Diversifying revenue in rural Africa through circular, sustainable and replicable biobased solutions and business models

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D4.1: Report on BIO4AFRICA trials and validation results: initial version

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°C	Celsius
CIRAD	Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement - C.I.R.A.D. Epic
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
D	Deliverable
DFF	Days to 50% Flowering
ENERGECO	Societe d'Economie d'Energie et d'Electro-Mecanique Energeco
EU	European Union
Fig.	Figure
FTIR	Fourier-Transform Infrared Spectroscopy
H	Hypothesis
H_2O	Water
H_2S	Hydrogen Sulphide
ha	Hectare
HPLC	High-Pressure Liquid Chromatography
HTC	Hydrothermal Carbonisation
IHE	Stichting IHE Delft Institute for Water Education
INP-HB	Institut National Polytechnique Felix Houphouet-Boigny
IPAR	Intercepted Photosynthetically Activate Radiation
kg	Kilogram
KRC	Kabarole Research and Resource Centre

L	Litre
LAI	Leaf Area Index
m	Metre
M	Month
MTU	Munster Technological University
n	Sample size
N_2	Nitrogen gas
NIR	Near Infra-Red
No.	Number
NTU	Nephelometric Turbidity Units
PHA	Polyhydroxyalkanoate
PM	Particulate matter
QPLAN	Q-PLAN INTERNATIONAL
RAGT	RAGT ENERGIE SAS
Stylo	*Stylosanthes guianensis*
t	Tonne
TRH	Hydraulic Retention Time
TRL	Technological Readiness Level
UASZ	University Assane Seck of Ziguinchor
µS/cm	MicroSiemens per centimetre
UV	Ultra-violet
WP	Work package

1. Executive Summary

This document details the planned pilot trials in four African countries, **Uganda, Ghana, Côte d'Ivoire, and Senegal,** of the European Union Horizon 2020-funded **BIO4AFRICA** project. The document describes the trial timelines and parameters to be examined, and preliminary results of trials initiated during the **initial trial reporting period (M18-23)**, where available. Three main categories of product are being piloted through a total of 22 different pilot trials: **animal feed** and **whey** from green biorefinery technology, **biochar** products from carbonisation technology, i.e. slow pyrolysis and hydrothermal carbonisation (HTC), and **pellets** and **briquettes** from densification technologies. These products have been adapted to local needs and contexts to develop specific use cases, e.g. with specific livestock, which are also examined in the pilot trials.

This deliverable builds on the knowledge generated through **WP1** and **WP2** of the BIO4AFRICA project, namely the identification and adaptation of small-scale, bio—based technologies that can add greater value to agri-food residues and other low-value bio-based materials. In large part, the pilot trials follow directly from the technology testing and piloting being carried out in **WP3** and outlined in **D3.1**. Accordingly, work on the pilot trials began in **M18** (November 2022), after completion of initial work in other work packages.

Four pilot trials were initiated during the initial trial reporting period, using locally available technologies and low-value agri-food residues to create novel, bio-based products. These include:

- In Ghana: soil amendment field trials with biochar.
- In Côte d'Ivoire: soil amendment greenhouse trials with biochar and sheep feeding trials with raw biomass pellets.
- In Senegal: solid fuel (cooking fuel) trials with biochar briquettes.

One of these trials was completed: sheep feeding trials in Côte d'Ivoire. The results indicate positive findings about the application of novel sheep feed pellets for both nutrition and intestinal parasite control. The initial results have been provided in this report (**section 6**), with final results to come in the **interim trial reporting period (M24-33**). The preliminary results indicate positive outcomes. Product production parameters, e.g. optimal feedstock combinations, have been identified through these trials, enabling products of consistent quality and associated application outcomes to be produced. The outcomes will support the realisation of circular bio-based business models.

The report also describes the next steps for the pilot trials in **WP4**. All remaining 18 pilot trials will begin during the **interim trial reporting period.** Some of the trials that have already begun using local technology will be replicated using products from new technologies, e.g. biochar from adapted Brazilian kiln technology. As far as possible, results about all trials taking place within the interim trial reporting period, will be included in **D4.3: Interim report on trials and results**. Final results for trials not reported on in full during the **interim trial reporting period** will be available during the **final trial reporting period**. These will be included in **D4.4: Final report on trials and results.**

2. Introduction

This document describes the pilot trial strategies and initial results of the four pilot cases of the BIO4AFRICA[1] project, in Uganda, Ghana, Côte d'Ivoire, Senegal and Kenya. The BIO4AFRICA project has the primary aim of supporting local bioeconomy development in rural African regions. The project, comprising Partners form five African countries (Uganda, Ghana, Côte d'Ivoire, Senegal, and Kenya) and six European countries (Denmark, France, Greece, Ireland, the Netherlands, and Spain), was initiated in June 2021 (**M1**), and has a duration of 48 months, finishing in May 2025 (**M48**).

2.1 BIO4AFRICA Project Strategy

BIO4AFRICA aims to support the bioeconomy in rural African regions through the development of circular, bio-based solutions and value chains to promote the cascading use of local resources and income diversification for agrarian communities. In order to achieve this, the project will support the implementation of small-scale, robust bio-based technologies with high replication potential and adapted to local needs, socio-economic and agri-environmental conditions, and biomass types. The technologies involved have been co-defined by the BIO4AFRICA partners (**WP1**) and adapted for local conditions, biomass types, and integrated in viable combinations (**WP2**), to support development of novel, bio-based business models (**D5.2: Inclusive and sustainable bio-based business models for rural Africa**). Three technologies in particular will be combined and transferred: small-scale green biorefineries, carbonisation, including slow pyrolysis and hydrothermal carbonisation (HTC), and densification technologies, e.g. briquetting and pelletizing. Bio-composite and bioplastic production will also be evaluated at laboratory-scale, while screening of bio-based products for further value addition opportunities will take place, e.g. high-value components of bio-based side-streams.

A total of four pilot cases in Uganda, Ghana, Côte d'Ivoire, and Senegal, with more than eight testing sites across the cases, will allow farmers and farmer groups to test these products in their local context. The use of novel biomass types in existing local technologies, e.g. local pyrolysis technology, and in the novel, adapted technologies, e.g. green biorefinery, will enable farmers to add value to local biomass and produce diverse bio-based products, including:

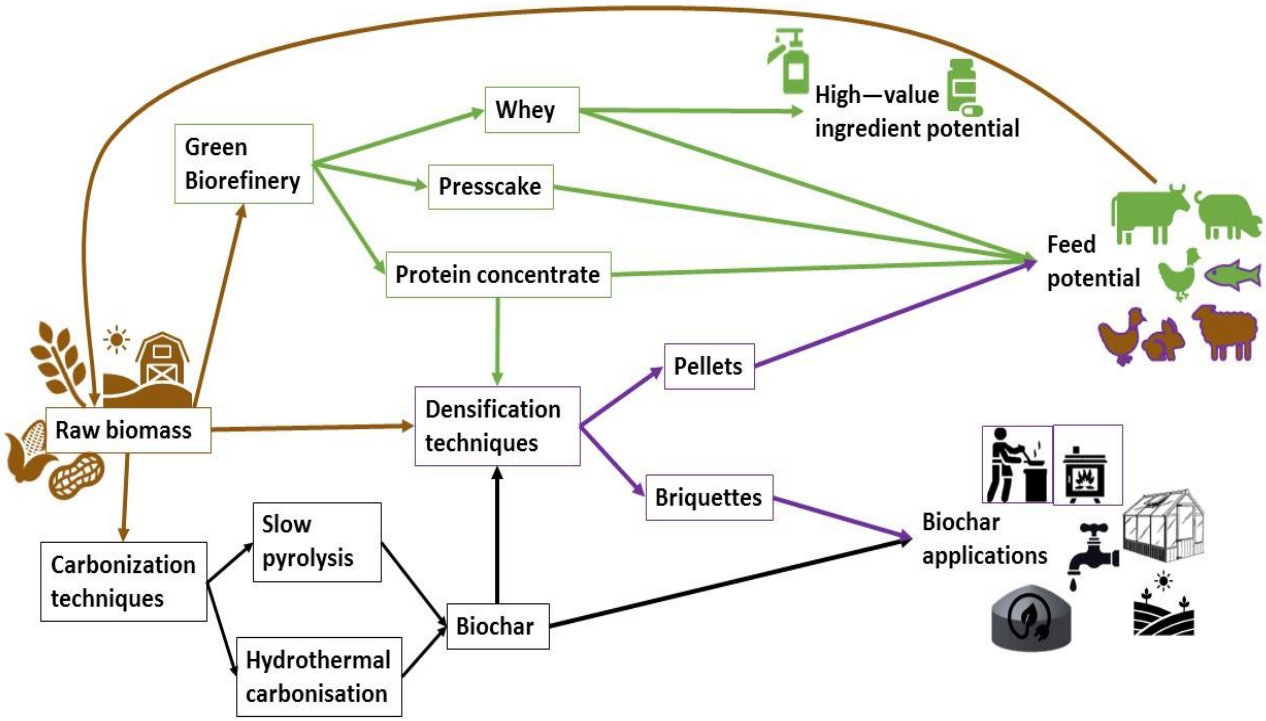
- biomass pellets as animal feed
- biochar as a soil amendment product
- biochar as a solid biofuel product
- biochar as an additive to enhance biogas production
- biochar powder for water filtration
- green biorefinery press cake as ruminant feeds (e.g., cattle)
- green biorefinery protein concentrate as a feed supplement for pigs, poultry and fisheries

[1] This project has been funded by the European Union (EU) Horizon 2020 Research and Innovation programme under Grant Agreement No 101000762.

- whey as animal feed for piglets
- fish feed pellets

In addition the potential for further value addition through side-stream valorisation, e.g. biorefinery whey extracts, will be explored through screening trials of whey applications. These products and applications are described in **Fig. 1**.

Figure 1: Diagram of bio-based technologies and products to be transferred and piloted during the BIO4AFRICA project



In addition, the implementation of pilot trials using existing, local technologies and novel, adapted technologies will allow farmers and other local, bio-based value chain actors to compare the benefits of adapted technologies with local technologies, under their own agro-ecological and socio-economic conditions, e.g. soil, climate, agricultural practices, prevailing ownership models, market access, etc. This process acknowledges the influence of local and regional "Agricultural Knowledge and Information Systems" for sustainable agri-food system development (Klerkx *et al.*, 2012). **Table 1** summarises the technologies, biomass types (inputs), and products (outputs) that will be evaluated, including those to be evaluated at pilot-scale.

