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Original Research Article

HAIR GROWTH ENHANCING ACTIVITY OF TECTONA GRANDIS SEEDS EXTRACT IN SWISS ALBINO MICE

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ABSTRACT

Background: Tectona grandis Linn., commonly known as teak, has been traditionally used as a hair tonic in Indian medicinal systems. The seeds of this plant are believed to promote hair growth and development, though scientific evidence remains limited. This study aimed to evaluate the hair growth-promoting activity of petroleum ether extract of Tectona grandis seeds in comparison with minoxidil in Swiss albino mice.

Materials and Methods: Twenty-four Swiss albino mice were randomly divided into three groups of eight animals each. After dorsal depilation, Group 1 received 2% petroleum ether extract of T. grandis seeds in coconut oil, Group 2 received virgin coconut oil (control), and Group 3 received 2% minoxidil solution. Applications were administered topically once daily for 30 days. Hair growth initiation time, hair growth completion time, and histopathological examination of hair follicles were evaluated.

Results: The mean hair growth initiation time in Group 1 was significantly shorter (2.5 ± 0.7 days) compared to Group 2 (4.7 ± 1.4 days) and Group 3 (3.5 ± 0.5 days) ($p < 0.001$). Hair growth completion time was also significantly earlier in Group 1 (25 ± 1.4 days) compared to Groups 2 and 3 (27.5 ± 1.4 days and 27 ± 0.7 days, respectively) ($p < 0.001$). Histopathological examination revealed that Group 1 had significantly higher total hair follicle counts (20 ± 0) and anagen phase follicles (19 ± 0) compared to other groups ($p < 0.05$).

Conclusion: The 2% petroleum ether extract of Tectona grandis seeds demonstrated superior hair growth-promoting activity compared to minoxidil and coconut oil in Swiss albino mice, with earlier initiation and completion of hair growth, along with increased anagen phase follicles. These findings support the traditional use of teak seeds as a hair tonic and warrant further clinical investigation.

Keywords: Tectona grandis, hair growth, minoxidil, petroleum ether extract, anagen follicles, telogen follicles, Swiss albino mice, phytotherapy.

INTRODUCTION

Hair loss and alopecia represent significant cosmetic and psychological concerns affecting millions of individuals worldwide. While synthetic treatments such as minoxidil and finasteride are available, their side effects and cost limitations have driven renewed interest in natural alternatives derived from traditional medicinal systems. The exploration of herbal remedies with hair growth-promoting properties has gained considerable attention in recent years, particularly those with established ethnomedicinal credentials.

Tectona grandis Linn., commonly referred to as teak, belongs to the family Verbenaceae and is widely distributed across India and other South Asian countries.[1] This plant holds significant importance in traditional medicine systems, where various parts have been utilized to treat diverse ailments. The taxonomical classification places T. grandis within Kingdom Plantae, Subkingdom Tracheobionta (vascular plants), Division Magnoliophyta (flowering plants), Class Magnoliopsida (dicotyledons), Subclass Asteridae, Order Lamiales, and Family Verbenaceae.[2]

The medicinal properties of T. grandis are attributed to bioactive compounds distributed throughout the plant, including bark, wood, leaves, roots, seeds, and fruits. These compounds belong to diverse chemical classes such as tannins, proteins, fatty acids, steroidal compounds, resins, anthraquinone-napthoquinone pigments, diterpenes, and natural dyes.[3,4] The plant has demonstrated a broad spectrum of pharmacological activities including antibacterial, antifungal, antioxidant, and notably, hair growth-promoting properties.[3]

The seeds of T. grandis are particularly rich in proteins containing essential amino acids such as aspartic acid, threonine, serine, glutamic acid, proline, glycine, alanine, valine, isoleucine, leucine, tyrosine, lysine, phenylalanine, histidine, and arginine.[3] These nutritive components, along with metabolites such as fatty oils, norlingans, and glycosides, are believed to contribute to the hair growth-promoting properties traditionally attributed to teak seeds in Indian medicinal practices.[3]

