DEVELOPMENT AND COMMERCIALISATION OF HERBICIDES AND PESTICIDES FROM PYROLYTIC OIL

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1. Executive Summary

The development and commercialisation of herbicides and pesticides derived from pyrolytic oil present a novel, sustainable pathway for agricultural innovation. Pyrolytic oil, obtained from the thermal decomposition of biomass, contains bioactive compounds such as phenols, organic acids, and ketones with demonstrated insecticidal, herbicidal, and antifungal properties. These components can be harnessed to create bio-based formulations that offer environmentally friendly alternatives to conventional synthetic agrochemicals.

The proposed project focuses on optimising pyrolysis conditions and feedstock selection to produce oil rich in active fractions, followed by fractionation and characterization using GC-MS and LC-MS techniques. Laboratory bioassays and field trials will evaluate efficacy against selected weeds and crop pests, as well as safety for non-target organisms. Formulation development will aim at producing stable, effective products suitable for smallholder and industrial agricultural applications.

Regulatory compliance will be pursued through engagement with NAFDAC in Nigeria to meet pesticide registration requirements, while exploring low-risk or organic product classifications. Commercialisation will target markets seeking eco-friendly pest management solutions, leveraging locally available biomass to reduce production costs and enhance circular economy benefits.

This initiative supports national and global sustainability goals by converting agricultural waste into value-added agrochemicals, reducing chemical residues in the environment, and promoting safer crop protection options. With strategic partnerships among universities, regulatory bodies, and agrochemical distributors, the project could achieve pilot-scale validation within three years and reach market readiness within five. The expected outcome is a competitive, bio-based pesticide and herbicide line that enhances agricultural productivity while protecting environmental and human health.

2. Introduction & Background

2.1 Context of the Research

Agriculture contributes over 20% to Nigeria's GDP and employs more than 60% of the population. However, pest and weed management relies heavily on imported synthetic chemicals, many of which are toxic and environmentally persistent. Pyrolytic oil, derived from agricultural waste, offers a promising alternative due to its bioactive compounds.

2.2 Statement of the Problem

Nigeria faces two interrelated challenges threatening both environmental sustainability and agricultural productivity: waste accumulation and dependence on imported agrochemicals. Each year, millions of tonnes of agricultural residues, municipal solid waste, and plastics are either openly burned or left to decay, leading to severe environmental pollution, greenhouse gas emissions, and public health risks. At the same time, the nation spends billions of naira annually importing synthetic herbicides and pesticides, many of which are toxic, environmentally persistent, and increasingly ineffective due to pest resistance.

This dependence on imported, chemical-based agro-inputs undermines Nigeria's drive toward self-reliance, local content development, and sustainable agricultural transformation. Moreover, the growing concern over the carcinogenic and endocrine-disrupting effects of conventional pesticides has created an urgent need for safer, bio-based alternatives.

Recent advances in pyrolysis technology demonstrate that bio-oil derived from agricultural and plastic waste contains bioactive compounds phenols, ketones, and organic acids that exhibit herbicidal, pesticidal, and antimicrobial properties. However, in Nigeria, there is limited research or industrial effort aimed at converting locally generated waste into such eco-friendly agrochemicals.

The lack of coordinated research, pilot-scale development, and commercialization pathways for pyrolytic-oil-based herbicides and pesticides represents a missed opportunity for innovation-led industrial growth. Addressing this gap will not only reduce environmental pollution but also enable Nigeria to produce affordable, safe, and sustainable agrochemicals, thereby strengthening food security and promoting green industrialisation in line with NASENI's mandate.

2.3 Rationale of the Study

The development and commercialisation of herbicides and pesticides from pyrolytic oil are justified by Nigeria's urgent need for sustainable agricultural inputs and waste-to-wealth innovation. The project directly addresses the twin challenges of environmental pollution from unmanaged agricultural and plastic waste, and overdependence on imported chemical agro-inputs. By transforming local waste into bioactive agrochemicals, the project supports circular economy principles, enhances local content development, and reduces foreign exchange outflow.

Furthermore, the initiative aligns with NASENI's mandate to promote indigenous science, technology, and engineering solutions for national industrial growth. It also contributes to national policies on green innovation, bioeconomy, and sustainable agriculture, while fostering technology transfer, youth employment, and rural enterprise development. Through laboratory research, pilot production, and commercialization, this project will establish Nigeria as a regional leader in eco-friendly agrochemical technology, supporting both food security and environmental sustainability.

