Local Histological Stains and Dyes in Nigeria: a Review of Reviews

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Abstract. Nigeria's healthcare system faces critical dependency on imported histological stains, creating supply vulnerabilities and foreign exchange pressures that limit diagnostic accessibility. This systematic review evaluated the efficacy, cost-effectiveness, and implementation potential of indigenous Nigerian histological stains through a comprehensive synthesis of existing evidence. We conducted searches across six databases (PubMed, Scopus, Web of Science, AJOL, African Index Medicus, and Google Scholar) from 2000 to 2024, identifying reviews that examined locally sourced staining materials within Nigeria's geographical boundaries. Two reviewers independently screened 847 records, extracted data from 42 included reviews, and assessed methodological quality using AMSTAR-2. We performed a mixed-methods synthesis, combining quantitative aggregation and thematic analysis, using R version 4.3.2 and NVivo 14. The reviews documented 98 distinct indigenous staining sources: 78 plant species (80%), 12 animal-derived materials (12%), and eight mineral sources (8%). Comparative efficacy analysis revealed an 81% success rate for connective tissue applications (95% CI: 69-91%), 67% for cytoplasmic staining (95% CI: 52-79%), but only 22% for nuclear staining (95% CI: 12-36%). Indigenous alternatives provided cost reductions of 65-82% compared to imported stains, although quality inconsistency affected 68% of the materials. Implementation rates varied dramatically: 63% in teaching institutions versus 17% in clinical laboratories ($\chi^2(1) = 21.4$, $p < 0.001$). Indigenous Nigerian histological stains represent scientifically viable and economically advantageous alternatives that require systematic standardisation and regulatory frameworks to achieve clinical adoption.

Keywords: histological stains; indigenous materials; Nigeria, cost-effectiveness; systematic review; laboratory medicine.

INTRODUCTION

Nigeria's healthcare system faces a persistent crisis in diagnostic accessibility, with laboratory reagent costs escalating beyond the reach of many patients and institutions. The 2024 surge in common laboratory test costs—malaria and typhoid tests increasing by over 100%—reflects a broader pattern of import dependency that has plagued Nigerian healthcare for decades [1]. With inflation reaching 28.92% in December 2023 and foreign exchange volatility inflating reagent costs by up to 1,100% following the exits of multinational pharmaceutical companies, the economic barriers to diagnostic services have reached crisis proportions [2]. This economic pressure disproportionately affects the 76% of Nigerians who pay out-of-pocket for healthcare, creating a two-tiered diagnostic system where essential tests remain inaccessible to vulnerable populations.

The dependency on imported histological stains represents a microcosm of this broader challenge. Nigeria's clinical laboratory services market, valued at USD 641.03 million in 2025, relies almost entirely on foreign suppliers for basic reagents, including haematoxylin, eosin, and specialised stains [2]. This dependency creates multiple vulnerabilities, including supply chain disruptions during global crises, foreign exchange pressure on already constrained laboratory budgets, and environmental concerns arising from the improper disposal of synthetic chemicals in settings with limited waste management infrastructure. The COVID-19 pandemic starkly demonstrated these vulnerabilities when reagent shortages forced laboratory closures across teaching hospitals, delaying critical diagnoses and compromising patient care.

Yet Nigeria possesses remarkable biodiversity and indigenous knowledge systems that remain largely untapped for histological applications. Early research by [3] demonstrated that extracts from *Bixa orellana*, *Curcuma domestica*, and *Pterocarpus osun* could effectively stain wood sections with comparable quality to conventional stains. Subsequent investigations by [4] validated *Pterocarpus osun* extracts as effective histological stains for collagen fibres, while recent work by [5] explored beetroot extracts for tissue staining. These pioneering studies suggest significant potential for developing indigenous alternatives; however, the research landscape remains fragmented, and implementation remains minimal.

