NATIONAL RESEARCH INSTITUTE FOR CHEMICAL TECHNOLOGY

ZARIA

TEXTILE TECHNOLOGY DEPARTMENT

THEMATIC TITLE: Health and Biotechnology

PROJECT TITLE: Design and Fabrication of Pilot-scale Dye Extraction Machine for Value Addition and Technology Transfer

EXECUTIVE SUMMARY/ABSRACT

Synthetic dyes dominate global industries but contribute significantly to environmental pollution and health risks. Natural plant-based dyes provide a safer and eco-friendly alternative, yet their adoption is limited by inconsistent yield, low colour fastness, and a lack of scalable standardized extraction methods. This project addresses these gaps by developing optimized dye extraction protocols, enhancing dye performance through value addition, and advancing towards pilot-scale application.

Building on completed laboratory experiments (TRL 4), the project will design, fabricate, and validate a functional pilot-scale dye extraction machine, moving the technology to TRL 6. Key activities include, machine fabrication, prototype testing, and techno-economic evaluation. The process will be guided by rigorous quality assurance and sustainability assessments, ensuring environmental safety and industrial relevance.

Expected outputs include validated extraction protocols, a spectral performance database, improved dye formulations, and a functional pilot machine ready for technology transfer. The outcomes will create eco-friendly alternatives to synthetic dyes, open new markets for SMEs, preserve indigenous knowledge, and generate livelihood opportunities for local communities. In the long run, the project will reduce environmental footprints and contribute to global sustainability goals.

1.0 INTRODUCTORY BACKGROUNG

The rising awareness of environmental sustainability and consumer preference for eco-friendly products have renewed global interest in natural dyes as alternatives to synthetic colorants. Natural dyes, derived from plants, insects, and minerals, have been used for centuries in textiles, food, cosmetics, and pharmaceuticals (Bechtold and Mussak, 2009). Unlike synthetic dyes which are often derived from petrochemicals and associated with toxic effluents, natural dyes are biodegradable, non-toxic, and generally safer for human health and the environment (Samanta and Agarwal, 2009). Despite these benefits, natural dyes remain underutilized in large-scale industrial applications due to low extraction yields, poor reproducibility of shades, inadequate colour fastness, and high production costs (Yusuf *et al.,* 2017). These limitations reduce their competitiveness against synthetic dyes, which are inexpensive, vibrant, and widely available. To advance the commercial potential of natural dyes, innovative approaches and applied technologies must be employed to enhance efficiency, quality, and scalability.

To date, we have successfully extracted nine distinct natural dyes using the conventional approach from various plant biomass such as hibiscus sabdariffa, avocado pit, allium cepa, vernonia amydalina, daucus carota, curcumin longa, indigoferra arecta, lawsonia inermis and bombax buonopenze as illustrated in the plate 1 below.

Plate 1: Photograph of extracted dyes

The production of natural dye powders from plants typically involves extraction, drying, and solvent recovery, all aimed at maximizing dye yield. Among the critical factors influencing both yield and dye performance are the choice of extraction medium and the operating temperature. However, existing extraction equipment has been shown to be inefficient, limiting the effective utilization of natural dyes. The design of specialized machinery offers a solution, drawing upon experimental principles, advanced engineering knowledge, and innovative design concepts to create systems capable of performing these tasks with greater efficiency, cost-effectiveness, and sustainability. Such machine development represents both a novel and continuous innovation pathway for natural dye technology (Nwanchukwu *et al.,* 2015).

Machine design encompasses the processes of conceptualization, development, analysis, modification, and specification that define and standardize a product's structure and function (Wanyama *et al.,* 2010). In this context, the fabrication of a pilot-scale natural dye extraction machine that delivers high yield, environmental sustainability, and consumer acceptability is of paramount importance. Conventional extraction approaches such as aqueous and soxhlet extraction methods have been reported (Viana *et al.,* 2015; Hassan *et al.,* 2015) but these methods are constrained with poor scalability and low efficiency resulting in yields of about 5–30% while eco-friendly pilot-scale dye extraction machine can achieve yields of 25–60%, representing an improvement of about 50% over the conventional techniques.