2.4 Justification in the Nigerian Context

Nigeria imports more than 80 % of its agrochemicals, leading to foreign exchange loss and exposure to toxic residues (Bello et al., 2024). At the same time, the country faces severe challenges in waste management and environmental degradation from plastic and agricultural residues. Developing herbicides and pesticides from pyrolytic oil therefore addresses two national priorities: promoting sustainable agriculture and solving waste disposal problems. The approach aligns with Nigeria's National Science, Technology, and Innovation Policy and NASENI's mandate to foster indigenous technology, industrial growth, and local content development. Moreover, the tropical biodiversity and high biomass availability in Nigeria provide a rich foundation for scalable feedstock sourcing. This research will build local capacity for green chemical engineering, bio-product innovation, and agro-industrial diversification, supporting the Federal Government's Renewed Hope Agenda on industrialisation and food security.

In conclusion, the conversion of pyrolytic oil into herbicidal and pesticidal formulations represents a feasible and environmentally sound strategy to enhance Nigeria's agricultural productivity while reducing dependence on imports. The existing scientific evidence provides a foundation, but local research is needed to tailor the process to Nigerian feedstocks, ecological conditions, and industrial infrastructure.

3.0 Literature Review

The use of pyrolytic oil-derived from the thermal decomposition of organic and plastic wastes- as a raw material for agricultural bioproducts is an emerging field with strong potential for sustainable pest and weed management. Pyrolysis converts agricultural residues, wood biomass, and municipal plastics into bio-oil, biochar, and gas under oxygen-deficient conditions (Elshareef et al., 2025). The resulting bio-oil is a complex mixture of phenols, furans, aldehydes, ketones, and organic acids that possess pesticidal, fungicidal, and herbicidal properties (Bhushan et al., 2022). This technology thus provides a circular economy pathway that addresses two global challenges: waste management and the need for eco-friendly agrochemicals.

Studies have shown that the chemical composition of pyrolytic oil depends on feedstock type and operating conditions. Elshareef et al. (2025) demonstrated that cotton stalk pyrolysis at 500 °C produced bio-oil rich in phenolic compounds with antimicrobial activity. Similarly, Anaga, Oji, and Okwonna (2023) found that co-pyrolysis of rice husk and polyethylene plastic waste yielded higher-quality bio-oil with improved calorific value and chemical stability. These findings suggest that Nigeria's abundant biomass and plastic wastes can be exploited to produce bio-oil locally.

The bioactivity of pyrolytic oil has been extensively studied for insecticidal and fungicidal effects. Cáceres et al. (2014) reported that straw-derived bio-oil significantly inhibited larvae of the Colorado potato beetle, while Bhushan et al. (2022) found that pyrolysis oil from lignocellulosic biomass acted as an insect growth regulator, suppressing stored-product beetles by over 60%. El-Sayed et al. (2022) also demonstrated that pyrolysis products from Leucaena leucocephala wastes achieved over 90% mortality of Sitophilus oryzae after seven days. Farobie et al. (2022) observed that macroalgae-derived bio-oil exhibited herbicidal effects by inhibiting seed germination and root elongation. These findings confirm that bio-oils possess multiple pesticidal functions that could replace or supplement synthetic agrochemicals.

3.1 Gap in Knowledge and Technology

Despite promising results, several gaps remain in transforming pyrolytic oil into commercial agrochemical formulations. First, most existing studies are laboratory-scale and lack process optimisation for large-scale or pilot-scale production. The variability in bio-oil composition from different feedstocks and pyrolysis parameters creates challenges in standardising formulation and stability (Bello et al., 2024). Secondly, comprehensive toxicological and environmental impact assessments of pyrolytic-oil-based products are limited, particularly in tropical ecosystems. Thirdly, there is little documentation on herbicidal efficacy under field conditions in sub-Saharan Africa, where weed species and climatic conditions differ significantly from temperate regions. Finally, there is a lack of local patents, pilot plants, and industrial partnerships that would support commercialisation and technology transfer in Nigeria.

4.0 Research Objectives

4.1 General Objective

To develop, optimise, and commercialise eco-friendly herbicides and pesticides derived from pyrolytic oil produced from agricultural and plastic waste in Nigeria, to promote sustainable agriculture, environmental protection, and industrial innovation.