Table 1: Testing and validation activities in BIO4AFRICA project (l = laboratory-scale validation tests, p = pilot-scale validation tests; s= product application screening tests)

Country	Technologies / processes	Inputs	Outputs	Validation tests
Uganda	• Green biorefinery • Carbonisation (hydrothermal carbonisation) • Densification (briquetting)	• Protein-rich leguminous plants, cassava leaves • Napier (elephant) grasses • Manure from cattle/dairy cows • Green biorefinery whey • Biochar for briquetting	• Animal feed: a) Press cake for ruminants, b) Protein concentrate for pigs & poultry, c) Whey as animal feed for pigs and for high-value ingredients screening • Biochar briquettes for cooking fuel • Biochar with struvite & manure for soil improvement	• Animal feed trials (dairy cows, pigs, piglets, poultry) (p) • High value whey ingredients screening (s) • Field trials of soil amendments (p) • Biochar briquettes for use as cooking fuel (l)
Ghana	• Green biorefinery • Carbonisation (slow pyrolysis) • Densification (pelletizing)	• Various local forage species • Green biorefinery whey • Green biorefinery protein concentrate for pelletizing • Crop residues (corn cobs, soybean husk, cowpea husk, rice bran, cassava peels, groundnut husk, maize stalks, cocoa husk)	• Animal feed: a) Press cake for ruminants, b) Protein concentrate for fish & pigs, c) Whey as animal feed for pigs • Protein concentrate pellets as fish feed • Biochar for soil improvement	• Animal feed trials (dairy cows, bulls, pigs, piglets) (p) • Aquaculture feed trials (Tilapia and catfish) (p) • High value whey ingredients screening (s) • Field trials of soil amendments using biochar (tomatoes, okra, chilli pepper) (p)

Côte d'Ivoire	• Carbonisation (slow pyrolysis) • Densification (pelletizing) • Bioplastics & bio-composites	• Cocoa pod shells • Cashew nut • Cashew shells • Cashew apple juice & molasses • Millet husks/stems • Leafy green biomass: *Cajanus cajan* (pigeon pea), *Leucaena leucophela* leaves, *Stylosanthes guianensis* (Stylo) leaves • Rubber seed • Coconut fibre • Palm tree branch fibre	• Biomass pellets for animal feed • Biochar granules for adsorption of water pollutants • Biochar for soil improvement • Bio-composites/bio-plastics	• Animal feed trials (sheep, rabbits, poultry) (p) • Tests of water filters using biochar (l, p) • Bioplastics/bio-composites tests (l) • Greenhouse and field trials of soil amendments (tomato and maize crops) (p)
Senegal	• Carbonisation (hydrothermal carbonisation & slow pyrolysis) • Densification (briquetting) • Bio-composites	• Peanut shells • Cashew hulls/apples • Rice husk • Typha	• Biochar briquettes for solid fuel (cooking fuel) • Biochar as biogas production additive & biogas pollutant adsorbent • Bio-composites	• Solid fuel (cooking fuel) tests (l, p) • Anaerobic digestion tests: biogas production with biochar additives and pollutant adsorption (p)

At least 300 farmers, farmer groups and other local bio-based value chain actors are expected to benefit from the pilot case trials, including pastoralists, small dairy farmers, low-income farmers, and female farmers. The pilot cases are embedded in a multi-actor, collaborative, and evidence-based value chain development strategy that engages communities, extension services, policy development, business supports and science and technology specialists, in the development of sustainable business models and at least 10 novel, bio-based value chains, including life cycle analysis of the products developed. This approach should result in performance improvements for the triple bottom-line of local agri-food systems in Uganda, Ghana, Côte d'Ivoire and Senegal, i.e. environmental, economic, and social performance.

2.2 Pilot Trial Report

The pilot trial period has been scheduled to take place between **M18-M44** of the Bio4Africa project. This report is the first of three to report pilot trial results at different phases of the pilot trial period: initial results, interim results, and final results. This report presents the pilot trial strategies, including methodologies for each of the pilot case countries, and initial results of pilot trials that have been completed. However, as this report is presented early in the implementation of the pilot trials (**M24** – six months from initiation of the pilot trial phase), most trials do not yet have results to report with most scheduled to take place later in the pilot trial phase. These will be described in the **Interim Report (D4.3, M34)** and **Final Report (D4.4, M44)** respectively, as appropriate. The following sections describe the pilot trials methodology and products (**Section 3**), the pilot trials to be caried out and any initial results, from each country: Uganda (**Section 4**), Ghana (**Section 5**), Côte d'Ivoire (**Section 6**), and Senegal (**Section 7**), with a final section describing conclusions and the way forward for the pilot trials over the next 10 months until the interim reporting period (**Section 8**).

3. Pilot Trials: Methodology and Products

3.1 Methodology

Trial results will be reported using a standardised reporting template (**Fig. 2**). This has been modelled on scientific abstracts, such as those used for conference submissions. The reporting template will therefore support those implementing trials to communicate the trial outcomes more broadly, e.g. in conferences and peer-reviewed journals.

Figure 2: BIO4AFRICA Standardised Trial Reporting Template

Title

Author 1[a], Author 2[b], Author 3[a,b...]

a: institution 1, b: institution 2, c...

Introduction (c. 100-150 words)

Materials and Methods (c. 400-500 words, including tables, figures, diagrams, etc.)

Results and Discussion (c. 400-500 words, including tables, figures, diagrams, etc.)

Conclusion (c. 100-150 words)

References

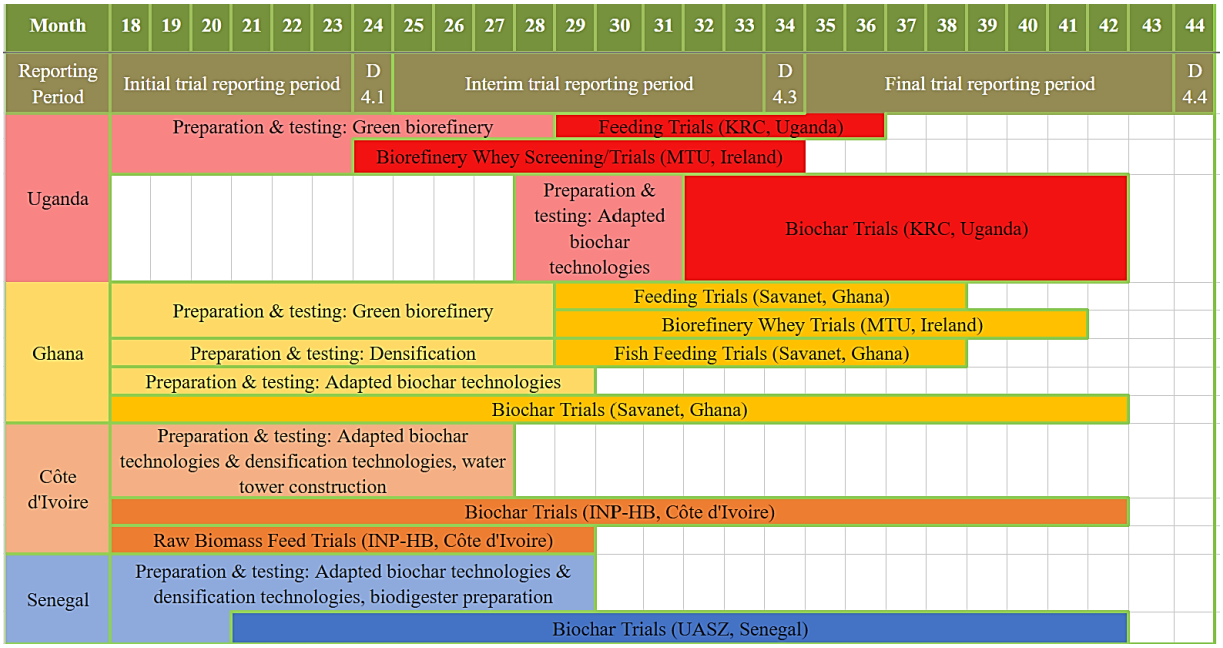
Total: 1,000 – 1,200 words

3.2 Technology Types and Products

Fourteen types of novel bio-based product will be tested at pilot trial scale or screened for novel applications (biorefinery whey), from three of the technology types to be implemented in the BIO4AFRICA project, **green biorefinery**, **carbonisation**, and **densification,** and combinations of those technologies. Those products that will be evaluated during the pilot trials, and a short description of the technologies involved in their production, are described below. An overview of the pilot trial plan is provided in **Fig. 3**. Due to variation in local technology availability and technology adaptation requirements, trials in some countries have been able to start earlier than in others. In the **initial trial reporting period (M18-23)**, trials in two main trial categories began: biochar trials (Ghana, Côte d'Ivoire, Senegal), and raw biomass pellet feeding trials (Côte d'Ivoire). The remaining trials, green biorefinery product feeding trials and biorefinery whey screening trials in Uganda and Ghana, pellet feeding trials in Ghana, and biochar trials in Uganda, will begin during the **interim trial reporting period (M24—33)**. During the same period, biorefinery whey screening trials are planned to be completed in Uganda, and raw biomass pellet feeding trials are planned to be completed in Côte d'Ivoire. All other trials will continue into the **final trial reporting period (M34-43)**, although preliminary results are likely

for most trials during the **interim trial reporting period**. The technologies and associated product testing plans are described in greater detail in **D3.1**, the **Initial Testing, Monitoring and Assessment Plan**.

Figure 3: Overview of pilot trials taking place between M18-M44 of the BIO4AFRICA project



3.2.1 Green Biorefinery

Green biorefinery involves mechanical refining of leafy biomass to generate multiple bio-based value streams, including a silage "press cake" that can be fed to ruminants, a protein concentrate that can be fed to monogastric animals, e.g. poultry, pigs and fish, and concentrated whey that can be used as animal feed (piglets), silage preservative, fertiliser, and can contain high-value components with potential applications as nutraceuticals and cosmeceuticals. Suppliers of the leafy feedstock thus gain additional revenue opportunities compared with grazing alone, while also generating a local supply of high-protein animal feed (protein concentrate) and storable ruminant fodder that contributes to animal productivity and does not compete with human food uses, and fertiliser that can be sold or returned to feedstock-producing fields. The BIO4AFRICA project will also examine the potential of "synergy forages", e.g. green, leafy residue from sweet potato and banana, to be used in the green biorefinery, which would add value to these feedstocks that might not otherwise be exploited.

The small-scale systems being implemented in the BIO4AFRICA project enable co—location near feedstock producers, reducing environmental footprint and economic costs associated with transport and ensuring good feedstock quality due to transport distances being relatively short. The local provision of high-protein animal feed also has the potential to increase the economic efficiency and reduce the environmental impact of animal rearing, due to less dependence on high-cost, imported feedstuffs, e.g. soy.

The green biorefinery technology being utilised in the BIO4AFRICA project, corresponding to **no. 18** in **D1.3** (**Catalogue of small-scale bio-based technologies suitable for rural Africa**), is close to commercialisation in

the EU, but is considered to have a Technology Readiness Level (TRL) of 5-7 in the African context, due to the very different type of feedstocks available.

Press Cake

Producing ruminant fodder in the form of fibre-rich press cake using the green biorefinery process described above (**Fig. 4**) offers some advantages over other livestock feed types, due to its suitability for storage and transport, nutrient conversion by livestock, and yield of additional products from the press cake production process, adding more value to the feedstock than if grazed or ensiled in a traditional way, e.g. protein concentrate that can be fed to monogastric animals, and whey (residual juice) high in soluble sugars and minerals (Jørgensen *et al.*, 2022; Serra *et al.*, 2023).