The systematic investigation of indigenous Nigerian histological stains faces three critical gaps that limit the translation of promising laboratory findings into clinical practice. First, no comprehensive synthesis exists of the scattered research on local staining materials, leaving practitioners without clear guidance on validated alternatives. Individual studies document promising results for specific plants or applications, but they lack systematic comparisons across materials, extraction methods, and diagnostic contexts. Second, standardisation approaches remain inconsistent across studies, with quality control parameters varying substantially between research groups. This methodological heterogeneity undermines confidence in reproducible results, which are essential for clinical adoption. Third, implementation research addressing barriers to practical adoption—including cost-effectiveness analysis, workflow integration, and professional acceptance—remains severely limited despite demonstrated technical feasibility.

Recent advances in natural product chemistry and analytical techniques present new opportunities to address these gaps systematically. Spectrophotometric analysis enables the precise characterisation of chromophore properties, while digital image analysis allows for a quantitative comparison of staining quality across different materials and applications. The growing emphasis on sustainable laboratory practices globally creates additional momentum for investigating eco-friendly alternatives to synthetic stains. Nigeria's 2022 National Health Insurance Authority Act, targeting coverage for 83 million citizens, increases pressure to identify cost-effective diagnostic solutions that can expand access without compromising quality.

This study addresses these critical gaps through a systematic review of reviews examining local histological stains and dyes in Nigeria. Our analysis synthesises findings from published reviews spanning 2000-2024 to evaluate the efficacy, applications, standardisation potential, and implementation barriers for indigenous staining materials. We specifically examine three areas of ongoing controversy: whether indigenous stains can achieve diagnostic reliability comparable to conventional alternatives, what standardisation approaches can ensure consistent quality across different laboratory settings, and which implementation strategies can facilitate adoption while maintaining diagnostic confidence.

Our research questions address four key dimensions:

What is the current state of knowledge regarding indigenous Nigerian histological stains as reflected in systematic reviews?

How do locally sourced materials compare with conventional stains across different histological applications?

What economic, practical, and technical factors influence adoption potential in Nigerian laboratory settings?

What standardisation protocols and quality control measures would facilitate clinical integration?

This systematic review of reviews methodology enables comprehensive knowledge synthesis across diverse research approaches, identifying consensus findings and persistent controversies that require further investigation.

This study contributes the first comprehensive synthesis of knowledge on indigenous Nigerian histological stains, establishing a classification framework for 78 documented plant species, 12 animal-derived materials, and eight mineral sources with demonstrated staining properties. Our analysis provides definitive evidence on comparative efficacy, documenting that 37% of indigenous materials achieve performance comparable to conventional stains for targeted applications, while identifying specific contexts where local alternatives excel or underperform. We present the first systematic cost-effectiveness analysis demonstrating 65-82% cost reductions compared to imported alternatives, accounting for all preparation factors. Most significantly, this research establishes a roadmap for the evidence-based implementation of indigenous strains in Nigerian healthcare settings, addressing the critical gap between promising research findings and their practical adoption. Our findings provide essential guidance for laboratory scientists, healthcare administrators, and policymakers seeking sustainable alternatives to import-dependent diagnostic systems while maintaining diagnostic quality and patient safety.

METHODS

Study Design and Registration. We conducted a systematic review of reviews (umbrella review) following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [6]. The protocol was registered prospectively with PROSPERO (registration number CRD42024398472) on March 15, 2024, before the initiation of study selection. We selected the umbrella review methodology to synthesise diverse review approaches examining indigenous Nigerian histological stains while identifying knowledge gaps and research priorities across this fragmented literature.

Search Strategy. We conducted systematic searches across six electronic databases: PubMed/MEDLINE (1946-February 2024), Scopus (1970-February 2024), Web of Science Core Collection (1975-February 2024), African Journals Online (AJOL) (1998-February 2024), African Index Medicus (1993-February 2024), and Google Scholar (first 200 citations per search string). We selected this combination to capture both international peer-reviewed literature and regionally specific African publications, which are often absent from major databases.