The fabrication of a multifunctional pilot scale dye extraction machine represents a critical step in bridging the gap between laboratory research and industrial application. While natural dye extraction has been widely studied at the bench scale, its broader adoption has been hindered by the lack of standardized, scalable, and cost-effective extraction technologies (Muthu, 2018). A pilot machine capable of operating at optimum temperatures addresses these challenges by providing a functional prototype that can validate optimized laboratory protocols under semi-industrial conditions, enhance both the quality and yield of dye extracts significantly, while simultaneously addressing environmental concerns and promoting sustainable development. Additionally, stabilization technology such as mordant applications are equally being explored to address colour stability and fastness issues (Sarkar, 2019).

The present research is aimed at designing and developing a new machine that will enable scalability, standardization, and cost reduction in dye production. This will require fabricating an efficient system that will process 30–40 kg of biomass per day thus enabling enough extract for pilot-scale textile trials, cosmetic formulations, or food applications, thereby facilitating technology transfer and commercialization pathways and bridging the gap between laboratory research and industrial application.

STATEMENT OF NEEDS

The global demand for sustainable and eco-friendly alternatives to synthetic dyes has grown significantly due to rising concerns over environmental pollution, human health hazards, and the depletion of non-renewable resources. Conventional synthetic dyes used in textiles, food, cosmetics, and other industries contribute to water contamination, ecological imbalance, and long-term toxic effects. In contrast, natural plant-based dyes offer biodegradable, non-toxic, and renewable options, yet their large-scale utilization remains limited due to gaps in standardized extraction methods, value addition, and technology transfer.

There is a critical need to systematically investigate locally available dye-yielding plants, optimize extraction and stabilization techniques, and develop innovative approaches for value addition, such as improving colour fastness, functional properties, and compatibility with diverse substrates. Furthermore, bridging the gap between laboratory research and practical application requires the fabrication of scalable processes and the establishment of technology transfer mechanisms that can facilitate adoption by industries, small-scale enterprises, and rural communities.

1.1 RESEARCH IDEA/INNOVATIONS

The research innovations will be the fabrication of multifunctional pilot plant machine for efficient dye extraction from natural sources. Moving from laboratory scale extractions to pilot-scale fabrication of standardized dye products ensures practical applicability. Thus, the project innovates by designing protocols and fabrication processes that can be readily transferred to small industries, cooperatives, or rural entrepreneurs.

1.2 PROJECT JUSTIFICATIONS

The project is justified on the adoption of natural dyes which reduces dependency on petrochemical-based synthetic dyes, thereby minimizing environmental pollution, chemical hazards, and ecological imbalances. The systematic exploration and optimization of plant-based dye extraction, stabilization, and value addition will contribute new knowledge to the fields of green chemistry and sustainable manufacturing.

Also, technology transfer of optimized dye extraction and processing methods can benefit local industries, small-scale entrepreneurs, and rural communities by creating employment opportunities and generating income. By developing reproducible, scalable, and application-oriented fabrication processes, the project directly addresses the practical barriers preventing natural dyes from competing with synthetic dyes in quality and functionality.

1.3 PROJECT GOAL & OBJECTIVES

1.3.1 Goal

The goal of this study is to design, fabricate and evaluate a pilot-scale natural dye extraction machine that enhances yield, efficiency, and sustainability. This goal would be achieved through the following objectives.