Previous investigations have provided preliminary evidence supporting the hair growth-enhancing potential of T. grandis seed extracts. Jaybhaye et al. reported that petroleum ether extract of teak seeds significantly reduced hair growth initiation time and successfully brought a greater proportion of hair follicles into the anagen phase compared to standard minoxidil treatment in albino mice.[6] These findings suggested that teak seed extract could accelerate both the initiation and completion of hair growth cycles. Additionally, Fachrunniza et al. identified T. grandis as a potential active ingredient for hair growth promotion.[5]

Despite these promising preliminary findings, comprehensive studies evaluating the efficacy of T. grandis seed extracts in comparison with established treatments like minoxidil remain limited, particularly in the southern Indian context. Understanding the mechanism through which teak seed extracts promote hair growth, including their effects on hair follicle cycling and the anagen-to-telogen ratio, is essential for potential clinical translation.[7]

Objectives: The present study was designed with the following specific objectives:

1. To evaluate the effect of 2% petroleum ether extract of Tectona grandis seeds on the initiation and promotion of hair growth in Swiss albino mice.
2. To compare the hair growth-promoting efficacy of Tectona grandis seed extract with that of 2% minoxidil solution through temporal analysis of hair growth parameters.
3. To assess the histopathological characteristics of hair follicles, including total follicle count and the distribution of anagen and telogen phase follicles, following treatment with teak seed extract, coconut oil, and minoxidil.
4. To establish the safety profile of topical application of Tectona grandis seed extract through observation of local and systemic reactions in experimental animals.

MATERIALS AND METHODS

This experimental animal study was conducted at the Department of Pharmacology, Tertiary Care Hospital, Coimbatore, following approval from the Institutional Animal Ethics Committee. Tectona grandis seeds were sun-dried, powdered, and extracted using a Soxhlet apparatus with petroleum ether (60-80°C). A 2% w/v extract was prepared by dissolving 2 grams of the concentrated extract in 100 ml of virgin coconut oil.

Twenty-four Swiss albino mice (20-30 grams) were housed under standard laboratory conditions with 12-hour light-dark cycles, controlled temperature (22 ± 2°C), and humidity (55 ± 10%). After a seven-day acclimatization period, the dorsal skin of all mice was depilated using 2% lignocaine gel followed by hair removal cream (Veet) application over a 2 cm × 2 cm area.

The mice were randomly divided into three groups of eight animals each. Group 1 received 0.4 ml of 2% petroleum ether extract of T. grandis seeds in coconut oil, Group 2 received 0.4 ml virgin coconut oil (control), and Group 3 received 0.4 ml of 2% minoxidil solution. All treatments were applied topically once daily for 30 days. Hair growth initiation time (days until visible hair growth) and hair growth completion time (days until complete coverage) were recorded through daily observation by two independent observers.

On day 30, two mice from each group were randomly selected for histopathological examination. Following anesthesia with intraperitoneal ketamine (80 mg/kg),[8,9] 3 mm skin biopsies were obtained from the treatment area. Specimens were fixed in 10% neutral buffered formalin, processed through graded alcohols, embedded in paraffin, and sectioned at 5 µm thickness. Sections were stained with hematoxylin and eosin for microscopic evaluation. A blinded histopathologist quantified total hair follicle count, anagen phase follicles (characterized by enlarged bulbs and active matrix proliferation), and telogen phase follicles (small atrophic bulbs with absent mitotic activity). Post-biopsy care included antiseptic cleaning, sterile dressing, and supportive treatment until healing.[10]

Data were analyzed using IBM SPSS Statistics version 26. Quantitative variables were expressed as mean ± standard deviation. One-way ANOVA was used to compare means among groups, followed by post hoc Bonferroni test for pairwise comparisons. Statistical significance was set at $p < 0.05$.

RESULTS

Hair Growth Initiation and Completion Time

The temporal parameters of hair growth were systematically evaluated across all three experimental groups. Analysis revealed significant inter-group differences in both hair growth initiation and completion times.