4.2 Specific Objectives

1. To produce and characterise pyrolytic oil from selected agricultural residues and plastic wastes under varying process conditions.
2. To identify and isolate bioactive compounds in the pyrolytic oil with herbicidal and pesticidal properties using modern analytical techniques (GC-MS, FTIR, HPLC).
3. To formulate and test prototype bio-herbicides and bio-pesticides under laboratory and greenhouse conditions for efficacy and safety.
4. To conduct toxicological and environmental impact assessments to ensure product safety for humans, soil, and beneficial organisms.
5. To design and establish a pilot-scale production unit for continuous pyrolysis and bio-oil-based agrochemical formulation.
6. To develop a commercialisation framework including patents, partnerships with local industries, and market feasibility studies for large-scale production and distribution.
7. To build national capacity through training of researchers, technicians, and agrochemical entrepreneurs in bio-based product development.

5.0 Research Questions and Hypotheses

1. What are the optimal pyrolysis conditions (temperature, feedstock type, residence time) for producing bio-oil with the highest concentration of bioactive compounds?
2. Which compounds in the pyrolytic oil exhibit significant herbicidal and pesticidal effects?
3. Can bio-oil-derived formulations effectively control common weeds and pests compared to conventional agrochemicals?
4. What are the potential toxicological and ecological effects of these bio-based products on crops, soils, and non-target organisms?
5. How can pilot-scale production and commercialization be achieved cost-effectively within Nigeria's agro-industrial context?

5.1 Hypotheses

1. H_1: Pyrolytic oil produced from selected agricultural and plastic wastes contains bioactive compounds with herbicidal and pesticidal properties comparable to synthetic agrochemicals.
2. H_2: Optimised pyrolysis conditions significantly improve the concentration and efficacy of bioactive compounds in the oil.
3. H_3: Bio-oil-derived herbicides and pesticides are environmentally safer and more sustainable than conventional chemical formulations.
4. H_4: Establishing pilot-scale production and commercialization is technically and economically feasible within Nigeria's industrial ecosystem.

6.0 Methodology

6.1 Research Design

Experimental design combining lab analysis, formulation trials, and field testing.

6.2 Materials and Methods

- Biomass feedstock: cassava peels, rice husks, coconut shells, Doum palm shell, etc.
- Pyrolysis unit for oil extraction
- GC-MS for compound analysis
- Formulation lab for emulsions and suspensions

6.3 Instruments/Technologies

- Pyrolysis reactor
- Analytical tools (GC-MS, HPLC)
- Spraying equipment for field trials

6.4 Research Plan

The research plan for production and commercialisation of biopesticides and bioherbicides from pyrolytic oil is presented in Figure 1.