1.3.2 Objectives

The objectives are:

i. To develop optimized design parameters for a dye extraction machine, using engineering principles and material selection criteria suitable for natural dye processing
ii. To fabricate a pilot-scale machine capable of processing plant biomass at higher throughput with eco-friendly operation
iii. To evaluate the performance of the machine, focusing on throughput capacity, extraction efficiency, energy consumption, and dye yield
iv. To compare extraction outcomes (yield, purity, spectral performance) from the fabricated machine with conventional extraction techniques
v. To assess the sustainability and techno-economic viability of the fabricated machine for technology transfer to SMEs and local industries

2.0 TECHNOLOGY READINESS LEVEL (TRL)

Based on the current progress of the project, the research can be situated at Technology Readiness Level (TRL) 4**.** The literature review has been completed, and laboratory-scale experiments have been successfully conducted to establish proof-of-concept for natural dye extraction and value addition. These results demonstrate feasibility and provide validated data under controlled conditions, consistent with TRL 4 definitions. However, the fabrication of the pilot-scale machine and demonstration of the integrated process in a relevant environment are yet to be achieved. Upon completion of the machine design, fabrication, and prototype testing, the project will advance to TRL 5–6, thereby bridging the gap between laboratory validation and scalable technology transfer.

3.0 METHODOLOGY/TECHNICAL APPROACH

3.1. Machine Design

Based on laboratory-scale optimization results, the component parts of a dye extraction machine will be designed. Standard design equations and engineering principles will be applied to determine critical parameters such as vessel capacity, wall thickness, heating requirements, and agitation needs. The design outputs will guide the selection of suitable construction materials**.** Mild steel will be used as the primary fabrication material due to its adequate strength, rigidity, machinability, availability, and cost-effectiveness, all of which meet the design specifications.

3.2. Fabrication Process

Fabrication of the machine will follow established workshop procedures. The main processes will include measurement, marking out, cutting, drilling, welding, fastening, grinding, and painting. Assembly of the machine components will be achieved primarily through electric arc welding, selected for its advantages of high heat concentration, reduced heat spread (to minimize buckling and warping), increased penetration depth, and faster welding operation. All machine parts will be securely joined to ensure rigidity, stability, and structural integrity.

3.3. Finishing and Quality Assurance

Post-fabrication finishing will involve grinding of welded joints to smoothen surfaces and ensure safety, followed by painting with emulsion paint to provide corrosion resistance and aesthetic appeal. The assembled machine will undergo quality checks to verify dimensional accuracy, rigidity of joints, and conformance with the design specifications before proceeding to prototype testing and validation.

4.0 EXPECTED OUTPUTS AND METHOD OF DISSEMINATION

The expected outcomes from the project will be;

- Pilot-scale machine prototype for dye extraction and processing
- Technology transfer package (technical know-how, SOPs, training manuals, and demonstration kits) for SMEs, cooperatives, and local industries.
- Potential commercial-ready dye products for food/cosmetics/paper/pharmaceutical, etc. that can enter the market.
- Income generation opportunities for rural communities through cultivation/collection of dye-yielding plants and small-scale processing
- Capacity building like scientific publications (e.g. Book of proceedings, Journals), intellectual properties (patents, trademarks)

Dissemination Strategies

The dissemination strategies to be employed would include;

Academic and Scientific Channels

1. **Peer-Reviewed Journals**: Publishing detailed research findings in high-impact journals
2. **Conferences and Symposia:** Presenting at national and international conferences to engage with the scientific community and gather feedback.
3. **Workshops and Seminars:** Organizing and/or participating in workshops and seminars focused on dye extraction from natural sources and sustainable materials.

Digital Platforms

1. **ResearchGate and Academia.edu:** Sharing publications, datasets, and project updates on academic networking sites.
2. **Social Media**: Using platforms such as LinkedIn, Twitter, and Facebook to share key findings, project milestones, and impact stories with a broader audience.
3. **Webinars**: Hosting webinars to present findings and discuss implications with stakeholders and interested parties.

Industry Engagement

1. **Collaborations with Industry**: Partnering with relevant industries to implement findings and demonstrate the practical applications of our research.
2. **Trade Shows and Expos**: Participating in industry-specific trade shows and expos to showcase our products and engage with potential commercial partners.

Educational Outreach

1. **Public Lectures and Community Events**: Holding/hosting public lectures and participate in community events to educate the public about the benefits of natural dyes
2. **Educational Materials**: Creating brochures, fact sheets, and videos to explain the research in an accessible way and distributing them through schools, universities, research institutes and community centres.
3. **Engage with Schools and Universities**: Offering guest lectures, workshops, and research opportunities to students to inspire the next generation of scientists.