The press cake is storable and transportable when baled and ensiled, enabling farmers to have greater access to appropriate livestock fodder on a year-round basis, giving more security for urban and peri-urban farmers, as well as rural farmers, and improving resilience to challenging climatic conditions, e.g. as experienced in the Tamale region of Ghana where the biorefinery will be implemented, and climate change.

Figure 4: Biorefinery press cake produced in Uganda

Protein Concentrate

Protein concentrate is one of the main products of green biorefinery, comprising precipitated proteins from the juice fraction of leafy biomass (**Fig. 5**). This is dried and powdered, and fed to monogastric animals such as pigs, or it can undergo **densification**, e.g. using pelletizing equipment, to produce protein-rich **feed pellets** that are more easily consumed by smaller monogastric animals such as chickens, and fish (**see section 3.2.3**). Extracting a substantial portion of the protein content of grass from the fibrous portion increases the value of the feedstock material, generating appropriate feedstuffs for a broader range of livestock, increasing local feed availability across different production systems, and contributing to greater overall efficiency of regional agri-food systems (Jørgensen *et al.*, 2022).

Figure 5: Biorefinery protein concentrate drying in Uganda

Whey

The whey, which is the residual juice fraction following protein precipitation (see **Fig. 6**) typically contains soluble carbohydrates, minerals, and proteins, especially non-protein nitrogen compounds, with the specific composition depending on the feedstock and precipitation process used (Jørgensen *et al.*, 2022). This whey has multiple uses, e.g. production of amino acid concentrates and other valuable biochemical "building blocks" and metabolites relevant for biotechnological applications, use as a sugar—rich animal feed, fertilizer, and a silage preservative, and co-digestion in anaerobic digestion systems, resulting in energy production and digestate that can be applied as fertilizer (Jørgensen *et al.*, 2022; Ravindran *et al.*, 2022). These uses can also be exploited in a cascading fashion, e.g. metabolite extraction followed by anaerobic digestion to produce energy and fertilizer (Ravindran *et al.*, 2022). This project will pilot application as animal feed (piglets) and examine the biochemical composition and potential high value uses, e.g. as nutraceuticals and cosmeceuticals.

Figure 6: Protein and whey collection tanks at small-scale green biorefinery in Uganda

Design considerations

Adaptation of the small-scale green biorefinery technology for use in the BIO4AFRICA test sites in Uganda and Ghana has involved careful consideration of biorefinery unit design and each stage of the biorefining process. These are summarised below and are described in detail in **D2.3** (**Design of green biorefinery**) and **D3.1** (I**nitial version of testing, monitoring and assessment plan**).

Design

- Structure
  - Five tonne platform capacity, roofed and easy to clean.
  - Soundproofing required if noise-sensitive structures are in the vicinity.
  - One-way system at biorefinery site, feedstock entry point and transport vehicles co-located.
  - Bulky products (whey and press cake) exit on the same side as feedstock entry and transport vehicle location.
  - Dried protein concentrate will exit on the opposite side of feedstock entry.
  - Other facilities include an office, laboratory, and dressing room for operators.
- Transport and storage
  - Refrigerated trucks advisable when transport time from field to biorefinery is greater than one hour.
  - Refining should take place within 4 hours of fresh leaf harvest[1], or longer if cold transport and storage are available.
- Testing
  - The following data collection and analyses will take place:
    - Registration of feedstock and products;
    - visual inspection of feedstock and products;

[1] Depending on type of leaves, temperature, and humidity.

- registration of energy consumption.
- mass balance for refinery performance (wet and dry);
- quality testing of products;
- dry matter determination (small oven with temperature as low as 60°C);
- protein content (N-Kjeldahl) (in future also NIR-analysis);

Biorefinery process

The various steps in the biorefinery process are described below, and a schematic diagram of the biorefinery system is presented in **Fig. 7**.

Feedstock preparation

- Weighing
  - The feedstock is weighed as the first step of the intake process.
- Washing
  - The leaves are washed to remove dirt and other impurities, and are brought into the biorefinery unit by a 5m conveyor belt.

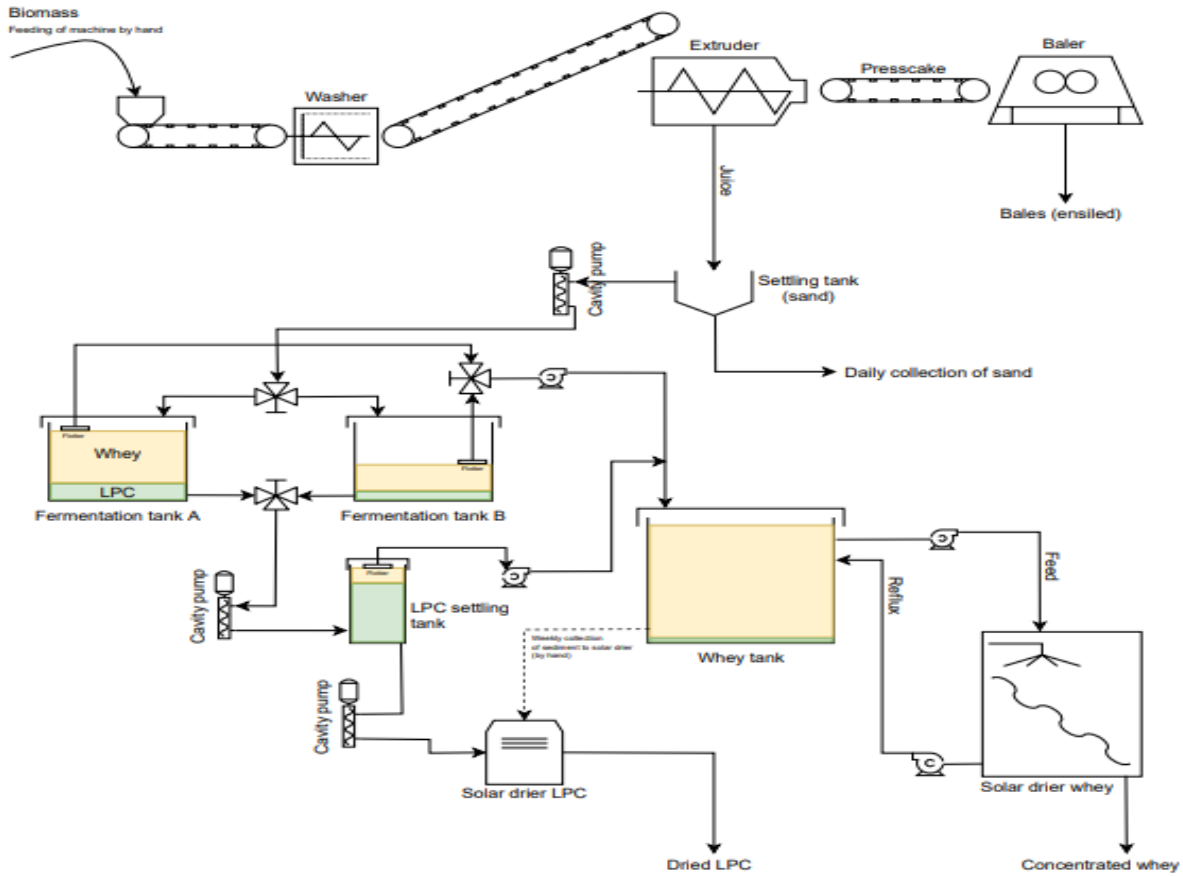
Feedstock refining

- Extrusion
  - The leaves are pressed and squeezed, creating two initial products: **press cake** (ruminant feed) and **juice**.
- Press cake ensiling
  - Press cake enters a baler, via another conveyor belt, where it is pressed and ensiled in bales of 50—60kg for easier transport and storage.
- Sedimentation
  - Juice is collected and enters a sedimentation container to remove any further solid materials, e.g. sand.
  - Juice is pumped to coagulation vessels.
- Protein coagulation and precipitation
  - Juice undergoes a primary precipitation process, resulting in two separate fractions: **whey** and **protein precipitate**. Whey is collected at this stage.
  - The protein precipitate goes through a secondary precipitation process, resulting in further separation of whey, which is again collected, and protein concentration. In the green biorefineries adapted for use in Uganda and Ghana, protein precipitation will be *Lactobacilli*-mediated rather than achieved through heating, reducing energy requirements.
- Protein drying
  - The concentrated protein "slurry" is pumped to a paved drying house, with passive solar dryer and a solar-powered ventilator for low wind/high humidity days, where it is spread out and turned until dry.
- Protein concentrate powder

- The **dried protein** is finally powdered and packed, and can be used as feed directly or condensed into pellets for feeding using **densification techniques (2.2.3)**.

- Whey collection
  - The whey fraction from juice refining is collected in 4m^3 steel vessels, that can be treated with UV light to prevent contamination.
- Whey concentration
  - The **whey** is concentrated in a passive solar whey concentrator, to a concentration of approximately 10 times the original concentration.

Figure 7: Biorefinery process



3.2.2 Carbonisation

At least three different approaches for transforming bio-based waste, e.g. rice husk and cashew apple, to novel value-added products will be examined during the pilot phase. These include pre-existing local slow pyrolysis technologies in Ghana, Côte d'Ivoire, and Senegal (**Fig. 8a** and **b**) and pollution-reducing slow pyrolysis technologies (e.g. Brazilian wood-burning kiln) in Ghana and Côte d'Ivoire (**Fig. 8c**), both of which utilise dry materials. Hydrothermal carbonisation technology (**Fig. 8d**), which utilises materials with higher

moisture content, e.g. animal manure, typha and cashew apple, will also be adapted for use in Uganda and Senegal. In addition to adaptation of the technologies to the local context, the project will assess the viability of different waste feedstocks, and generate specific biochar products to meet specific needs, e.g. cooking fuel, pollutant adsorption, anaerobic digestion additives, and soil amendment.

Figure 8: Carbonisation technologies in the BIO4AFRICA project using traditional kilns, e.g. kilns from a) Ghana and b) Côte d'Ivoire; adapted, pollution-reducing kilns, e.g. wood-burning kilns from Brazil (c); and hydrothermal carbonisation technology, e.g. as adapted for use in Senegal (d)

a) 

b) 

c) 

d) 

The Brazilian kiln technology has been designed to combust woody material. The kiln comprises four circular ovens, where the feedstock is carbonized to create biochar, in a process lasting 6-7 days. The ovens are connected to a brick furnace with a 3.5m chimney to collect gases released during pyrolysis. Brazilian kiln pyrolysis has been evaluated as having a TRL of 5-7, with an aim to improve the TRL through adaptation to

local feedstocks derived from agri-food sidestreams. The slow pyrolysis technologies implemented in the BIO4AFRICA project are described in greater detail in **D2.4** (**Pyrolysis units – initial version**), and **D3.1** (**Initial version of testing, monitoring and assessment plan**).

The HTC technology to be used in the BIO4AFRICA project is based on the design of Robbiani (2013). This is a highly prospective technology in the African context and is considered to have a TRL of 3-5. The suitability of the technology to wet biomass, e.g. cashew apple and livestock manure, and affordability of implementation make this technology particularly suitable for pilot locations with wet agri-food sidestreams, e.g. cashew production in Senegal and livestock-rearing in Uganda.