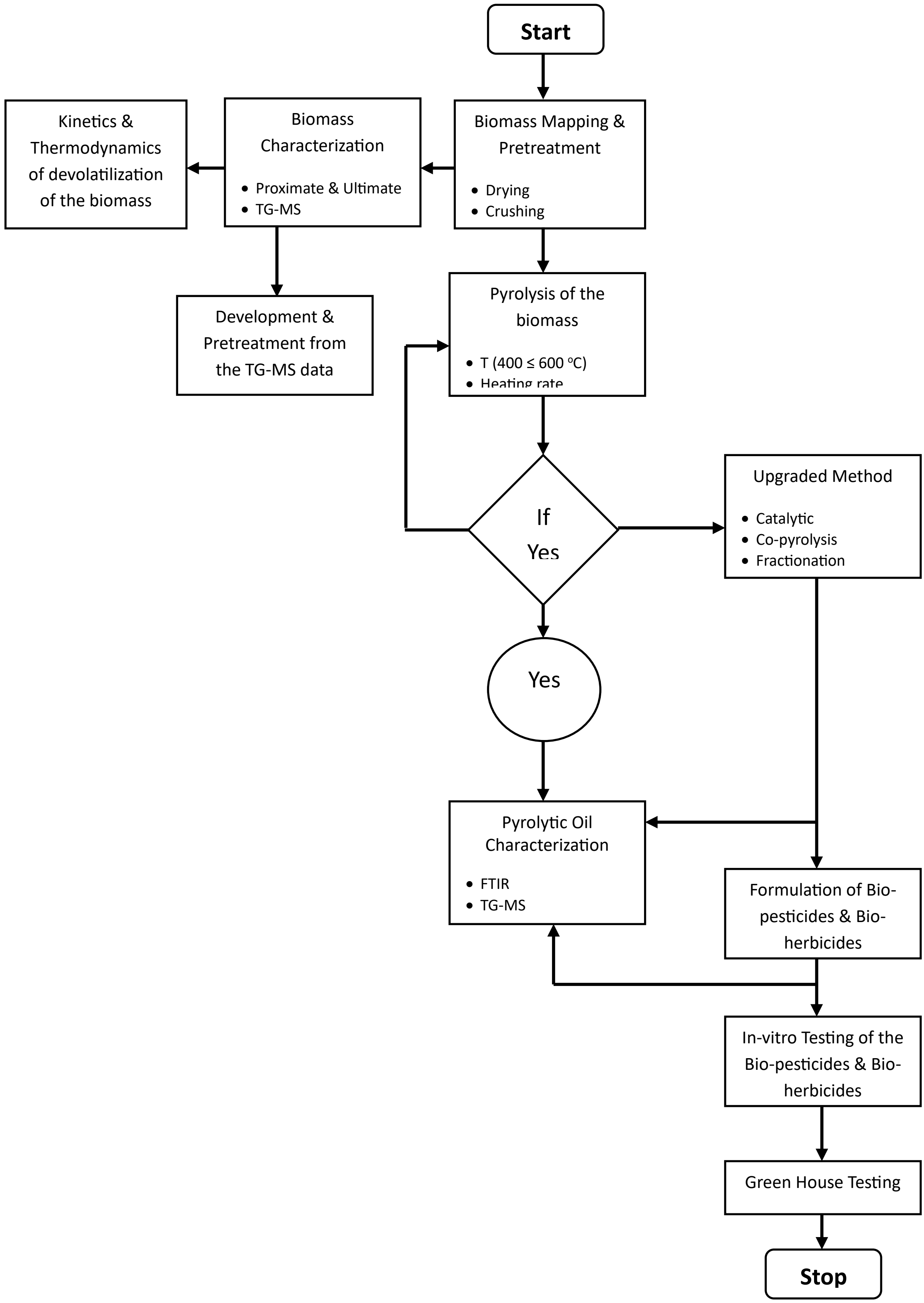

Figure 1: Research plan for biopesticides and bioherbicides production from Agro-wastes

6.4.1 Biomass Mapping, Collection and Characterization

A geospatial analysis will be conducted using Geographic Information Systems (GIS) to identify and map the most abundant and readily available agricultural and forestry residues in Nigeria's six geopolitical zones. This analysis will leverage existing data on crop production, agricultural land use, and biomass waste generation. The identified biomass will be collected and characterized. The biomass will be subjected to proximate, ultimate and lignocellulosic analysis.

6.4.2 Biomass Pyrolysis and Pyrolytic Oil Characterization

A laboratory-scale fast pyrolysis reactor will be used to convert the prepared biomass samples into pyrolytic oil. The pyrolysis will be conducted under controlled conditions and atmosphere to ensure a high yield of liquid product. The chemical composition of the pyrolytic oil will be analyzed using advanced analytical techniques, such as Gas Chromatography-Mass Spectrometry (GC-MS) to identify and quantify the individual organic compounds present in the oil. Fourier-Transform Infrared (FTIR) Spectroscopy will be used to identify the functional groups present in the oil.

6.4.3 Development of Predictive Model for Pyrolytic Oil Yield and Composition

In put data such as proximate analysis (volatile matter, fixed carbon, ash content), ultimate analysis (C, H, N, O, S), and lignocellulosic composition (cellulose, hemicellulose, lignin) data will be collected along without put data such as pyrolytic oil yield and chemical composition from chromatographic analysis. The data will be cleaned and normalized. The study will explore various Machine Learning Models to capture complexity of non-linear relationships. The model's performance will be evaluated on the unseen testing set using metrics like the R-squared value (R2), to measure how well the model predicts the output, and the Root Mean Squared Error (RMSE), which quantifies the model's prediction error. The trained model will be analysed to understand the relationship between the input variables and the oil's composition. This analysis will guide the optimization process, identifying the ideal combination of feedstock and pyrolysis conditions to produce consistently high-quality oil for biopesticide and bioherbicide formulation.

6.4.4 Evaluation of Various Upgrading Techniques

Different pyrolytic oil upgrading techniques such as catalytic process, co-pyrolysis, solvent extraction, stage-wise pyrolysis and condensation will be implemented. The pyrolytic oil produced from each upgrading technique will be rigorously characterized elemental Analysis (CHNSO), Gas Chromatography-Mass Spectrometry (GC-MS) to identify and quantify the specific chemical compounds in the oil, such as phenols, furans, and hydrocarbons, Fourier-Transform Infrared (FTIR) Spectroscopy to identify functional groups present, particularly oxygen-containing groups. Viscosity and Density measure physical properties relevant to spray properties. A comparative analysis of the results from all five techniques will be performed.