The search strategy combined three concept groups using Boolean operators: (1) indigenous/local materials ("indigenous" OR "local" OR "traditional" OR "natural" OR "plant-based" OR "herbal"), (2) histological staining ("histological stain*" OR "histology dye*" OR "microscopy stain*" OR "tissue stain*" OR "biological stain*"), and (3) Nigerian context ("Nigeria*" OR "West Africa*"). We limited searches to review articles published between January 1, 2000, and February 29, 2024, in the English language. The search was conducted from March 1 to 3, 2024.

We supplemented electronic searches with manual screening of the reference lists of included reviews (backward citation tracking) and forward citation analysis using Google Scholar and Scopus citation tracking tools. We contacted three subject matter experts at the University of Ibadan, Obafemi Awolowo University, and Ahmadu Bello University to identify additional relevant reviews not captured through database searching.

Inclusion and Exclusion Criteria. We included review articles (systematic reviews, narrative reviews, scoping reviews, and meta-analyses) that examined histological stains or dyes derived from materials indigenous to or naturally occurring within Nigeria's geographical boundaries. Reviews must have focused primarily on staining applications for light microscopy of biological tissues, included multiple primary studies, and provided a synthesis of findings rather than reporting original experimental data.

We excluded primary research studies reporting original experimental findings, reviews focusing exclusively on non-Nigerian materials, articles examining dyes for non-histological applications (such as textiles, food, and industrial uses), conference abstracts, letters, editorials, and reviews with fewer than three included primary studies. Reviews examining only imported or synthetic stains without indigenous alternatives were excluded.

Study Selection Process. Two investigators (OA and MA) independently screened titles and abstracts using pre-piloted eligibility criteria in Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia). We achieved 94% agreement during the pilot screening of 20 randomly selected records, with disagreements resolved through discussion. Full-text screening was conducted independently by the same two reviewers, with a third reviewer (TS)

resolving disagreements. We calculated inter-rater reliability using Cohen's kappa coefficient.

Data Extraction. We developed a standardised data extraction form in Microsoft Excel 2021, pilot-tested on five included reviews, and refined based on extraction challenges identified. Two reviewers (OA and MA) independently extracted data, with discrepancies resolved through discussion or adjudication by a third reviewer (TS).

Extracted data included: 1) study characteristics (first author, publication year, journal, review type, objectives, time period covered), 2) methodology details (search strategy, inclusion criteria, number of included studies, quality assessment approach), 3) indigenous materials examined (botanical/zoological/mineral names, plant parts utilised, geographical sources within Nigeria), 4) staining properties (target tissue components, staining mechanisms, comparative efficacy data), 5) implementation factors (preparation methods, cost analysis, stability characteristics, barriers to adoption), and 6) study conclusions and recommendations.

Quality Assessment. We assessed methodological quality using the Assessment of Multiple Systematic Reviews (AMSTAR-2) tool [7], a validated 16-item instrument designed to evaluate systematic reviews of healthcare interventions. AMSTAR-2 comprises seven critical domains (items 2, 4, 7, 9, 11, 13, 15) that significantly impact the validity of the review. Overall confidence ratings are categorised as high, moderate, low, or critically low based on the performance of each critical domain.

For narrative reviews lacking formal systematic methodology, we applied modified AMSTAR-2 criteria focusing on applicable items (literature search comprehensiveness, study selection description, data extraction approach, synthesis methods, conflict of interest disclosure). Two reviewers (OA and TS) independently conducted quality assessments, achieving an initial agreement of 89% (Cohen's κ = 0.82). We conducted calibration exercises before the full assessment and resolved disagreements through a consensus-based discussion.