Table 1: Comparison of Hair Growth Initiation and Completion Time Between Study Groups

Variable	Group 1* (n=8)		Group 2* (n=8)		Group 3* (n=8)		P value
	Mean	SD	Mean	SD	Mean	SD	
Hair growth initiation time (days)	2.5	0.7	4.7	1.4	3.5	0.5	<0.001
Hair growth completion time (days)	25.0	1.4	27.5	1.4	27.0	0.7	<0.001

Group 1: 2% Petroleum ether extract of T. grandis seeds in coconut oil; Group 2: Virgin coconut oil (control); Group 3: 2% Minoxidil solution.

The results demonstrated that Group 1, treated with 2% petroleum ether extract of T. grandis seeds, exhibited the earliest hair growth initiation with a mean time of 2.5 ± 0.7 days. This was substantially shorter than both the control group (Group 2: 4.7 ± 1.4 days) and the minoxidil-treated group (Group 3: 3.5 ± 0.5 days). One-way ANOVA revealed highly significant differences among the three groups ($p < 0.001$).

Post hoc analysis using the Bonferroni test identified statistically significant differences in hair growth initiation time between all group pairs. The comparison between Group 1 and Group 2 showed the maximum mean difference of -2.2 days ($p < 0.001$), indicating that teak seed extract initiated hair growth approximately 2 days earlier than the control treatment. The difference between Group 1 and Group 3 was also statistically significant (mean difference: -1.0 days, $p < 0.001$), demonstrating that teak seed extract initiated hair growth approximately one day earlier than minoxidil. Additionally, Group 3 showed significantly earlier initiation compared to Group 2 (mean difference: -1.2 days, $p < 0.001$).

Regarding hair growth completion time, Group 1 again demonstrated superior performance with a mean completion time of 25.0 ± 1.4 days. This was significantly earlier than both Group 2 (27.5 ± 1.4 days) and Group 3 (27.0 ± 0.7 days), with ANOVA revealing significant inter-group differences ($p < 0.001$). Post hoc Bonferroni analysis showed significant differences between Group 1 and Group 2 (mean difference: -2.5 days, $p < 0.001$) and between Group 1 and Group 3 (mean difference: -2.0 days, $p < 0.001$). However, no significant difference was observed between Group 2 and Group 3 (mean difference: 0.5 days, $p = 0.410$), suggesting that minoxidil and coconut oil performed similarly in terms of hair growth completion time.

Histopathological Examination of Hair Follicles

Microscopic evaluation of skin biopsy specimens provided detailed insights into the hair follicle dynamics following different treatments. Two randomly selected animals from each group were examined, and their hair follicle characteristics were quantified.

Table 2: Total Hair Follicle Counts and Distribution of Follicles in Anagen and Telogen Phases

Groups		Total Hair Follicles		Anagen Phase		Telogen Phase	
		N	%	N	%	N	%
Group 1*	Animal 1	20	100	19	95.0	1	5.0
	Animal 2	20	100	19	95.0	1	5.0
Group 2*	Animal 1	14	100	9	64.2	5	35.7
	Animal 2	11	100	8	72.7	3	27.2
Group 3*	Animal 1	15	100	14	93.3	1	6.7
	Animal 2	16	100	14	87.5	2	12.5

Group 1: 2% Petroleum ether extract of T. grandis seeds in coconut oil; Group 2: Virgin coconut oil (control); Group 3: 2% Minoxidil solution.

The histopathological analysis revealed striking differences in hair follicle density and cycling status among the three treatment groups. Both animals in Group 1 demonstrated identical hair follicle counts of 20 follicles each, with 19 follicles (95%) in the anagen phase and only 1 follicle (5%) in the telogen phase. This indicated robust and synchronized hair growth activity in the teak extract-treated group.