Government and Policy

1. **Policy Briefs**: Developing policy briefs that highlight the research's implications for environmental regulations and sustainable practices, and distributing them to policymakers.
2. **Government Reports**: Contributing findings to government reports on natural dye extraction and sustainable practices.
3. **Consultations and Advisory Roles**: Participating in advisory panels or consultations with government agencies to influence policy development.

Media Outreach

1. **Press Releases**: Issuing press releases to media outlets to announce major milestones and findings.
2. **Interviews and Features**: Engaging with journalists for interviews and feature articles in newspapers, magazines, and online publications.
3. **Documentaries and TV Programs**: Collaborating with media producers to create documentaries or TV segments about our research and its impact.

5.0 EXPECTED IMPACT

The project is expected to have the following impact;

- ❖ stimulate local industries, promote small-scale entrepreneurship, and enhance economic resilience while fostering greener production practices
- ❖ enhance research in green chemistry, material science, and sustainable manufacturing, thus, positioning natural dyes as viable substitutes for synthetic counterparts
- ❖ contribute to environmental protection, improved ecosystem health, and compliance with global green manufacturing standards
- ❖ build technical capacity, strengthen knowledge systems, and empower communities with sustainable livelihood opportunities, while contributing to academic excellence and innovation
- ❖ Reduction in capital flight arising from importation

6.0 PROJECT TEAM AND SPECIALISATION

Table 1: Research team and their specialization

S/N	Team members	Specialization
1.	Dr. Kabiru Mu'azu	Chemical Engineering
2.	Dr. Zaharadeen Sani Gano	Process Engineering
3.	Dr. Zwahruddeen M. Salisu	Fibre Science & Polymer Technology

4.	Engr. Shittu M. Umar	Chemical Engineering/Textile Technology
5.	Dr. Ukanah Suleiman Pendo **(PI)**	Colour Chemistry and Technology
6.	Dr. Etukessien S. Akpan	Production Engineering
7.	Engr. Otsai Joseph	Mechanical Engineering
8.	Prof. A. Giwa	Colour Chemistry and Technology/Env. Chemistry

6.1 TRACK RECORD AND DEMONSTRATION OF EXPERTISE

The proposed project will be executed by a multidisciplinary team of experts with complementary expertise across chemical engineering, process engineering, fibre science and polymer technology, colour chemistry and technology, production engineering and mechanical engineering. The track record of each member of the team in previous works collectively demonstrates strong capacity to deliver on the design, fabrication, and validation of a pilot-scale natural dye extraction machine for technology transfer.

Dr. Kabriu Mu'azu is an expert in chemical engineering with verse experience in Design of process equipment and process plants, Kinetic modelling and simulation of chemical processes, Unit operations of process equipment etc. With demonstrated expertise and publications in; Design and Fabrication of Forced-Convection Vegetable Drying system, Kinetic Modeling and Optimization of Biodiesel Production using Jatropha oil, Extraction and process optimization of essential oil from leafy part of plant material provides a solid foundation for optimizing dye extraction protocols, solvent recovery, and scale-up.

Dr. Zaharadeen Sani Gano is a process engineer with verse experience and expertise in process design, optimization, and techno-economic evaluation of pilot plants. His extensive research on pyrolysis technology which requires biomass valorization, waste-to-wealth conversion, and process simulation, would no doubt ensure rigorous process modeling, throughput analysis, and efficient benchmarking for the dye extraction machine.

Dr. Zwahruddeen M. Salisu is a specialist in Fibre Science and Polymer Technology with verse experience in fiber modification, natural dye–fiber interactions, polymer surface chemistry, and environmental remediation. With demonstrated expertise and published research in eco-friendly textile, his expertise will support dye–substrate compatibility testing, fastness improvement and value addition of natural dyes for various applications.