Biochar

Biochar produced through the carbonisation technologies described above will be applied for a number of purposes during the regional pilots. The characteristics of biochar are influenced by pyrolysis temperature and feedstock type, therefore the trials present substantial knowledge and practice development potential, given that they use a variety of agri-food waste sidestreams, even where existing carbonisation technology is used to produce the biochar, e.g. local kilns. This is particularly true of biochar generated through HTC, due to the relatively low TRL level of this technology compared with the other technologies being examined in the BIO4AFRICA project.

Biochar has diverse impacts on soil properties, including pH, cation exchange capacity, porosity, and soil organic carbon, with implications for fertility, water holding capacity, and nutrient retention, and consequently influencing crop production parameters, e.g. yield (Kamali *et al.*, 2022). In three of the pilot regions, Uganda, Ghana and Côte d'Ivoire, biochar will be applied as a soil amendment in a combination of pot, greenhouse, and field trials, depending on the region, with monitoring of both soil-specific and crop-specific parameters. In this project, biochar will also be further processed using **densification techniques** (**briquetting**, see **Section 3.2.3**) to improve its applicability to solid fuel uses, e.g. cooking fuel.

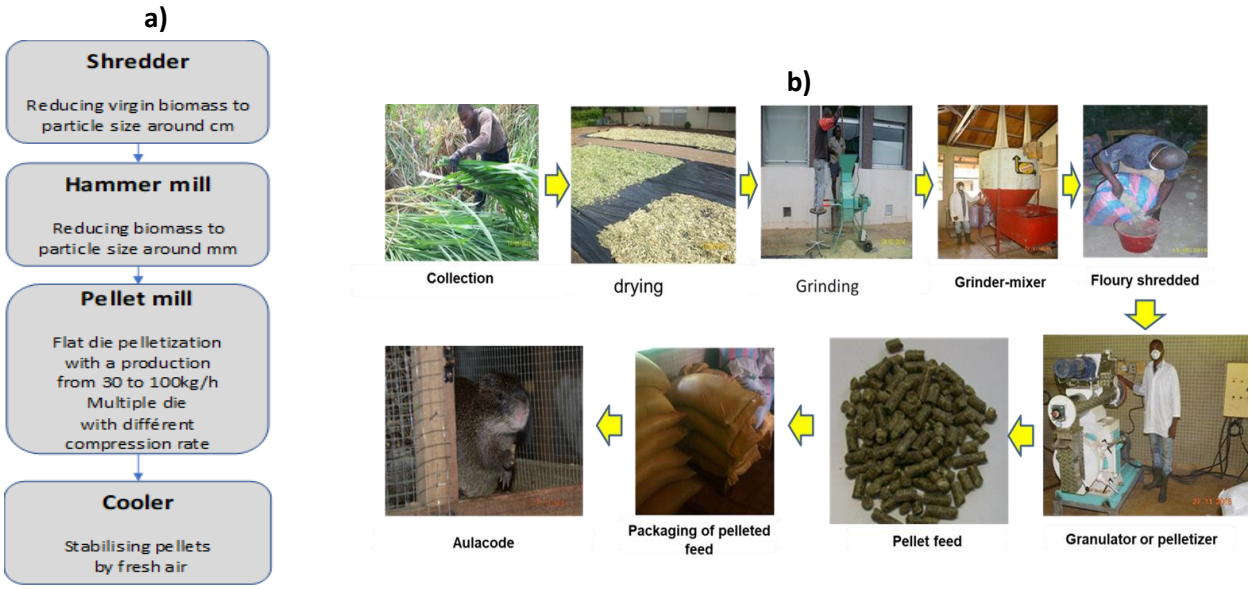
Biochar has the capacity to adsorb pollutants, a characteristic which has been applied for soil remediation (Kamali *et al.*, 2022; Brassard *et al.*, 2019). In the BIO4AFRICA project, this characteristic will be exploited for the purification of water in Côte d'Ivoire, with implications for human health. The pollutant adsorption capacity of biochar also has a beneficial role for anaerobic digestion. Zhao *et al.* (2021) describe the use of biochar for the purification of biogas through removal of other gases, e.g. CO_2 and H_2S, increasing the calorific value of the resulting biogas. The stability and efficiency of biogas production can also be enhanced through biochar addition, as biochar can mitigate the inhibitive effect of compounds arising in the anaerobic digestion feedstock, e.g. heavy metals, antibiotics, and compounds generated during the anaerobic digestion process, e.g. volatile fatty acids (Zhao *et al.*, 2021). The potential for biochar derived from carbonisation of local agri-food sidestreams to enhance anaerobic digestion efficiency and improve the purity of the resulting biogas will be examined in Senegal.

3.2.3 Densification

Densification techniques involve applying pressure to dry materials through different mechanical means, such as flat die or ring die pellet mills, in order to compact and compress the materials into a desired shape

and size, e.g. pellets (small size), or briquettes (larger size). If biomass is entire or has large particle size prior to densification, it should pass through a shredding process and hammer mill to reduce particle size, before proceeding to densification and finally cooling (see **Fig. 9**). These techniques can add greater value to products by improving storability, transportability, and ultimately saleability (Zainuddin *et al.*, 2014). Densification can also adapt biomass and bio-based products, e.g. biochar and protein concentrate, to consumer needs, and especially in the case of livestock feed, making the target feed more ingestible and attractive to animals. The densification technologies implemented in the BIO4AFRICA project are described in greater detail in **D3.1** (I**nitial version of testing, monitoring and assessment plan**).

Figure 9: a) schematic description of densification stages (RAGT, 2022) and b) pelletising process for animal feed pellets in Côte d'Ivoire



In BIO4AFRICA, briquetting and pelletising processes will be enlarged to 150-200kg/h, to accommodate the local feedstocks with greater efficiency than that offered in existing systems, allowing better value chain development. Novel feedstocks, in both raw form and transformed through carbonisation or green biorefinery, will also be employed to explore value addition potential for these biomass types. Enlarged densification systems to accommodate raw biomass (Côte d'Ivoire), biorefinery protein concentrate (Ghana) and biochar (Uganda and Senegal), are perceived to have TRL of 5-7, with biochar briquetting in particular being less mature, with TRL of 3-6.

Pellets

Pellets will be produced in the BIO4AFRICA project for animal feed purposes. Protein concentrate from green biorefinery will be processed into pellets in Ghana, in order to make this feedstuff easier to feed to fish and piloted for aquaculture—based fish production. Combinations of novel raw biomass types, e.g. agri—food

residues such as rubber seeds, and forage species, will be processed into pellets in Côte d'Ivoire (**Fig. 9b**) and piloted among poultry, sheep and pig farmers for feeding and additional outcomes, e.g. anthelminthic effects on intestinal parasites of sheep.

Briquettes

Biochar briquettes from agri—food residues will be produced in Senegal and Uganda for solid and cooking fuel purposes (see **Fig. 10a** for examples). Firewood and charcoal are used as domestic cooking fuel in many countries in sub—Saharan Africa and can result in indoor air pollution and negative health impacts, especially for women and children, in addition to forest degradation and deforestation (Sow, 2022; Chidumayo & Gumbo, 2013). Biochar from agri—food residue has the potential to provide a more sustainable alternative to wood-derived charcoal, while also generating value for feedstock producers. These briquettes will be evaluated and piloted in Senegal, including using improved "Jambar" stoves (**Fig. 10b**) that produce less smoke and are more efficient in fuel use than traditional stoves, when using traditional fuels (wood and charcoal) (Sow, 2022). The results will thus illustrate the viability of biochar briquettes compared with traditional fuels, but also using improved cookstove technology.

Figure 10: a) various types of biochar "briquettes" and b) improved "Jambar" stove, used in Senegal

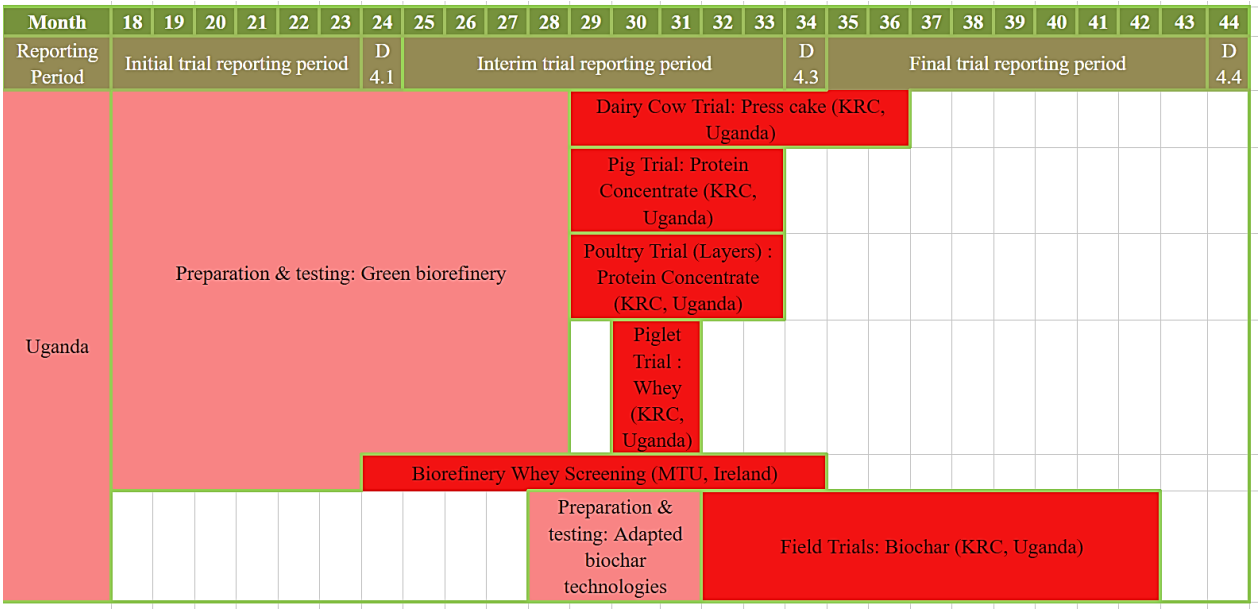
a)

b)

4. Pilot Trials in Uganda

In Uganda pilot trials of green biorefinery products (press cake, protein concentrate, and whey) and HTC products (manure-derived biochar as soil amendment) will be evaluated, with trials led by Kabarole Research and Resource Centre (KRC). An overview of trial plans specific to Uganda is provided in **Fig. 11**. Initial results from all trials apart from biochar trials[1] will become available during the interim trial reporting period, **M24-M33**. Final results will become available during the final trial reporting period, **M34-M43**.

Figure 111: Overview of pilot trials taking place in Uganda



4.1 Green Biorefinery

Testing and optimisation of the small-scale green biorefinery and biorefinery products is currently underway in Uganda, e.g. assessing livestock acceptance of press cake as fodder (**Fig. 12**). Pilot trials of green biorefinery products are planned to take place from October 2023 (**M29**), with biorefinery whey screening for high-value ingredients due to begin earlier, in May 2023 (**M24**), as whey from different feedstocks becomes available.

[1] Due to start date of **M32**.