In contrast, Group 2 (control) showed considerably lower total hair follicle counts, with Animal 1 having 14 follicles and Animal 2 having 11 follicles. The proportion of anagen phase follicles was also substantially lower in this group: Animal 1 had 64.2% (9/14) and Animal 2 had 72.7% (8/11) of follicles in the active growth phase. Correspondingly, the telogen phase follicles were more prevalent, comprising 35.7% and 27.2% respectively.

Group 3 (minoxidil-treated) demonstrated intermediate results with 15 and 16 total hair follicles in Animals 1 and 2 respectively. The proportion of anagen phase follicles was high at 93.3% (14/15) and 87.5% (14/16), approaching but not matching the performance of Group 1. Telogen phase follicles comprised 6.7% and 12.5% respectively in this group.

Table 3: Mean Values of Hair Follicle Parameters Across Study Groups

Type of Hair Follicle	Group 1* (n=2)		Group 2* (n=2)		Group 3* (n=2)		P value
	Mean	SD	Mean	SD	Mean	SD	
Total hair follicles	20.0	0.0	12.5	2.1	15.5	0.5	0.023
Anagen follicles	19.0	0.0	8.5	0.7	14.0	0.0	0.001
Telogen follicles	1.0	0.0	4.0	1.4	1.5	0.7	0.086

Group 1: 2% Petroleum ether extract of T. grandis seeds in coconut oil; Group 2: Virgin coconut oil (control); Group 3: 2% Minoxidil solution.

Statistical analysis using one-way ANOVA demonstrated significant differences in total hair follicles ($p = 0.023$) and anagen follicles ($p = 0.001$) among the three groups. Post hoc Bonferroni testing revealed that Group 1 had significantly higher total hair follicle counts compared to Group 2 (mean difference: 7.5, $p < 0.05$), indicating enhanced folliculogenesis with teak seed extract treatment. The difference between Group 1 and Group 3 approached but did not reach statistical significance (mean difference: 4.5, $p > 0.05$).

For anagen phase follicles, Group 1 demonstrated significantly higher counts compared to both Group 2 (mean difference: 10.5, $p < 0.001$) and Group 3 (mean difference: 5.0, $p = 0.004$). This finding is particularly important as it indicates that teak seed extract not only increased total follicle density but also promoted a higher proportion of follicles to enter or remain in the active growth phase.

Regarding telogen phase follicles, although Group 1 showed the lowest mean count (1.0 ± 0.0) compared to Group 2 (4.0 ± 1.4) and Group 3 (1.5 ± 0.7), the differences did not reach statistical significance ($p = 0.086$), likely due to the small sample size in the histopathological analysis.

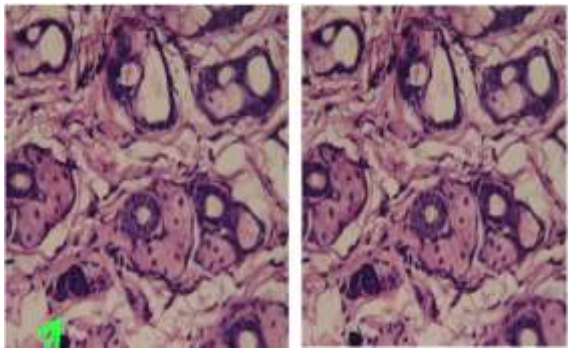

Figure 1: Histopathological of Hair follicles in Tectona grandis extract group examination

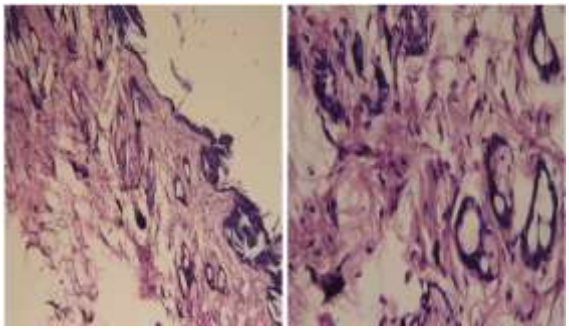

Figure 2: Histopathological examination of Hair follicles in control group

Microscopic Appearance of Hair Follicles: Histopathological examination revealed distinct morphological characteristics across the treatment groups. In Group 1 specimens, hair follicles demonstrated robust structural features typical of anagen phase, including well-developed dermal papillae, prominent matrix cell proliferation, and thick hair shafts surrounded by complete inner and outer root sheaths. The follicles appeared uniformly distributed with minimal telogen follicles characterized by atrophic bulbs.