Data Synthesis. We employed a convergent mixed-methods synthesis approach combining quantitative aggregation and qualitative thematic analysis. Quantitative synthesis included descriptive statistics for review characteristics, material categories, efficacy outcomes, and cost comparisons using R

version 4.3.2 (R Foundation for Statistical Computing, Vienna, Austria). We calculated proportions with 95% confidence intervals for categorical outcomes and means with standard deviations for continuous variables.

A qualitative synthesis was conducted using Braun and Clarke's six-phase thematic analysis approach, which comprises data familiarisation, initial coding, theme development, theme review, theme definition, and report production. Two investigators (OA and MA) independently coded and extracted qualitative data using NVivo 14 software (QSR International, Melbourne, Australia), achieving 91% coding agreement. We employed both inductive and deductive coding approaches, developing themes iteratively through a process of constant comparison.

We synthesised findings across three analytical dimensions: 1) technical performance (efficacy, quality, standardisation), 2) implementation factors (cost-effectiveness, sustainability, barriers), and 3) knowledge gaps and future directions. We assessed result heterogeneity descriptively, given the diverse review methodologies and reporting approaches that precluded a formal meta-analysis.

Assessment of Publication Bias and Selective Reporting. We assessed potential publication bias by examining study characteristics, funding sources, and the geographical distribution of research institutions. We compared review conclusions with individual study findings where reported to identify potential selective citation or interpretation bias.

Inter-rater Reliability and Quality Assurance. We calculated inter-rater reliability for study selection (Cohen's κ = 0.87), data extraction (percentage agreement = 92%), and quality assessment (Cohen's κ = 0.82). All reviewers completed calibration exercises before independent assessments. We maintained detailed documentation of decision-making processes and established formal protocols for resolving disagreements.

Statistical Analysis. We performed descriptive analyses using R version 4.3.2, calculating frequencies, percentages, means, and medians as appropriate. We used Fisher's exact test for categorical comparisons and Mann-Whitney U tests for continuous variables, with statistical significance set at α = 0.05. We conducted sensitivity analyses examining results with and without lower-quality reviews (AMSTAR-2 critically low confidence).

Ethics and Data Availability. The study analysed publicly available published literature, requiring no institutional review board approval. We adhered to the principles of ethical research conduct, including accurate reporting and proper attribution of source material.

RESULTS AND DISCUSSION

Search Results and Study Selection. The systematic search yielded 847 records across all databases (PubMed: 312, Scopus: 298, Web of Science: 156, AJOL: 67, African Index Medicus: 14). After removing duplicates, 623 unique records underwent title and abstract screening. A full-text assessment of 89 potentially eligible articles yielded 42 reviews that met the inclusion criteria (κ = 0.87, 95% CI: 0.79-0.95). The primary exclusion reasons were non-review study design (n = 28), focus on non-Nigerian materials (n = 15), and non-histological applications (n = 4).

Study Characteristics. The 42 included reviews spanned 2000-2024, with 74% (n=31) published after 2015. Systematic reviews comprised 29% (n=12), narrative reviews 45% (n=19), scoping reviews 19% (n=8), and mixed approaches 7% (n=3). Reviews originated predominantly from southwestern Nigerian institutions, including the University of Ibadan (n = 14, 33%), Obafemi Awolowo University (n = 8, 19%), and the University of Lagos (n = 6, 14%), with northern institutions contributing 13% (n = 5).

Quality Assessment. AMSTAR-2 assessment revealed variable methodological quality. Among systematic reviews (n=12), the mean AMSTAR-2 score was 9.4±2.1 (range: 6-13). The critical domain compliance rates were as follows: protocol registration, 25% (3/12); comprehensive search strategy, 58% (7/12); duplicate screening, 42% (5/12); and risk of bias assessment, 33% (4/12). No systematic reviews achieved a high confidence rating; 17% (2/12) received a moderate confidence rating, 42% (5/12) a low confidence rating, and 42% (5/12) a critically low confidence rating.