Figure 122: Dairy cows demonstrating good uptake of press cake during pilot trial preparation phase in Uganda

4.1.1 Press Cake

In Uganda, press cake will be trialled with dairy cows, in order to assess its performance as a feedstuff in comparison with a control diet (Elephant grass – *Pennisetum purpureum*). Two experimental treatment diets, each including a different press cake type, and the control diet will be trialled with pregnant dairy cows at six months into gestation. Three replicates will be carried out, with one cow per treatment (total no. dairy cows = nine). The parameters to be examined are described in **Table 2**. The trial is planned to take place in October 2023 (**M29**), and initial results should be available during the interim reporting period (**M24-M33**), with final results due in the final reporting period (**M34-M43**).

Table 2: Parameters to be examined in press cake feeding trials in Uganda

Dairy cow intake/ performance	Dairy cow manure
Voluntary intake	Organic matter
Milk yield	Nitrogen
Milk composition	Phosphorus
	Potassium

4.1.2 Protein Concentrate

Protein concentrate will be examined in Uganda as a feedstuff for two different animal types: pigs and laying poultry. Pig feed trials will evaluate protein concentrate performance in terms of voluntary intake, growth performance, feed efficiency, and carcass composition/characteristics. Poultry trials will evaluate protein concentrate performance in terms of growth performance, feed efficiency, egg characteristics and production, and carcass composition/characteristics.

Pig feed

Three experimental treatment diets incorporating protein concentrate and a control diet will be trialled with three-month old pigs. Three replicates will be carried out, with two pigs per treatment, one male and one female (total no. pigs = 24). The parameters to be examined are described in **Table 3**. The trial is planned to take place in October 2023 (**M29**), and initial results should be available during the interim reporting period (**M24-M33**), with final results due in the final reporting period (**M34-M43**).

Table 3: Parameters to be examined in protein concentrate pig feeding trials in Uganda

Pig intake/ performance	Pig slurry
Daily feed intake	Organic matter
Average daily weight gain	Nitrogen
Feed conversion efficiency	Phosphorus
Carcass characteristics/ composition	Potassium

Poultry feed

Three experimental treatment diets incorporating protein concentrate and a control diet will be trialled with one day old laying hen chicks. Three replicates will be carried out, with 20 birds per treatment (total no. birds = 240). Carcass characteristics will be examined using a sub-sample of two birds from each treatment, at the end of the starting period (eight weeks) and the growing period (16 weeks), in each replicate (total no. of birds = 48). Eggs will be analysed weekly for each treatment, in each replicate. The parameters to be examined are described in **Table 4**. The trial is planned to take place in October 2023 (**M29**), and initial results should be available during the interim reporting period (**M24-M33**), with final results due in the final reporting period (**M34-M43**).

Table 4: Parameters to be examined in protein concentrate poultry feeding trials in Uganda

Egg characteristics on a weekly basis	Bird performance @ 8 weeks/16 weeks	Chicken manure
Egg weight	Gastro-intestinal tract weight	Organic matter
Shell weight	Caecal weight	Nitrogen
Shell thickness	Dressed carcass weight	Phosphorus
Albumen weight	Carcass skin colour	Potassium
Albumen length & width		
Yolk weight		
Yolk colour		

4.1.3 Biorefinery Whey

The whey fraction of juice from the green biorefinery feedstocks will be evaluated as a feedstuff, by incorporation into weaner piglet diets and examining voluntary intake, growth performance, and feed efficiency. The whey will also be shipped for screening at Munster Technological University (MTU) for high-value ingredients, e.g. bio-active compounds.

Pig feed

Three experimental treatment diets incorporating biorefinery whey and a control diet will be trialled with seven-week-old piglets (weaners), in three replicates. Two piglets will be involved in each treatment, one male and one female (total no. piglets = 24). The parameters to be examined are described in **Table 5**. The trial is planned to take place in November 2023 (**M30**), and initial results should become available during the interim reporting period (**M24-M33**), with final results due in the final reporting period (**M34-M43**).

Table 5: Parameters to be examined in biorefinery whey pig feeding trials in Uganda

Piglet intake/ performance	Pig manure
Daily feed intake	Firmness
Average daily weight gain	Organic matter
Feed conversion efficiency	Nitrogen

Piglet intake/ performance	Pig manure
	Phosphorus
	Potassium

High-value ingredient screening

Samples of green biorefinery whey will be frozen and transported to MTU in Ireland to evaluate the presence of high-value ingredients, especially bio—active compounds and those with applications for animal and human health, e.g. cosmeceuticals and pharmaceuticals. Screening will include chromatography techniques, including High-Pressure Liquid Chromatography (HPLC), Fourier-Transform Infrared Spectroscopy (FTIR), and biochemical assays. Screening will be carried out for bioactivities relating to digestive, immune, skin and hair health using established biomarkers. The results will provide insight into additional applications of biorefinery whey that could provide greater value addition opportunities compared with use as animal feed, silage preservative, or fertilizer alone, especially if derived through a cascading biorefinery approach, through which the aforementioned known applications could also be achieved. The initial steps for biorefinery whey screening, e.g. planning logistics, began in April 2023 (**M23**), with the first whey delivery expected in May (**M24**) and initial results should become available during the interim reporting period (**M24-M33**), with final results due in the final reporting period (**M34-M43**).

4.2 Carbonisation

In Uganda, HTC will be used to transform animal manure, e.g. from the feeding trials, into biochar. This will be used as a soil amendment in field trials. The HTC technology will be implemented in Uganda in **M30** (November 2023), after which biochar production will begin.

4.2.1 Biochar soil amendment

The biochar produced in Uganda will be used as a soil amendment, and compared with baseline, pre-application data, and manure and struvite applied as a control. Complete Randomized Block Design will be used for designing the pilot-scale field trial experiments, with biochar amount increasing in 20g increments from 0-100g. The pilot trial will examine the effect on crops produced under the experimental and control treatments (high-value short-term crops, e.g. green vegetables, and annual crops, e.g. maize and beans), over the course of two seasons.

Parameters and Timeline

The parameters to be examined are described in **Table 6**. The trial is planned to take place in **M32** (January 2024), after installation of the HTC technology. Results will become available during the final trial reporting period, **M34-M43**

Table 6: Parameters to be examined in soil amendment trials in Uganda

Soil characteristics	Crop characteristics
Soil physical parameters	Crop health
Soil chemical characteristics	Crop growth
Soil fertility	Crop yield

5. Pilot Trials in Ghana

An overview of trial plans specific to Ghana is provided in **Fig. 13**. As described in this overview schedule, biochar soil amendment field trials began in Ghana in **M18** using biochar produced using local pyrolysis technologies. Initial results from these trials will become available during the interim trial reporting period, **M24-M33**. Final results for all trials will become available during the final trial reporting period, **M34-M43**.

Figure 13: Overview of pilot trials taking place in Ghana

5.1 Green Biorefinery

The small-scale green biorefinery is currently in the construction stage in Ghana, and should be operational later in 2023, and livestock facilities have been prepared, e.g. for pig feeding trials (**Fig. 14**). Biorefinery product trials are due to start in **M30** (November 2023), including biorefinery whey screening for high-value ingredients.

Figure 134: Pigs and piglets of type likely to be used in feeding trials in Ghana

5.1.1 Press Cake

In Ghana, press cake will be trialled with dairy cows and bull cattle in two separate experiments, in order to assess its performance as a supplementary feedstuff, in comparison with a control diet of pasture grazing only. The nutritional characteristics of the press cake will be examined before feeding.

The press cake trials will involve a randomized trial with two experimental treatment diets, and a control diet treatment (no press cake supplementation). The treatments will be replicated five times with dairy cows and bull cattle in separate trials, with one animal per treatment (dairy cows = 5; bulls = 5). Animals will be housed at night and will have free access to water, mineral lick and after consumption of the press cake, to natural pasture during the daytime. Animals will be of the same age and will be managed for optimal health during the trials.

Parameters and Timeline

The parameters to be examined in each trial are described in **Table 7**. The data collected will be analysed with appropriate statistical software. The trial is planned to take place from November 2023 (**M30**), and initial results may be available during the interim reporting period (**M24-M33**), with final results due in the final reporting period (**M34-M43**).

Table 7: Parameters to be examined in press cake feeding trials in Ghana

Dairy cow performance	Bull performance
Feed efficiency	Feed efficiency
Feed conversion ratio	Feed conversion ratio

Dairy cow performance	Bull performance
Milk response	Initial weight
Milk composition	Daily weight gain
Faecal Organic matter	Final weight
Hematological parameters	Carcass yield and composition
	Faecal Organic matter
	Hematological parameters

5.1.2 Protein Concentrate

Protein concentrate will be examined in Uganda as a feedstuff for two different animal types: pigs and fish. Pig feed trials will evaluate protein concentrate performance in terms of voluntary intake, growth performance, feed efficiency, and carcass composition/characteristics. In fish feeding trials, protein concentrate will undergo densification treatment first, to convert the concentrate powder to pellets. This is described in greater detail in **section 5.2.1**, below.

Pigs

In Ghana, the protein concentrate feeding trial with pigs will involve a control treatment diet (Treatment 1), containing no protein concentrate but 11.8% fish meal. These will be compared with two experimental treatment diets, containing 10% protein concentrate (Treatment 2) and 8.5% protein concentrate (Treatment 3), respectively. The balance of other dietary components has been adjusted to account for the differences in protein concentrate and fish meal in these three treatment diets (see **Table 8** below).

Table 8: The formulated pig trial treatment diets. Treatment 1=control (0% BIO4AFRICA product); Treatment 2=10% inclusion of BIO4AFRICA concentrate; Treatment 3=8.5% inclusion of BIO4AFRICA concentrate

Diet composition	Treatment1	Treatment 2	Treatment 3
Maize (%)	45.91	47.93	49.73
Brewers spent grain (%)	21.26	23.00	24.73
Fishmeal (%)	11.81	0.00	0.00
Soya bean meal (%)	19.22	16.95	14.80

Diet composition	Treatment1	Treatment 2	Treatment 3
BIO4AFRICA protein concentrate (%)	0.00	10.12	8.54
Oyster shell (%)	1.10	1.30	1.50
Salt (%)	0.50	0.50	0.50
Premix (%)	0.20	0.20	0.20

The experiment is designed as a completely randomized, controlled trial, with five animals randomly allocated to randomly to each of the three dietary treatments (no. pigs = 15). The animals will be weaned piglets of the same weight and age, that have received worming and vaccination treatment. There will be a two-week period of adjustment to the diets, and piglets will be housed and fed individually. Feeding will take place twice a day, at 08:00 and 14:00, with free access to water.

Parameters and Timeline

The parameters to be examined are described in **Table 9**. The data will be analysed with appropriate statistical software. The trial is planned to take place from November 2023 (**M30**), and initial results may be available during the interim reporting period (**M24-M33**), with final results due in the final reporting period (**M34-M43**).

Table 9: Parameters to be examined in protein concentrate pig feeding trials in Ghana

Pig intake/ performance	Pig slurry
Daily feed intake	Organic matter
Average daily weight gain	Nitrogen
Feed conversion efficiency	Phosphorus
Carcass characteristics/ composition	Potassium

5.1.3 Biorefinery Whey

The whey fraction of juice from the green biorefinery feedstocks will be evaluated as a feed for piglets, examining voluntary intake, growth performance, and feed conversion efficiency. The whey will also be shipped for screening at MTU for high-value ingredients, e.g. bio-active compounds.