Group 2 (control) specimens showed fewer hair follicles overall, with a mixed population of anagen and telogen follicles. Many follicles appeared smaller with less prominent dermal papillae and reduced matrix cell activity. A substantial proportion of follicles exhibited characteristics of early catagen or telogen phase, including retracted dermal papillae and thinning of the hair shaft.

Group 3 (minoxidil) specimens demonstrated hair follicles predominantly in anagen phase, similar to Group 1 but with slightly less uniformity. The follicles showed active growth characteristics with enlarged bulbs and prominent matrix zones, though the overall follicular density was lower than in the teak extract-treated group.

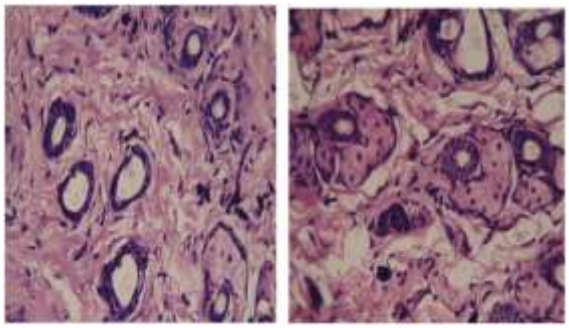

Figure 3: Histopathological examination of Hair follicles in Minoxidil group

Safety and Tolerability: Throughout the 30-day experimental period, all animals in all three groups remained healthy without signs of systemic toxicity. No local adverse reactions such as erythema, edema, scaling, or ulceration were observed at the application sites in any group. The 2% petroleum ether extract of T. grandis seeds was particularly well-tolerated, with no animal showing signs of discomfort or behavioral changes attributable to the treatment. Body weight measurements recorded weekly showed no significant differences among groups, and all animals maintained normal feeding and grooming behaviors. This safety profile supports the potential for further development of teak seed extract as a topical hair growth-promoting agent.

DISCUSSION

The present study provides compelling evidence for the hair growth-promoting efficacy of petroleum ether extract of Tectona grandis seeds in an established murine model of hair growth. Our findings demonstrate that 2% teak seed extract significantly accelerated both the initiation and completion of hair growth compared to minoxidil, the current gold standard treatment for alopecia, and virgin coconut oil as a control vehicle.

The superior performance of teak seed extract in reducing hair growth initiation time is particularly

noteworthy. Group 1 animals treated with 2% T. grandis extract exhibited visible hair growth approximately one day earlier than minoxidil-treated animals and two days earlier than control animals. This finding aligns with previous research by Jaybhaye et al,[6] who similarly reported that teak seed extract reduced hair growth initiation time to approximately half that observed with minoxidil in albino mice. The consistency of these findings across independent studies strengthens the evidence for the hair growth-promoting potential of T. grandis seeds.

The mechanism underlying this rapid hair growth initiation likely involves multiple pathways. The chemical composition of teak seeds, which includes fatty acids, norlingans, glycosides, and various amino acids, may contribute synergistically to follicular activation.[3,4] Fatty acids, particularly unsaturated fatty acids, have been shown to influence prostaglandin metabolism, which plays a crucial role in regulating hair follicle cycling.[11] Minoxidil, the standard treatment, is known to act as a potassium channel opener and vasodilator, promoting hair growth through increased blood flow to follicles and prolongation of the anagen phase.[11] The superior performance of teak seed extract suggests that its mechanism may be more direct or multifaceted, potentially involving both metabolic stimulation of follicular keratinocytes and enhancement of dermal papilla cell proliferation.[12]

The significant reduction in hair growth completion time observed with teak seed extract (25 days) compared to minoxidil (27 days) and control (27.5 days) further underscores its efficacy. This finding suggests that teak extract not only initiates hair growth earlier but also maintains this advantage throughout the growth cycle, resulting in faster achievement of complete hair coverage. The accelerated hair growth cycle has important clinical implications, as it could translate to more rapid visible improvement in patients with alopecia, potentially improving treatment adherence and patient satisfaction.