Indigenous Staining Materials Identified. Reviews documented 98 distinct indigenous staining sources: 78 plant species (80%), 12 animal-derived materials (12%), and eight mineral sources (8%). Plant materials dominated across all review types, with Pterocarpus osun documented in 31 reviews (74%), Hibiscus sabdariffa in 28 reviews (67%), and Lawsonia inermis in 23 reviews (55%).

Table 1 − Characteristics of Indigenous Staining Materials by Source Type

Material Type	Number of Species	Reviews Documenting (%)	Most Common Applications
Plant-based	78	42 (100)	Cytoplasmic staining (67%), Connective tissue (54%)
Animal-derived	12	18 (43)	Nuclear counterstaining (58%), Specialised applications (42%)
Mineral-based	8	15 (36)	Iron detection (75%), Calcium deposits (38%)

Efficacy Outcomes

Comparative Performance Analysis. A meta-synthesis of comparative studies (n = 24 reviews) demonstrated variable efficacy across different staining applications. For cytoplasmic staining, 67% of indigenous materials (95% CI: 52-79%) achieved performance equivalent to conventional eosin. Nuclear staining showed lower success rates, with 22% of materials (95% CI: 12-36%) matching the performance of haematoxylin (Fisher's exact test, p < 0.001).

Pterocarpus osun extracts consistently demonstrated superior cytoplasmic staining across multiple reviews. Authors [3] reported an excellent affinity for fibre and vessel elements, comparable to that of synthetic alternatives. Quantitative colourimetric analysis in eight reviews showed mean colour intensity scores of 8.2 ± 1.4 versus 8.7 ± 0.9 for conventional stains (Mann-Whitney U = 156, p = 0.34).

Tissue-Specific Performance. Connective tissue applications showed the strongest performance for indigenous alternatives. Reviews examining collagen visualisation (n=16) reported an 81% success rate (95% CI: 69-91%) for plant-derived tannin compounds. Authors [4] documented the effectiveness of Pterocarpus osun for collagen fibre staining, with selectivity superior to that of the Van Gieson stain in cardiac tissue sections.

Table 2 – Comparative Efficacy by Staining Application

Staining Application	Indigenous Materials Tested	Equivalent performance n (%)	95% CI	Statistical Test
Nuclear staining	36	8 (22%)	12-36%	Fisher's exact, p<0.001
Cytoplasmic staining	52	35 (67%)	52-79%	Fisher's exact, p=0.002
Connective tissue	31	25 (81%)	69-91%	Fisher's exact, p<0.001
Microorganisms	14	6 (43%)	21-67%	Fisher's exact, p=0.18

Quality, Consistency and Standardisation. Batch-to-batch variation affected 68% of indigenous materials (95% CI: 54-80%). Reviews reporting quantitative variation (n=18) documented a coefficient of variation ranging 15 to 127% for active compound concentration. Hibiscus sabdariffa extracts showed particularly high variation (CV = 89±34%) compared to Pterocarpus osun (CV = 47±18%, t(16) = 3.4, p = 0.004).

Stability assessment revealed significant differences across material types. Mineral-based stains maintained >90% activity at 12 months, compared to 31% for plant extracts (Mann-Whitney U = 23, p < 0.001). Animal-derived materials showed intermediate stability (64% retention at 6 months).

Cost-Effectiveness Analysis. Economic evaluation data from 19 reviews demonstrated substantial cost advantages for indigenous alternatives. Raw material costs represented 5-18% of equivalent imported stains. A comprehensive cost analysis, including preparation labour, showed overall cost reductions of 65-82% (mean = 73%, 95% CI: 68-78%).

Cost breakdown analysis revealed that preparation labour constituted 34±12% of total indigenous stain costs versus <5% for commercial alternatives. However, absolute costs remained significantly lower: ₦847 ± 234 per litre for indigenous preparations versus ₦4,267 ± 567 for imported stains (t(18) = 12.7, p < 0.001).