Pig feed

The experimental design for feeding piglets with biorefinery whey concentrate will involve five treatments: four experimental weaner diets containing biorefinery whey, and one control treatment without whey. Three seven-week-old piglets will be randomly assigned to each of the treatments (no. piglets = 15). The parameters to be examined are described in **Table 10**. The trial is planned to take place from November 2023 (**M30**), and initial results should become available during the interim reporting period (**M24-M33**), with final results due in the final reporting period (**M34-M43**).

Table 10: Parameters to be examined in biorefinery whey pig feeding trials in Ghana

Piglet intake/ performance	Pig manure
Daily feed intake	Firmness
Average daily weight gain	Organic matter
Feed conversion efficiency	Nitrogen
	Phosphorus
	Potassium

High-value ingredient screening

As in the case of biorefinery whey produced in Uganda, samples of green biorefinery whey will be frozen and transported to Ireland, where MTU will evaluate the presence of high-value ingredients, especially bio—active compounds and those with applications for animal and human health, e.g. cosmeceuticals and pharmaceuticals. Screening will include chromatography techniques, including HPLC, FTIR, and biochemical assays. Screening will be carried out for bioactivities relating to digestive, immune, skin and hair health using established biomarkers. The results will provide insight into additional applications of biorefinery whey that could provide greater value addition opportunities compared with use as animal feed, silage preservative, or fertilizer alone, especially if derived through a cascading biorefinery approach, through which the aforementioned known applications could also be achieved. Biorefinery whey screening of whey produced in Ghana is due to take place from November 2023 (**M30**), and initial results should become available during the interim reporting period (**M24-M33**), with final results due in the final reporting period (**M34-M43**).

5.2 Densification

Protein concentrate from the small-scale green biorefinery will be incorporated into fish feed pellets in Ghana using densification, specifically pelletizing. The pelletizing equipment transforms the dried pellet ingredients into a compressed, transportable, and storable feed that can be easily handled and fed to animals, including fish.

5.2.1 Fish feed pellets

The fish feed pellets to be developed in Ghana, will use diverse biomass types to create a balanced food for the fish species involved, the Nile Tilapia (*Oreochromis niloticus*) and Catfish fingerlings, with a separate trial for each species. The control treatment diet will include protein sources (fish meal, palm kernel meal, cowpea husk, soybean husk), carbohydrates (fermented corn cob, rice bran, cassava meal/peels), lipids (palm kernel oil, palm oil), vitamins and minerals (premix), salt, and starch or other binder. Four experimental treatment diets will be examined, in which some of the protein content in the "control" pellet ingredients will be substituted with biorefinery protein concentrate.

The trials will be replicated twice, with each species divided into five groups of five (no. tilapia = 30, no. catfish = 30). During the experiment, water quality (acidity, alkalinity, salinity, water temperature, and the rate of water circulation) will also be analysed, and the system of production and feeding schedule will be consistent across treatments.

Parameters and Timeline

The parameters to be examined are described in **Table 11**, and include growth, health, and nutritional value parameters. The trial is planned to take place from November 2023 (**M30**), and initial results should be available during the interim reporting period (**M24-M33**), with final results due in the final reporting period (**M34-M43**).

Table 11: Parameters to be examined in protein pellet fish feeding trials in Ghana

Fish performance	Biochemical parameters	Hematological parameters	Other
Growth	Total cholesterol	Red blood cells	Digestive enzyme activity in the gastrointestinal system (protease, amylase, lipase)
Feed utilisation	High-density lipoprotein in cholesterol	Haemoglobin	Gene expression of growth-related genes (n = 5)
Digestibility	Low-density lipoprotein in cholesterol	Packed cell volume	
Liver histology	Total protein	Mean corpuscular volume	

Fish performance	Biochemical parameters	Hematological parameters	Other
Proximate composition (Protein, lipid, ash, moisture)	Albumin	Mean corpuscular haemoglobin & haemoglobin concentration	
Fatty acids	Globulin	White blood cells	
Amino acids	Alanine		
	Aminotransferase		
	Aspartate aminotransferase		

Figure 15: Fish species: tilapia (a) and catfish (b), and c) aquaculture pools to be used in fish feeding trials in Ghana

a) 

b) 

c) 

5.3 Carbonisation

In Ghana, pre-existing local pyrolysis technology has been used to generate biochar from agricultural residues. This has been used as a soil amendment in field trials, described in **section 5.3.1**, below. Adapted Brazilian kiln technology will be implemented in Ghana between **M28-29** (September-October 2023), after which further biochar production will begin, and additional field trials will be conducted using that biochar as a soil amendment (**M30 – November**).

5.3.1 Biochar soil amendment

In Ghana, biochar has been produced from groundnut husk, rice husk/hulls, and corn stover. This was applied as a soil amendment in three different experimental treatments: alone (5t/ha application rate) and in combination with compost[1] (5t/ha application rate). Two different control treatments were used: 0 fertilizer application, and compost (5t/ha application) (see **Table 12**). Three different types of crops are being examined: tomato, okra, and chili pepper. A Complete Randomized Block Design was chosen, with half-acre plots for each crop in different parts of the North-East region of Ghana - Zangum, Nabari, and Gbeligu. Three replications will be carried out, and the plots will be irrigated during the dry season, and rainfed otherwise. This approach will also be implemented for replicate trials using biochar made from the same biomass but using the adapted Brazilian kiln technology.

Table 12: Soil amendment trials in Ghana: Experimental design

Treatment Name	Treatment Type	Amendment application rate
T1	Control	Control: No fertilizer
T2	Compost with biochar	5t/ha Compost with biochar added
T3	Biochar	5t/ha biochar
T4	Compost	5t/ha compost

Parameters and Timeline

The parameters being examined are described in **Table 13**. Partial budget analysis will also be applied to conduct an economic analysis of biochar-based soil amendment. The trial started in **M18** (November 2022), using biochar created from local pyrolysis technologies. Trials using biochar produced from the same feedstocks but using Brazilian kiln technology are planned to begin between **M28-29**, based on the installation of the Brazilian kiln technology. Initial results from the trial using biochar from local pyrolysis

[1]Comprised of blended compost components, rice husk, and cow dung.

technology will become available during the **interim trial reporting period, M24-M33**. Final results for soil amendment trials using biochar from adapted Brazilian kiln technology, and comparative results between both trials, will be available during the **final trial reporting period, M34-M43.**

Table 13: Parameters being examined in soil amendment trials in Ghana

Soil Characteristics	Compost Characteristics	Crop characteristics
Soil Structure	Moisture	Plant Height
Soil pH	Volatile Matter	Branches/Plant
Water Retention Rate	Fixed Carbon	No. Leaves
Nutrient content: Nitrogen, Phosphorus and Potassium	Ash Content	Stem Diameter
	Water Retention	Chlorophyll Content
	Permeability	Days to 50% Flowering (DFF)
	Water Infiltration	Leaf Area Index (LAI)
	Aeration	Intercepted Photosynthetically Activate Radiation (IPAR)
	Structure	No. Fruit/Plant
		Average Fruit Weight
		Fruit Yield/Plot
		Ash Content
		Protein Content
		Moisture Content
		Fibre
		Vitamins

6. Pilot Trials in Côte d'Ivoire

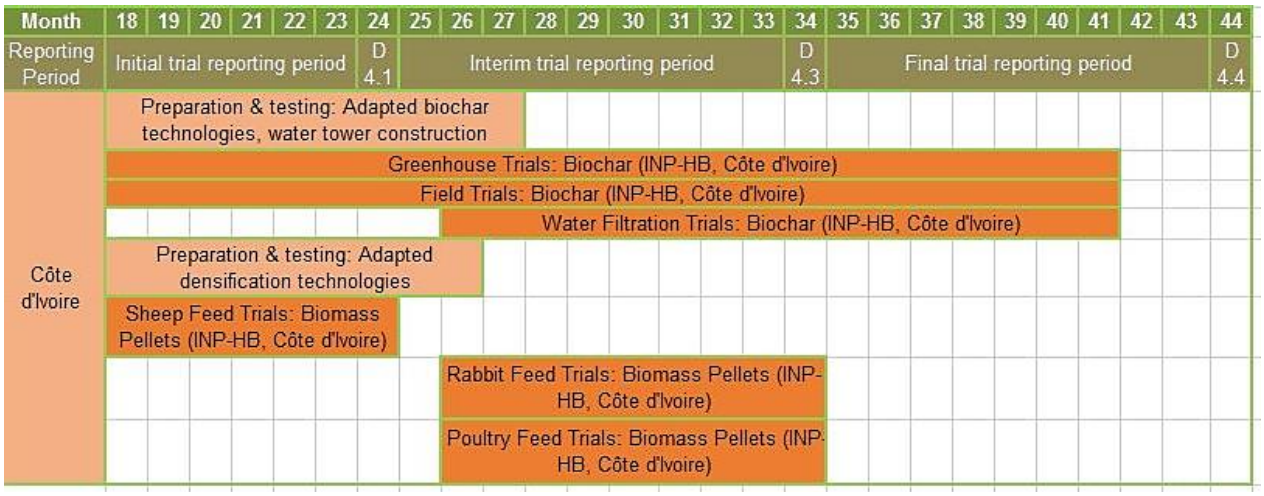
Three main types of trial are being undertaken in Côte d'Ivoire: biochar applications as a soil amendment and a pollution adsorbent, raw biomass pellet feeding trials. An overview of trial plans specific to Côte d'Ivoire is provided in **Fig. 17**. As described in this overview schedule, a number of pilot trials began in Côte d'Ivoire during the initial reporting period, in **M18**:

- Greenhouse trials (biochar as soil amendment);
- Sheep feed trials (raw biomass pellets);

The biochar and sheep feed trials have used locally available technologies for biochar production and pellet production. Preliminary results of soil amendment greenhouse trials and sheep feeding trials are available and are described in **sections 6.1** and **6.2**.

Further adaptation and improvement of production technology took place towards the end of the **initial reporting period** (**M18-M23**), with the instalment of adapted Brazilian kiln technology (**M25, June 2023**) for biochar production, and a larger, more efficient pelletizing machine, with greater productivity and quality (**M25, June 2023**). Results from further biochar and animal feed trials using the new technology adapted to conditions in Côte d'Ivoire will become available during the **interim trial reporting period**, **M24-M33**. Lastly, final results for biochar trials (greenhouse, field, and water filtration trials) with biochar produced using adapted Brazilian kiln technology will become available during the **final trial reporting period**, **M34-M43**.

Figure 146: Overview of pilot trials taking place in Côte d'Ivoire



6.1 Carbonisation

Pre-existing local pyrolysis technology has been used in Côte d'Ivoire to generate biochar from agricultural residues. This has been used as a pollution adsorbent for drinking water filtration (**section 6.1.1**), and as a soil amendment in greenhouse and field trials (**section 6.1.2**). Adapted Brazilian kiln technology will be

implemented in Côte d'Ivoire in **M25** (**June 2023**), and further biochar production will take place with this technology, and subsequently additional trials of each type.