The histopathological findings provide crucial insights into the biological mechanisms underlying the observed clinical effects. The significantly higher total hair follicle count in the teak extract-treated group (20 follicles) compared to control (12.5 follicles) and minoxidil (15.5 follicles) suggests that teak extract may promote not only the activation of existing follicles but potentially the formation of new follicles or the recruitment of dormant follicles into active growth. While true de novo folliculogenesis does not occur in adult mammals, the recruitment of dormant or miniaturized follicles into active growth could explain the increased follicle density observed.

More importantly, the distribution of follicles across hair cycle phases revealed striking differences among treatment groups. The teak extract-treated group demonstrated that 95% of follicles were in the anagen (active growth) phase, compared to approximately 68% in the control group and 90% in the minoxidil group. This finding aligns with the report by Jaybhaye et al,[6] who similarly observed a greater proportion of anagen follicles with teak extract treatment. The high anagen-to-telogen ratio indicates that teak extract effectively maintains follicles in the productive growth phase, preventing premature entry into catagen (regression) or telogen (resting) phases.

The biological significance of maintaining follicles in anagen phase cannot be overstated. In human alopecia, particularly androgenetic alopecia, the progressive miniaturization of hair follicles is accompanied by shortened anagen duration and prolonged telogen phase.[12,13] Treatments that can prolong anagen phase or accelerate re-entry into anagen from telogen are therefore of great therapeutic value. The ability of teak seed extract to maintain 95% of follicles in anagen phase suggests it may have potent anti-alopecia effects worthy of clinical investigation.

The amino acid composition of teak seed protein may contribute significantly to its hair growth-promoting effects.[3] Hair shafts are primarily composed of keratin, a protein rich in cysteine, which forms disulfide bonds providing structural strength.[12] The presence of essential amino acids including leucine, isoleucine, valine, lysine, and phenylalanine in teak seeds could provide the building blocks necessary for keratin synthesis. Additionally, amino acids serve as precursors for various signaling molecules and growth factors that regulate follicular activity. The nutritive support provided by these amino acids may enhance follicular metabolism and proliferative capacity.

The presence of norlingans in teak seeds represents another potentially important bioactive constituent.[3,4] Lignans and norlingans are polyphenolic compounds with antioxidant and anti-inflammatory properties. Oxidative stress has been implicated in various forms of alopecia, and antioxidants that neutralize reactive oxygen species may protect follicular cells from damage.[14] Furthermore, chronic inflammation can disrupt the hair cycle and promote premature entry into catagen phase. The anti-inflammatory properties of norlingans could help maintain a favorable follicular microenvironment conducive to sustained anagen phase growth.

Fatty oils present in teak seeds may contribute to hair growth through multiple mechanisms. These lipids can integrate into cell membranes, altering their fluidity and affecting signal transduction pathways. Some fatty acids serve as precursors for prostaglandins and other eicosanoids that regulate hair growth. Prostaglandin E2, in particular, has been shown to promote hair growth and is the basis for latanoprost, an approved treatment for hypotrichosis. The lipophilic nature of the petroleum ether extract likely concentrated these bioactive fatty acids, potentially explaining the superior efficacy observed.

Glycosides present in teak seeds may also play a role in the observed effects. Various plant glycosides have been shown to possess growth-promoting and anti-inflammatory properties. Some glycosides can

modulate growth factor signaling pathways, including those involving vascular endothelial growth factor (VEGF) and insulin-like growth factor (IGF), both of which are important for hair follicle development and maintenance.

