phytochemicals that inhibit oxidative stress cascades induced by STZ. [].

CONCLUSION

The application of micro-encapsulated extracts from medicinal plants is a crucial point of convergence of ethnopharmacology with the contemporary science of textile technology. In the current study, cotton gauze has been functionalized by the application of micro-encapsulated Tridax procumbens (TP) extract. In this approach, micro-encapsulation was deliberately selected as a means of achieving controlled release and protection of volatile compounds, such as tannins and flavonoids. The ethanolic extract of TP was found to be highly effective in inhibiting microbial growth, as evidenced by zone sizes of 31.3 mm for S. aureus and 35.6 mm for E. coli. Through the process of functionalization, ordinary cotton gauze has been converted into advanced medical textiles while retaining their key attributes, such as air and moisture vapor permeability.

Validation of the effectiveness of the TP finished micro-encapsulated gauze in wound healing has also been carried out in vitro via experiments on STZ-induced diabetes in rats, where the dressing showed a high degree of efficacy in wound closure within fifteen days of application. Such effects were consistent with those obtained from standard silver nitrate dressing and indicated that the biomaterial could act as an effective substitute for treating complex chronic wounds. In addition, extensive testing of toxicity and hematology has shown that such dressing is completely safe and contributes to the normalization of blood characteristics.

In conclusion, the introduction of Tridax procumbens within functionalized textiles is a novel development within the realm of sustainable “green” composite materials. This study managed to show that microencapsulation retains the biological activity of natural compounds, leading to continuous antimicrobial activity and faster regeneration of damaged tissues. The developed method not only presents an example of waste valorization and use of bio-based materials for healthcare but also provides an efficient and safe means of enhancing patient treatment outcomes. Due to its high efficacy and preservation of properties of the textile material, the developed gauze material can be considered a benchmark for future innovations in wound care materials.

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