6.1.1 Water filtration

Biochar produced from cocoa pods and cashew nut shells will be applied for use in drinking water filtration systems for the removal of organic and inorganic pollutants, at laboratory scale (WP3) and pilot trial scale (WP4). The trials will first be implemented with biochar created using local pyrolysis technologies, and after the installation of adapted Brazilian kiln technology the trials will also be conducted with biochar created with that technology. Commercial activated carbon will be used as a control treatment. A range of Empty Bed Contact Times will be tested, and the regenerative capacity of the adsorbent will be evaluated by repeating the adsorption/desorption cycle using hot and cold water and the performance of the resulting product will be evaluated in the filter.

Laboratory scale

INP-HB, with the support of IHE, has conducted biochar water filtration tests using a tubular filter with a fixed bed of biochar and using household water from the village of Dougba, near Yamoussoukro, as part of WP3 activities. These tests began in **M18** (November 2023), using pyrolysis created using traditional kiln technology, and will be repeated using biochar from adapted Brazilian kiln technology following installation of that technology in **M25** (June 2023). The treated water samples from both the experimental biochar and control treatments were compared with the WHO standards for potable water on a daily basis. In addition to evaluating pollutant removal efficiency, trials were conducted to optimise filtration system performance parameters such as water filter height, biochar particle size, filtration time, saturation time, and biochar regeneration. The results are described in **D3.2**.

Pilot trials

The optimised filtration system will be piloted in real conditions in the village of Djahakro, near Yamoussoukro, and the agricultural farm of INP-HB. The prototype design comprises a raw water tower, powered by a mechanical solar pump, immersed in a 3m deep borehole, which is connected to a water source, e.g. lake. Three series of three filters (no. filters = nine) filter the water as it flows to a second "treated water" tank, from which it can be further routed to a third and final "storage tank". The biochar and control activated carbon treatments will be used in the filters, to remove pollutants from the raw water. The pilot scale filtration systems are due to be constructed by **M24** (May 2023).

Parameters

The parameters to be examined in the pilot trials are described in **Table 14**.

Table 14: Parameters to be examined in water filtration trials in Côte d'Ivoire

Biochar filtration parameters	Water quality & potability parameters
Pollutant removal efficiency	Chemical Oxygen Demand
Breakthrough time	Calcium ions, hardness
Regeneration capacity	pH
	Turbidity
	Conductivity
	Nitrate
	Carbonate
	Phosphate
	Bacteriological analysis: Colony count of target microorganisms, e.g. *E. coli*, *Streptococci, GAM*
	Copper ions, lead ions

Results

The **calibration tests** of the laboratory-scale water filter have been completed, and the design has been optimised, while the biochar **physicochemical parameters** described in **Table 14** above have been evaluated. These results are described in detail in **D3.2**.

Next steps

Further laboratory-scale analysis will take place as part of **WP3 activities**. The pilot trial will begin later in 2023, following construction of the water tower in May, and when the level of rivers will be sufficient to run the trial (c. April-October). Final results from all evaluations will be available during the **final reporting period (M34-M43)**.

6.1.2 Biochar soil amendment

Biochar created from millet residue, namely husks and stems, using traditional technology is being trialled as a soil amendment in greenhouse trials. Trials for production of tomato and maize began in **M18** (November 2022). These will be supplemented by trials using biochar produced by the adapted Brazilian kiln technology, to begin in **M28** (September 2023).

Greenhouse trials

Three different types of soil will be treated with three different rates of biochar amendment and compared with a control treatment with no biochar added. These combinations will be used to produce tomato and maize, with 12 blocks per plant. The experiments will be replicated three times (total tomato plants = 36, total maize plants = 36). The tomato trials were completed with biochar produced from traditional kiln technology in **M21 (see Fig. 17)**, and the greenhouse trials will continue with maize trials, followed by replication with biochar produced using adapted Brazilian kiln technology in **M28.**

Figure 17: Greenhouse trials using biochar-based soil amendments for a) tomato production and b) maize production in Côte d'Ivoire

a) 

b) 

Field trials

For the field experiment, biochar made with the same feedstocks and the adapted Brazilian kiln technology, will be applied to soil in a 0.5ha plot in each of three different localities and compared to a control plot of equal size with no biochar applied. These plots will be sub-divided, with half of each experimental and control plot used to grow tomato, and the other half used to grow maize, resulting in three plots of 0.25ha per crop and treatment combination, one in each locality (total tomato plots = six; total maize plots = six). The field experiments will begin in **M28** (September 2023), when biochar from the adapted Brazilian kiln technology is available.

Parameters and Timeline

The parameters to be examined are described in **Table 15**. The initial results from the tomato trials are currently being evaluated and will be available during the **interim trial reporting period**, **M24-M33**. Initial trial results will also be available concerning maize greenhouse trial and field trials for both crops during the interim trial reporting period. Final results for all soil amendment trials will become available during the **final trial reporting period**, **M34-M43.**

Table 15: Parameters to be examined in soil amendment trials in Côte d'Ivoire

Soil characteristics	Soil and crop characteristics
pH	Leaf-scale gas exchange
Nutrient content: Nitrogen, Phosphorus, Potassium	Chlorophyll fluorescence
Cation-Exchange Capacity	Plant growth
Enzymatic Activity	Fruit yield
Mycorrhizae	

6.2 Densification

Novel animal feeds will be created in Côte d'Ivoire from agri-food sidestreams, e.g. rubber seed meal, forage species, e.g. *Stylosanthes guianensis* (Stylo) leaves, and biomass with potential anthelminthic effects, e.g. *Cajanus cajan* (pigeon pea). These biomasses will remain raw, i.e. not transformed by thermal, chemical, or biological means, or minimally treated, but will be compressed using the densification technique of pelletizing (**Fig. 19**). The feed pellet composition will be designed for specific animals, i.e. sheep, rabbits, and chickens, and some will be designed to provide additional non—nutrition benefits, e.g. parasite control. The pellets will be trialled in feed trials with farmers to assess their performance in realistic conditions. Sheep feeding trials began in **M18** (November 2022), using pellets produced from pre-existing pelletizing technology, and were completed at the end of **M22** (March 2023). Subsequent trials will make use of a larger and more efficient pelletizing technology, which is expected to be installed in **M26** (July 2023).

Figure 18: Existing pelletizing mill in Côte d'Ivoire, to be replaced with a higher throughput mill to increase viability of animal feed pellet production

6.2.1 Sheep feed pellets

Feeding trials of sheep using raw biomass pellets, for supplementation of sheep nutrition and control of gastro—intestinal parasites, began in **M18** (November 2022). The pellets have been produced using *Cajanus cajan* (pigeon pea) and *Leucaena leucocephala* leaves, locally available fodder with parasitic control potential. These pellets were trialled in a multi-location trial, with three study areas (the South, the Centre, and the North of Côte d'Ivoire). Six farms were selected in each zone, with 12 sheep selected per farm (no. farms = 18, no. sheep = 216). Half of the animals on each farm were randomly assigned to the experimental treatment diet, and half to the control diet of standard feed supplementation, as normal for sheep production.

The trial hypotheses are as follows:

- H1: The pellets based on tanning plants allow to reduce the parasite load of the lambs by at least 80%;
- H2: Pellets made from these plants reduce lamb mortality from 20% to less than 10%;
- H3: Pellets made from these plants improve lamb weight by 25% at 9 months of age.

Parameters

The parameters evaluated in this trial are described in **Table 16.**

Table 16: Parameters to be examined in sheep feeding trials in Côte d'Ivoire

Sheep intake/ performance
Daily feed intake
Animal weight
Feed conversion ratio
Health status, including parasite load
Lamb mortality
Carcass characteristics/ composition

Preliminary results

Some preliminary results from the sheep feeding trials are available, based on trials completed in the Central and Southern region farms. The first results obtained are encouraging. The sheep demonstrated good daily feed intake, and an 80% reduction in parasite load. Lamb mortality was halved, to 10% mortality. The weight of lambs fed the experimental pellets at nine months of age demonstrated a 25% gain, from 20kg to 25kg. Extrapolation of these results to farmer income implies a 15% increase in farmer income compared with the control diet.

Next steps

The results from the Northern region farms will be available during the **interim trial reporting period** (**M24—M33**). Further analysis of zootechnical and sanitary parameters, including the final trial region, will allow final, overall results to be evaluated and implication of these pellets for local farmers to be understood. Following the implementation of a larger and more efficient pelletizing machine, more pellets may be produced to reach more producers with this experimental product.

6.2.2 Rabbit feeding trials

Feeding trials similar to those described in **section 6.2.1** will be carried out among rabbit farmers using pellets containing Stylo leaves, with the aim of improving rabbit productivity. Zootechnical parameters will be examined to evaluate the effects of the pellets, as in the sheep feeding trials. These pellets will be produced

using the larger pelletizing equipment that will be installed in **M26** (July 2023), and the rabbit feeding trials will take place thereafter. Results will be available during the **interim trial reporting period** (**M24—M33**).

6.2.3 Chicken feeding trials

Biomass pellets containing sun-dried and heat-treated[1] rubber seed meal will be trialled on broiler chicken farms for the purpose of evaluating their influence on chicken productivity. The trials will be carried out on the farm of INP—HB in Yamoussoukro. Three experimental treatment diets will be fed, containing pellets with varying amounts of rubber seed meal pellets (10%, 20% or 30%). These will be compared with a control diet of industrial feed with no rubber seed meal pellets. The nutritional content of the pellets will be analysed, in addition to the outcomes for the chickens.

Thirty chickens (Cobb 500 breed) will be randomly assigned to each treatment group, and each treatment will be replicated three times (no. chickens = 360). The chickens will be randomly assigned at one-day-old to one of four 15m^2 floor pens with a deep layer of wood-chip litter, with a treatment group of 30 chickens per pen. Chickens will be fed a standard starter ration for the first week, following which they will be fed the assigned treatment diet from until 42 days old, at a rate of 0.2kg/day. This will be supplemented by free access to water. At the end of trial, chickens will be slaughtered by electrical stunning.

Parameters and Timeline

The parameters to be examined are described in **Table 17**. The data will be analysed using STATA 12, including analysis of covariance, to understand differences between the diets. These pellets will be produced using the larger pelletizing equipment that will be installed in **M26** (July 2023), and the chicken feeding trials will take place thereafter. Results will be available during the **interim trial reporting period** (**M24—M33**).