The data will be used to identify the most effective and efficient upgrading technique for producing pyrolytic oil of the desired composition, considering factors such as cost and scalability.

6.4.5 Formulation of Pyrolytic Oil Base Pesticide and Herbicide

The process focuses on creating an emulsion concentrate (EC) or a suspo-emulsion (SE), which are common and effective delivery systems for pesticides and herbicides. The pyrolytic oil, surfactants, stabilizers, co-solvents, and diluents will be formulated and optimized. The formulated samples will be characterized to ascertain their properties.

6.4.6 Experiment to Determine the Efficacy of the Prepared Pesticide and Herbicide Samples

Laboratory experiments will be conducted to determine the bio-pesticide and herbicidal efficacy of pyrolytic oil-based herbicide and pesticide against some field and stored insects and pests of agricultural importance. The sample insects and pests will be reared, the pyrolytic oil-based pesticides formulated will be prepared at different concentration in distilled water containing a small amount of a wetting agent to ensure uniform coverage. Small leaf section from the host plant will be dipped into each of the biopesticides prepared for a set period. The reared pests will be transferred to each treated leaf. In addition, two control groups will be prepared: a negative control (untreated leaves) and a solvent control (leaves treated with only the wetting agent and water) to account for any effects of the solvent or handling. The pest oviposition and mortality rate will be monitored, and data will be collected at regular intervals. Probit analysis will be used to determine the lethal concentration (LC50) and lethal time (LT50), which are key indicators of efficacy. The treatments will be experimented at three different rates to assess its effects on plant growth and development. Data on growth and yield components will be recorded at two weeks intervals. Also, plant and soil samples will be obtained before and after the study to ascertain its effects on plant composition and physico-chemical properties, respectively of the soil. Data collected will be subjected to analysis of variance and treatment means will be separated using Least Significant Difference at 5% probability level.

6.4.7 Pilot Plant Design and Fabrication

The pilot plant for the manufacture of the most effective bio-herbicides and pesticides will be modeled and simulated using ASPEN Plus. The physical components will be designed, fabricated and assembled. The pilot plant will be tested, fine-tuned to produce the bioherbicides and biopesticides.

6.4.8 Commercialization Route

The economic viability of the entire project is a synergistic relationship between three products. The production of the primary product biopesticides and herbicides directly generates two high-value co-products (biochar and syngas). The syngas is used to power the facility, reducing operational costs, while the biochar provides a significant and high-margin revenue stream. This synergistic model makes the venture more resilient to market fluctuations and provides multiple pathways to profitability. A traditional analysis that only considers the agrochemicals would significantly underestimate the project's true financial potential.

6.4.9 Data Collection & Analysis

- Lab efficacy tests (insect mortality, weed suppression)
- Field trials across agro-ecological zones
- Statistical analysis using ANOVA and regression models

6.4.10 Project Work Plan

Milestone	*Timeline (Months)*
Biomass sourcing & pyrolysis	1–3
Oil characterization	4–5
Formulation development	6–8
Lab & field efficacy testing	9–12
Environmental & safety assessment	13–14
Commercial model development	15–16
Final reporting & dissemination	17–18

7.0 Expected Results & Deliverables

- Prototype bio-herbicide and bio-pesticide formulations.
- Validated production process for pyrolytic oil-based agrochemicals.
- Scientific publications and technical reports.
- Technology transfer package for local manufacturers.
- Capacity building for researchers and agrochemical producers.
- Patent applications for novel formulations.

8.0 Relevance to NASENI Mandate & National Development

8.1 Industrialisation & Local Content

- Promotes indigenous agrochemical production.
- Reduces reliance on imported toxic pesticides.

8.2 Technology Transfer

- Provides scalable models for SMEs and agrochemical firms.
- Encourages adoption of pyrolysis technology in agriculture.

8.3 Socio-Economic Growth

- Enhances farmer access to affordable, safe pest control.
- Creates jobs in biomass sourcing, processing, and distribution.

8.4 Potential Beneficiaries

- Government agencies (FMARD, NESREA).
- Private agrochemical firms.
- Farming communities.
- Research institutions.

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