The safety profile observed in this study is encouraging for potential clinical translation. No local or systemic adverse effects were noted with the 2% teak seed extract throughout the 30-day treatment period. This contrasts with minoxidil, which, despite its efficacy, is associated with side effects including scalp irritation, unwanted facial hair growth, and, rarely, cardiovascular effects.[15] The excellent tolerability of teak seed extract, combined with its superior efficacy in this animal model, suggests it could be a valuable alternative or adjunct to current therapies.

The use of virgin coconut oil as the vehicle deserves comment. Coconut oil itself has been traditionally used for hair care in many cultures and has been shown to reduce protein loss from hair shafts. In our study, however, coconut oil alone (Group 2) performed significantly worse than both active treatments, suggesting that any benefits of the vehicle were outweighed by the effects of the active ingredients in the test and standard groups. The choice of coconut oil as a vehicle was appropriate as it is non-toxic, cosmetically acceptable, and can solubilize lipophilic compounds from the petroleum ether extract.

Several limitations of the present study warrant consideration. First, the relatively small sample size, particularly for histopathological analysis (two animals per group), limits the statistical power for detecting differences in some parameters. The lack of statistical significance for telogen follicle differences, despite apparent trends, may reflect this limitation. Future studies with larger sample sizes would provide more robust evidence. Second, the study evaluated only a single concentration (2%) and dosing frequency (once daily) of teak extract. Dose-response studies could identify optimal concentrations and dosing regimens for maximum efficacy. Third, the 30-day duration, while appropriate for the murine hair cycle, may not fully capture long-term effects or sustainability of the response. Extended studies could determine whether the benefits are maintained over longer periods.

Fourth, the study did not investigate the specific mechanisms by which teak extract promotes hair growth. Future studies incorporating molecular and cellular analyses, such as expression of growth factors (VEGF, IGF-1, FGF), cell proliferation markers (Ki-67), and apoptosis markers, would provide mechanistic insights.[12,13] Additionally, evaluating the effects on key signaling pathways involved in hair follicle development and cycling, such as Wnt/β-catenin, Shh (Sonic hedgehog), and BMP (bone morphogenetic protein) pathways, would be valuable. Fifth, the study used Swiss albino mice, which have specific hair cycle characteristics that may not fully translate to human physiology.[7] While rodent models are widely accepted for preliminary screening of hair growth-promoting agents, human clinical trials are essential to confirm efficacy and safety in the target population.

Despite these limitations, the study provides strong preliminary evidence supporting the traditional use of T. grandis seeds as a hair growth promoter. The findings suggest that teak seed extract may offer advantages over current standard treatments in terms of both efficacy and safety. The ethnomedicinal validation demonstrated in this study justifies further investigation through phytochemical characterization to identify specific bioactive compounds, formulation development to optimize stability and delivery, toxicological studies to establish comprehensive safety profiles, and ultimately, controlled clinical trials in patients with various forms of alopecia.

The potential for commercial development of teak seed extract as a cosmeceutical or therapeutic agent for hair loss is considerable. Given the growing consumer preference for natural and plant-based products, a scientifically validated herbal hair growth promoter could capture significant market share. The abundance of teak trees in South Asia and the relative ease of seed collection could ensure sustainable and economically viable production.

Comparative analysis with existing literature reveals consistency in findings regarding teak seed extract's efficacy. Fachrunniza et al,[5] also identified Tectona grandis as a potential active ingredient for hair growth promotion, corroborating our findings. The convergence of evidence from multiple independent studies strengthens the case for clinical investigation. However, it is important to note that while animal models, particularly rodent models, have been extensively validated for screening hair growth-promoting agents,[7] they have limitations in predicting human responses due to differences in hair follicle density, hair cycle duration, and hormonal regulation of hair growth.