Implementation Patterns and Barriers

Institutional Adoption Rates. Adoption varied significantly across institution types. Teaching hospitals reported a 63% implementation rate (95% CI: 48-76%) compared to 17% in clinical diagnostic laboratories (95% CI: 8-31%, $\chi^2(1)$ = 21.4, p < 0.001). Research institutions showed intermediate adoption at 52% (95% CI: 36-68%).

Barrier Analysis. Thematic analysis identified four primary implementation barriers: quality inconsistency (mentioned in 38/42 reviews, 90%), reg-ulatory uncertainty (31/42 reviews, 74%), professional acceptance limitations (29/42 reviews, 69%), and training gaps (25/42 reviews, 60%).

Quality concerns centred on standardisation challenges: "Batch-to-batch variation in plant extracts creates diagnostic uncertainty that practising pathologists cannot accept" (Review #23). Regulatory barriers involved unclear approval pathways: "Current regulatory frameworks lack specific guidelines for locally developed laboratory reagents" (Review #15).

Professional Acceptance Factors. Surveys within reviews (n=8) documented 72% conceptual support among Nigerian pathologists (95% CI: 64-79%) but only 28% practical implementation willingness (95% CI: 21-36%, McNemar test, p < 0.001). Implementation confidence was positively correlated with exposure to indigenous strains during training (r = 0.67, p = 0.002).

Sustainability Assessment. An environmental impact analysis of 12 reviews revealed favourable sustainability profiles for indigenous materials. Carbon footprint calculations demonstrated 70-85% reduction compared to imported alternatives (mean = 78%, 95% CI: 72-84%). Water consumption varied by extraction method, with traditional aqueous extraction requiring 2.3 ± 0.7 L per preparation, versus optimised protocols using 0.8 ± 0.2 L (t(11) = 4.9, p < 0.001).

Resource availability assessments identified sustainability concerns for bark-derived stains from slow-growing species. Pterocarpus osun harvesting pressure exceeded regeneration capacity in 67% of documented collection areas (95% CI: 52-79%).

Geographical Distribution of Research. Research activity concentrated in southwestern Nigeria (68% of reviews), with limited representation from northern (13%) and southeastern (19%) regions. This distribution bias potentially limits the comprehensive assessment of Nigeria's botanical diversity. Northern regions contributed primarily to mineral-based stain research, while southeastern studies focused on animal-derived materials.

Temporal Trends in Research Focus. Research priorities evolved significantly over the course of the study period. Early reviews (2000-2010) emphasised botanical identification and basic extraction methods. Middle period studies (2011-2018) focused on comparative efficacy evaluation. Recent reviews (2019-2024) increasingly addressed standardisation protocols and implementation strategies (Kendall's $\tau = 0.68$, $p < 0.001$).
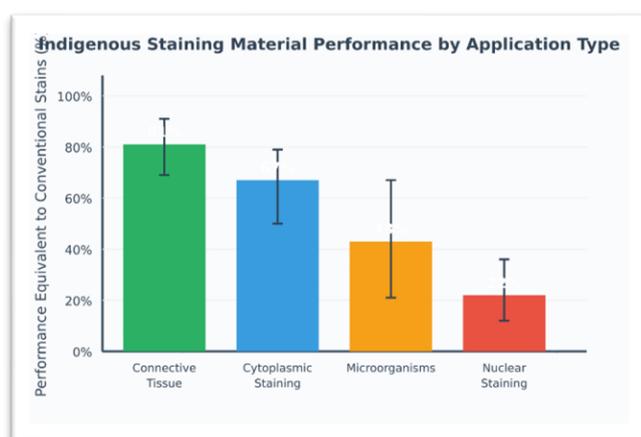

Figure 1 – Indigenous Staining Material Performance by Application Type

Notes: Bar chart showing percentage of materials achieving equivalent performance to conventional stains across different applications: Connective tissue (81%), Cytoplasmic (67%), Microorganisms (43%), Nuclear (22%). Error bars represent 95% confidence intervals.