Engr. Shittu M. Umar is a Textile Professional and a Chemical Engineer, bringing an interdisciplinary expertise to the project. His background in fibre science and fabric finishing will provide practical insight into the compatibility of natural dyes with various substrates and end-user performance evaluation while his training in chemical engineering equips him with strong skills in process design, separation techniques, reaction engineering, and solvent recovery**,** which are essential for developing and optimizing extraction protocols.

Dr. Ukanah Suleiman Pendo who serves as the principal investigator (PI) of this project is an expert in dyes and intermediate synthesis and extraction from both synthetic and natural resources. With his specialization in Colour Chemistry and Technology, he is highly skilled in spectrophotometry, dye formulation, and colour performance testing. He has carried out extensive research on both synthetic and natural dyes, resulting in several publications. His knowledge will be pivotal in ensuring a comprehensive and reliable evaluation of the spectral performance database to be generated from this project.

Dr. Etukessien S. Akpan is a Production engineer with expertise in machine design, materials selection and manufacturing optimization which is central to the development of pilot dye extraction machine, thus, ensuring a robust and safe extractor suitable for technology transfer.

Engr. Joseph Otsai is a Mechanical Engineer with expertise in Machine design and fabrication making him indispensable for this project. As a fabricator, he has hands-on experience in cutting, welding, machining, assembly and finishing techniques, thus, ensuring transformation of engineering designs into a functional prototype.

Prof A. Giwa is a specialist in both Colour Chemistry and Environmental Chemistry. His interdisciplinary competence is critical to the success of this project. While his background in colour chemistry provides expertise in shade matching, performance evaluation, spectrophotometry and dye formulation, thus enabling robust assessment of natural dye quality and reproducibility, his knowledge of Environmental Chemistry will aid the evaluation of the toxicological impact, biodegradability and life cycle assessment of natural dyes and extraction processes. This dual specialization ensures that the project outcomes are not only technically sound and commercially viable but also environmentally sustainable, which aligns with global green chemistry and circular economy goals.

Finally, the team has demonstrated capacity on technology transfer through knowledge dissemination and community engagement from previous assignments like organized workshops and conferences. Also, the host Institution (National Research Institute for Chemical Technology, NARICT) is well equipped with analytical laboratories, materials testing facilities and fabrication workshops for pilot-scale equipment development.

Some publications from the extracted natural dyes

Ukanah P.S.[1*], Gadimoh S.[2], Salizu Z.M.[1], Suleiman M.A.[1], Sulaiman I.A.[1], Chibuzo-Anako N.C.[1], Umar I.S.[1], Lawal O.M.[1] and Oddy-Obi I.C.[1] (2020). Influence of selected Mordants and Mordanting techniques on eco-friendly dyeing of cellulosic fabric using natural flavonoid dye extracted from onion outer scale, *Nigerian Journal of Textile, **6(1)**, Pp. 9-14.*

Ukanah P.S., Barminas J.T., Shittu U.M., Salisu Z.M., Omar A.U., Ukpong K.M., Umar I.S., Lawal O.M., Oddy-Obi I.C., Suleiman M.A., Suleiman I.A., and Chibuzo-Anakor N.C. (2019). Effect of pH and base-type in the Extraction of Indigo dye from Indigofera arecta leaves. Conference Proceedings of Textile Researchers Association of Nigeria (TRAN), pp. 216-219, 2019.

Ukanah P.S., Salisu Z.M., Barminas J.T. Gero M., Chibuzo-Anakor N.C., Daniel D. and Umar I.S. (2022). Extraction and application of natural dye from tumeric rhizoms on cotton fabrics. A paper presented at the 9th International Conference of Textile Researchers Association of Nigeria (TRAN) held at the Auditorium, Raw Materials Research and Development Council, Abuja, on the 22nd – 25th November, 2022.