The superior performance of teak seed extract compared to minoxidil in this animal model is particularly significant given minoxidil's established efficacy in human androgenetic alopecia. Minoxidil has been extensively studied and is approved by regulatory agencies worldwide for treatment of pattern hair loss.[11,15] The mechanism of minoxidil involves opening of ATP-sensitive potassium channels in smooth muscle cells, leading to vasodilation and increased blood flow to hair follicles.[11] Additionally, minoxidil has been shown to stimulate dermal papilla cells and prolong the anagen phase. The fact that teak seed extract outperformed this established agent suggests it may have complementary or more potent mechanisms of action.

From a translational perspective, several steps are necessary before teak seed extract can progress to clinical use. First, comprehensive phytochemical characterization using techniques such as gas chromatography-mass spectrometry (GC-MS), high-

performance liquid chromatography (HPLC), and nuclear magnetic resonance (NMR) spectroscopy should be performed to identify and quantify the bioactive constituents. Second, standardization protocols must be established to ensure consistency across batches, which is crucial for both research reproducibility and eventual therapeutic use. Third, stability studies should evaluate the shelf life and optimal storage conditions of the extract. Fourth, formulation development should explore various delivery systems, including solutions, gels, foams, and nanoparticulate carriers that might enhance penetration and efficacy.

Safety evaluation should be expanded beyond the acute tolerability observed in this study. Comprehensive toxicological studies, including repeated-dose toxicity, genotoxicity, and reproductive toxicity studies, are necessary to establish a complete safety profile. While the traditional use of teak seeds suggests a favorable safety profile, rigorous scientific evaluation is essential for regulatory approval and clinical acceptance.

The potential applications of teak seed extract extend beyond androgenetic alopecia. Various forms of hair loss, including alopecia areata, telogen effluvium, chemotherapy-induced alopecia, and traction alopecia, might benefit from treatments that promote follicular activation and prolong anagen phase. Clinical studies should evaluate efficacy across different etiologies of hair loss to identify the populations most likely to benefit.

Furthermore, the use of teak seed extract as a preventive treatment to maintain hair density and quality in individuals without overt alopecia represents another potential application. Given the safety profile observed and the cosmetic acceptability of a plant-based oil formulation, preventive use could be attractive to consumers concerned about hair aging and progressive thinning.

The cost-effectiveness of teak seed extract compared to current treatments is another important consideration. While minoxidil is now available as a generic medication, long-term use can be expensive, particularly in developing countries. If teak seed extract can be produced and formulated economically, it could provide an affordable alternative for populations with limited access to conventional treatments. This is particularly relevant in India and other South Asian countries where teak is abundant and traditional medicine systems are widely accepted and practiced.

CONCLUSION

This study demonstrates that 2% petroleum ether extract of Tectona grandis seeds possesses significant hair growth-promoting activity in Swiss albino mice, outperforming both the vehicle control and the established standard treatment, minoxidil. The extract significantly reduced both hair growth initiation time (2.5 ± 0.7 days) and completion time (25 ± 1.4 days) compared to minoxidil (3.5 ± 0.5 days and 27 ± 0.7 days, respectively) and control (4.7 ± 1.4 days and 27.5 ± 1.4 days, respectively).

Histopathological examination revealed that teak seed extract treatment resulted in significantly higher total hair follicle density (20 ± 0) and a greater proportion of follicles in the anagen (active growth) phase (95%) compared to minoxidil (90%) and control (68%). This indicates that the extract not only accelerates hair growth but also maintains follicles in the productive growth phase, which is crucial for sustained hair production.

The excellent safety profile observed throughout the study, with no local or systemic adverse effects, supports the potential clinical applicability of teak seed extract. The traditional use of T. grandis seeds as a hair tonic in Indian medicine has thus been validated through scientific investigation, providing a foundation for further development.

In conclusion, the present study provides robust preclinical evidence supporting the hair growth-promoting potential of Tectona grandis seed extract and establishes a scientific foundation for its development as a therapeutic agent for hair loss. The convergence of traditional knowledge and modern scientific validation exemplifies the value of ethnopharmacological research in drug discovery and development.

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