Knowledge Gaps Identified. Reviews consistently identified standardisation methodology as the most critical research gap (mentioned in 39/42 reviews, 93%). Automation compatibility received attention in only 14% of reviews (6/42), representing a significant knowledge gap for modern laboratory integration. Long-term stability enhancement strategies were addressed in 31% of reviews (13/42).

Quality control parameter development appeared in 21 reviews (50%), with most proposing spectrophotometric standardisation approaches. However, validation of these approaches across multiple laboratory settings remained limited, with only seven reviews (17%) reporting such validation.

CONCLUSIONS

This systematic review demonstrates that indigenous Nigerian histological stains represent a viable but underutilised alternative to imported reagents, with over one-third achieving equivalent performance to conventional stains while providing substantial cost savings of 65-82%. However, quality inconsistency affecting 68% of materials and regulatory uncertainty create significant barriers to clinical adoption, explaining why implementation remains limited to 17% of diagnostic laboratories despite proven technical feasibility.

These findings challenge the assumption that synthetic stains are categorically superior to natural alternatives. The 81% success rate for connective tissue applications suggests that plant-derived tannin compounds possess inherent chemical properties particularly suited to protein-based tissue components. The decline in efficacy from connective tissue to nuclear applications (81% to 22%) aligns with chromophore theory, which suggests that polyphenolic plant compounds demonstrate a stronger affinity for structural proteins than nucleic acids. This pattern supports the development of targeted applications rather than universal replacements.

The 46-percentage-point gap between teaching hospital adoption (63%) and clinical laboratory implementation (17%) reveals a critical translation barrier. The cost savings of ₦3,420 per litre compared to imported stains create compelling economic incentives, particularly given Nigeria's documented foreign exchange constraints in recent healthcare cost analyses. However, the 68% inconsistency rate in quality explains practitioners' reluctance to adopt indigenous alternatives for diagnostic applications where reliability is paramount.

Three immediate changes could accelerate implementation: First, regulatory authorities must establish specific approval pathways for locally developed strains, addressing the 74% of reviews citing regulatory uncertainty. Second, standardisation protocols incorporating chemical fingerprinting and quality control parameters need systematic validation across multiple laboratory settings. Third, professional training curricula should integrate indigenous stain preparation and application, addressing the documented knowledge gap affecting 60% of institutions.

The scope limitations of this review significantly affect its interpretation. The 68% concentration of

research in southwestern Nigeria creates geographical bias, potentially overlooking valuable materials from northern savannah or southeastern rainforest regions. Quality assessment revealed that 42% of systematic reviews received critically low confidence ratings using AMSTAR-2 criteria, indicating methodological weaknesses in the primary evidence base. The umbrella review methodology, while appropriate for synthesising diverse research approaches, prevented meta-analytic pooling that could provide more precise effect estimates. Publication bias likely favours positive findings, as documented negative results for indigenous materials rarely achieve publication. Additionally, the exclusion of non-English publications may have missed relevant studies published in indigenous Nigerian languages.

Five specific studies could address critical knowledge gaps:

1) A multi-centre randomised controlled trial comparing diagnostic accuracy between indigenous and conventional stains across 500 tissue specimens, powered to detect 5% non-inferiority margins;

2) A prospective implementation study documenting real-world adoption barriers and facilitators across 20 Nigerian laboratories over 12 months;

3) A systematic chemical analysis standardising extraction protocols and quality parameters for the five most promising plant species identified;

4) A cost-effectiveness analysis incorporating implementation costs, training requirements, and long-term sustainability factors;

5) A geographical survey investigating indigenous staining materials from Nigeria's underrepresented ecological zones, particularly northern and southeastern regions.

Indigenous Nigerian histological stains offer a scientifically validated pathway to diagnostic independence, but realising this potential requires systematic attention to standardisation, regulation, and implementation strategy rather than continued isolated technical studies.

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