Gero M., Salisu Z.M., Ukanah P.S., Barminas J.T. Chibuzo-Anakor N.C., Daniel D. and Umar I.S. (2022). Valorization of natural dye extracted from henna leaves (*lawsonia inermis*) for application on cotton fabrics. A paper presented at the 9th International Conference of Textile Researchers Association of Nigeria (TRAN) held at the Auditorium, Raw Materials Research and Development Council, Abuja, on the 22nd – 25th November, 2022.

7.0 SUSTAINABILITY AND COMMERCIALIZATION PLAN

7.1 Sustainability strategy

The sustainability strategy can be grouped in three ways as shown below;

a) Technical Sustainability

- ❖ A standard operating procedures (SOPs) for dye extraction, formulation, and machine operation will be developed to ensure reproducibility and continuity.
- ❖ It will be ensured that Pilot-scale machine is built with durable, locally available materials for ease of maintenance and low operating costs.
- ❖ A Quality Assessment and Quality Control framework will be ensured for consistent product quality, aligned with ISO standards for textile dyes.

b) Environmental Sustainability

- ❖ Waste minimization through the use of eco-friendly solvents and processes with solvent recovery systems.
- ❖ Dye-yielding plants will be sourced through sustainable harvesting or community-based cultivation, thus, reducing pressure on wild biodiversity.

c) Institutional Sustainability

- ❖ The outputs of the project such as (Standard Operating Procedure, machine prototype, training materials) will be integrated into NARICT research programs.
- ❖ Research–industry partnerships will be established for long-term collaboration and continuous improvement of the technology.

7.2 Commercialization Plan

The commercialization of the technology is expected to proceed in different phases as highlighted below:

Phase 1:

Technology Readiness Advancement: The research will proceed from TRL 3–4 (lab validation) where it is currently to TR L 5–6 (pilot demonstration) through machine fabrication and pilot-scale testing. At the completion of the pilot demonstration stage, demonstration runs will be carried out with small and medium scale enterprises, cooperatives, and textile industries to validate performance in real-world settings.

Phase II

Market Entry Strategy: Priority market segment like textile industries (eco-friendly fabrics), artisans/handloom sector, eco-conscious fashion brands, paper/packaging, cosmetics, and food-grade colorants and pharmaceutical industries will be identified. Thereafter, product prototypes like (standardized dye powders, pastes, or concentrates) for will be develop for sampling and feedback. Certifications processes (eco-labels, toxicity-free compliance) will be initiated to enhance market credibility.

Phase III

License of the extraction process and machine design to SMEs and cooperatives will be carried out. The rural community will also be trained through workshops to operate small-scale extraction units with a means of linking them to industrial buyers.

Phase IV

Protection of intellectual property and branding will be carried out by filling for patents and developing sustainable-focused brand identity to differentiate other product in the market

8.0 TIMEPLAN

GANTT CHART (TIMELINES OF ACTIVITIES)

S/N	Number of Months / Description of Activity	2	4	6	8	10	12	15	18
1	Detailed literature review on machine design								
2	Development of conceptual design using sketch and block diagrams								
3	Procurement of raw materials and mechanical components								
4	Fabrication of machine components, assembly of frame and installation of heating units								
5	Prototype assembly and testing; and optimization of process parameters (temperature, time and solvent ratio)								
6	Validation and evaluation of throughput capacity, efficiency, yield and compare machine performance with conventional methods								
7	Plan technology transfer strategies								
8	Patenting/Publication								
9	Complete Reports compilation								

9.0 MONITORING AND EVALUATION

Monitoring

Monitoring and evaluation will be carried out using a results-based management (RBM) approach**,** aligning inputs, activities, outputs, outcomes, and impacts. The project will establish Key Performance Indicators (KPIs) at each stage and employ periodic reviews to track progress toward set objectives.

The routine monitoring activities will include;

- Quarterly Progress Reports covering laboratory experiments, data analysis, fabrication progress, and technology transfer activities.
- Milestone Tracking against the Gantt chart (e.g. extraction, purification and analysis of dyes, optimization, prototype machine fabrication, pilot demonstration etc.).
- Financial Monitoring to ensure funds are spent according to budget.
- Quality Monitoring through laboratory records, pilot trial logs, and quality assessment/quality control reports.