Table 17: Parameters to be examined in raw biomass pellet chicken feeding trials in Côte d'Ivoire

Pellet composition	Chicken intake/ performance
Dry matter	Daily feed intake
Crude protein	Daily weight gain
Dietary Hydrogen Cyanide	Weekly weight gain (post—fasting)
Starch	Feed: Weight gain ratio
Total fibre	Carcass characteristics/ composition

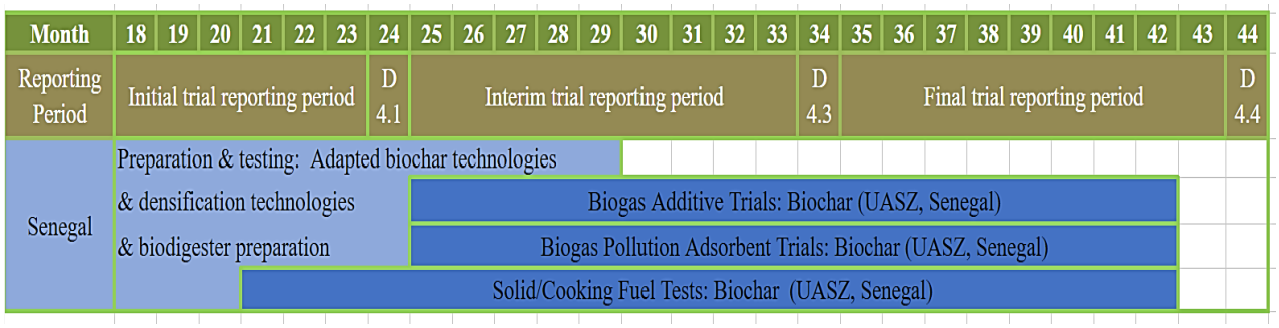
[1] To reduce cyanide content.

Pellet composition	Chicken intake/ performance
Lipid content, fatty acid composition	Meat quality: chicken breast, liver, and thigh composition
Total ash	

7. Pilot Trials in Senegal

A number of trials of biochar-based products will take place in Senegal, including use of biochar as an additive to optimise biogas production and as a pollution adsorbent during biogas production. Densification technology will also be used to create biochar briquettes for use as solid fuel, specifically for cooking. Initial results from planned trials in Senegal will become available during the interim trial reporting period, **M24-M33**. Final results for all trials will become available during the final trial reporting period, **M34-M43**.

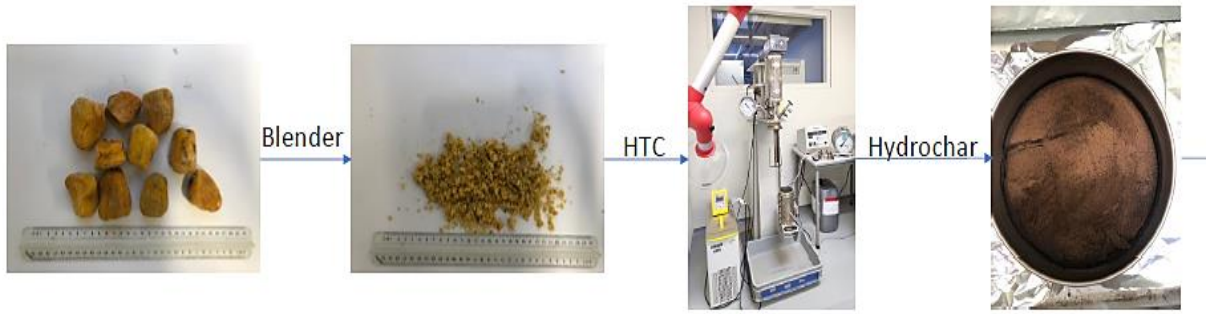
Figure 19: Overview of pilot trials taking place in Senegal



7.1 Carbonisation

In Senegal, local dry pyrolysis technology (barrel reactor), adapted dry pyrolysis technology (rotary kiln carbonizer) and HTC technology will be used to transform agri-food residues, e.g. cashew apple pulp (**Fig. 20**), into biochar This will be used as a pollution adsorbent and performance improver in biogas production (**section 7.1.1**). Biochar will be further treated using **densification technology** (**briquetting, section 7.2**), to be evaluated for use as solid fuel (cooking fuel) (**section 7.2.1**). The dry pyrolysis technologies will be implemented in Senegal from **M28** (September 2023), while HTC technology will be implemented in **M28-29** (September-October 2023), with biochar from dry feedstocks and wet feedstocks being produced after the instalment of each technology, respectively.

Figure 20: Schematic diagram illustrating biochar production from cashew apple pulp (hydrochar) using HTC at laboratory scale in IHE, to be used as a biogas additive



7.1.1 Biogas additive

Biochar produced using cashew apple pulp and typha (HTC technology) and rice husk and peanut shells (dry pyrolysis technology) will be used as a biogas additive with two different purposes. The first will be to use the biochar during anaerobic digestion to enhance biogas production (performance improver). The second is to use biochar as pollution adsorbent to purify the biogas post-production (purification).

Performance improver

The biochar will be added as an inoculum to an agri-food residue substrate generated by a 10m^3 digestor on the UASZ campus which includes cow dung, rice husk, and cashew apple. The rate of biochar addition will be controlled, ranging from 0% biochar addition to a 1:1 biochar and substrate mixture, in increments of 5% increase in biochar and a corresponding 5% decrease in substrate concentration, per trial. A continuously stirred tank reactor of 20L effective volume will be used, working under mesophilic conditions.

Purification

Biochar will also be tested as an adsorbent for the removal of H_2S present in biogas generated using the pilot digestors. Trials will be conducted by UASZ in cooperation with IHE in a 6L capacity tubular filter containing a fixed bed of biochar. The trial will evaluate different Empty Bed Contact Times, and the regeneration potential of the adsorbent by repeating the adsorption-desorption cycle using hot and cold water and evaluating the performance of the resulting product. The H_2S adsorption capacity will be evaluated against international standards on a daily basis, and a control trial using a bed of commercial activated carbon will also be run for comparison.

Parameters and Timeline

The parameters to be examined in both biogas additive trials are described in **Table 18**. The trial is planned to take place from **M25** (June 2023), using biochar produced in the local pyrolysis reactor and oven, and later adapted pyrolysis kiln technology designed to take dry materials for rice husk and peanut shell biochar, and HTC technology for cashew apple pulp biochar. Trial results will become available during the final trial reporting period, **M34-M43**

Table 18: Parameters to be examined in biochar biogas additive trials in Senegal

Biodigester operating parameters	Biogas characteristics	Pollution adsorption parameters
Temperature	Gas composition (CH_4, H_2S, CO_2, N_2, H_2O, trace gases) & proximate analysis	H_2S removal efficiency
Waste feedstock (volume of feeding)	Cumulative biogas and methane yield (total and per organic dry matter)	Breakthrough time
TRH	pH (alkalinity)	Regeneration potential
pH of substrate (alkalinity)	Methane production rate	
Kinetics of daily & cumulative bjiogas production (%N, % organic matter, % dry matter, %C, C/N ration)	Biogas quality analysis	
	Heating value	

7.2 Densification

Biochar from dry agri-food residues will be compressed into briquettes in Senegal, for use as solid fuel, e.g. cooking. A combination of pre-existing local pyrolysis and densification technology was used in **M21** (February 2023) to produce briquettes for trials that began in **M22** (March 2023). These are described in more detail below (**section 7.2.1**). Additional local dry pyrolysis technologies (barrel reactor), adapted dry pyrolysis technology (rotary kiln carbonizer), and improved briquetting technology will be implemented in Senegal from **M24** (May 2023), and the briquettes produced from the additional technologies will subsequently be evaluated.

7.2.1 Solid fuel for cooking

Biochar for fuel use will be generated from dry agri-food residues: peanut shells, corn stalks or millet stalks, and will subsequently be transformed into biochar briquettes. UASZ, ENERGECO, and CIRAD will evaluate the application as solid fuel for cooking using improved "Jambar" stoves with an extractor chimney (see **Fig. 10, section 3.2.3**). The parameters to be examined are described in **Table 19**. The trial began in **M22** (April 2023), using biochar produced with pre-existing technology. Further carbonisation and briquetting technologies are due to be implemented from **M24** (May 2023), which will allow more efficient production of better-quality

briquettes. Initial results from this trial, should be available during the interim trial reporting period, **M24-M33**. Final results will become available during the final trial reporting period, **M34-M43**.

Table 19: Parameters to be examined in trials of solid fuel for cooking in Senegal

Briquette characteristics	Emissions characteristics
Proximate analysis	Toxic emissions during combustion
Ultimate analysis	Gas production
Bulk density	Carbon dioxide (CO_2)
Impact resistance	Carbon monoxide (CO)
Ease of ignition	Particulate matter (PM2.5)
Calorific value	
Mechanical resistance	
Moisture uptake	
Cooking applications (time required to prepare a pre-defined meal)	

8. Conclusion and Way Forward

This document details the planned pilot trials, including timelines and parameters to be examined during the trials. The document also details trials that were initiated during the **initial trial reporting period (M18-M23)**, and preliminary and final results where available.

Twenty-two trial plans have been developed around the products from three main technology types: **green biorefinery**, **carbonisation** (slow pyrolysis/HTC), and **densification** (pelletizing/briquetting). Four of those trials were initiated between **M18-M23**, in Ghana, Côte d'Ivoire and Senegal. These were trials that could begin using pre—existing locally available technologies with the novel agri-food residues and uses identified through this project, i.e. **biochar** products in Ghana (**soil amendment field trials**) and Côte d'Ivoire **(soil amendment greenhouse trials)**, and products of **densification** in Côte d'Ivoire (**sheep feed**) and Senegal (**solid fuel for cooking**).

Of the four trials that were initiated, one trial was completed, sheep feeding trials in Côte d'Ivoire. Initial results have been provided in this report, with final results to come in the **interim trial reporting period (M24-33**). From the preliminary results, positive outcomes have been experienced in the sheep feeding trials, and optimal feedstock combinations, have been identified, enabling products of consistent quality and associated application outcomes to be produced. Laboratory-scale water filtration has also been completed in Côte d'Ivoire as part of WP3 activities, and a large-scale water filtration trial is planned in Côte d'Ivoire in the interim trial reporting period of WP4. Greater production of sheep feed pellets is also likely to take place when new pelletizing technology installed in Côte d'Ivoire.

Pelletizing equipment is just one of the adapted technologies to be implemented in the interim trial reporting period. New densification equipment will also be installed in Ghana and Senegal for the production of products for use in pilot trials, and green biorefinery equipment will be installed in Ghana, while adapted carbonisation technology, e.g. Brazilian kiln and HTC, will be implemented in each of the four countries during the interim trial reporting period.

As a consequence of the installation of additional technologies, the remaining 18 pilot trials will begin during the **interim trial reporting period (M24—33)**, and replication of trials already initiated with products from new technologies, e.g. biochar from adapted Brazilian kiln technology. **Preliminary results** will be collected about all trials taking place within the interim trial reporting period, in so far as possible, for inclusion in **D4.3: Interim report on trials and results**. A further six trials will be completed within the interim trial reporting period, including **pig, chicken** and **piglet feeding trials** and **biorefinery whey screening** in **Uganda** and **rabbit and poultry biomass pellet feeding trials** in **Côte d'Ivoire**. Preliminary results for some of these, and the final results for trials completed in the initial trial reporting period, are expected by the end of the interim trial reporting period.

No further trials will be initiated in the **final trial reporting period (M34-43).** Final results for the trials not reported on in full during the **interim trial reporting period** will be available during the final trial reporting period. These will be included in **D4.4: Final report on trials and results.** The preliminary results will already feed into other work packages before the final trial reporting period is over, and close cooperation with collaborators on other work packages, e.g. **WP5, WP6 and WP7** will ensure that applicable results are shared when available to ensure good functioning of the project.

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