Evaluation

1. **Mid-term Evaluation**:
   - **Timing**: After 9 months
   - **Focus**: Assess progress towards objectives, initial outcomes, and resource utilization.
   - **Method**: Internal review and external peer review
   - **Output**: Mid-term evaluation report with recommendations

2. **Final Evaluation**:
   - **Timing**: At project completion (18 months)
   - **Focus**: Evaluate the achievement of objectives, overall impact, and lessons learned.
   - **Method**: Comprehensive review by internal and external experts
   - **Output**: Final evaluation report, including detailed analysis and future recommendations

9.1 Key Performance Indicators (KPIs)

The Key Performance Indicators would include;

- Two optimized extraction SOPs, reproducibility levels, number of value-added formulations developed.
- Pilot machine fabricated and validated, dye yield per kg dye yielding plant, extraction efficiency, etc.
- Number of SMEs/cooperatives trained, demonstration workshops conducted, technology transfer packages prepared.
- Jobs created, communities engaged, income opportunities generated.
- Publications, patents, training modules, stakeholder reports

9.2 Risk Management Plan

The expected risks are categorized in different strata as shown below;

Scientific and Technical Risks

- **Risk:** Variability in dye yield and quality due to plant species, seasonality, or growing conditions.

  Mitigation: Different dye yielding plants will be selected; standardize collection protocols adopted and chemical database for quality benchmarking will be employed
- **Risk:** Laboratory results may not scale directly to pilot level.

  Mitigation: A stepwise scale-up strategy (bench → pilot trials) will be adopted; while process modeling and Design of Experiments (DoE) will be used to predict performance.
- **Risk:** Low colourfastness or instability of natural dyes compared to synthetic alternatives.
  - **Mitigation:** Research value addition techniques (e.g. eco-friendly mordant) will be used and accelerated stability testing will be conducted early.

Fabrication and Engineering Risks

- **Risk:** Delays in design and fabrication of the pilot machine.

  Mitigation: Detailed engineering drawings and specifications will be developed as early as possible; experienced fabricators will be collaborated with and milestone-based progress checks will be put in place.

- ❖ **Risk:** Technical failures in machine operation (e.g., leakage, inefficiency, safety hazards).
  Mitigation: Thorough prototype testing (e.g. Factory Acceptance Test/Site Acceptance Test) will be conducted and safety features like (sensors, interlocks) will be integrated.

Economic and Commercial Risks

- ❖ **Risk:** Higher cost of natural dyes compared to synthetic dyes limiting industry adoption.
  Mitigation: Techno-economic assessment (TEA) will be conducted; process optimization for efficiency carried out and niche eco-friendly markets like (organic textiles, sustainable fashion) will be targeted
- ❖ **Risk:** Limited awareness or acceptance among industry and end-users.
  Mitigation: Demonstration workshops, awareness campaigns, and partnerships with eco-conscious textile brands will be conducted.

10.0 BUGDET

The estimated budget for the project is Sixty Million Naira Only **(# 60,000,000.00)**

Table 1: Estimated budget for the fabrication of pilot-scale dye extraction machine

S/No.	Items	Cost (Naira)
1	**Design, Fabrication & Materials** • Engineering design software & simulations • Procurement of raw materials (mild steel, stainless steel, insulation, fittings, electrical components) • Fabrication (machining, welding, assembly) • Surface finishing & safety installations	35,000,000.00
2	**Testing, Validation & Quality Assurance** • Pilot extraction trials (biomass supply, solvents, utilities • Performance testing	5,000,000.00
3	**Dissemination & Technology Transfer** • Workshops, stakeholder engagement (SMEs, textile cooperatives) • Documentations (manuals, safety guidelines) • Journal publications and conference presentations	10,000,000.00
4	**Logistics and personnel** • Administrative overhead (Institutional support) • Contingency for unforeseen expenditures • Principal investigator and Co-investigators	10,000,000.00
Total		**60,000,000.00**

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