INDUSTRIAL RESEARCH, PROCESS OPTIMIZATION, AND COMMERCIAL PRODUCTION OF SWEET POTATO-BASED STARCH DERIVATIVES, COLD-WATER-SOLUBLE STARCH, SWEET SYRUPS, CORRUGATED PACKAGING ADHESIVES, AND ANIMAL FEED FOR AGRO-ALLIED AND CONSUMER MARKETS IN NIGERIA

EXECUTIVE SUMMARY

Project Title:
Industrial Research, Development, and Commercial Production of Sweet Potato Starch Derivatives, Sweet Syrups, Adhesives, and Feed Formulations for Consumer and Agro-Allied Markets

Vision & Purpose:

This project seeks to establish a commercially scalable agro-industrial platform for producing multiple value-added products from Nigerian-grown sweet potatoes. Drawing from over a decade of applied R&D, peer-reviewed publications, and field-tested prototypes, the project aims to reduce Nigeria's dependence on imported starch derivatives and sweeteners, curtail post-harvest losses, and catalyze local innovation in agro-processing.

The Opportunity:
Nigeria is the second-largest producer of sweet potatoes in sub-Saharan Africa, yet less than 5% of the crop is industrially processed. Imports of starch-based raw materials exceed ₦100 billion annually. This project proposes a holistic conversion of sweet potato tubers into:

1. **Native starch** (for food and industrial applications),
2. **Cold-water-soluble starch (CWSS)** for use in laundry and textile stiffening,
3. **Sweet syrup concentrates** derived from the naturally sweet supernatant,
4. **Corrugated board adhesives** from starch hydrolysis, and
5. **Nutritionally enhanced animal feeds** from process residues.

Approach:

A pilot facility with 500 kg/day starch capacity will be established using locally fabricated stainless-steel equipment, and fitted with a 40KVA generator and pillow packaging machine. The project will advance existing research into optimized industrial processes under a Research–Development–Commercialization (R-D-C) framework. Strategic sourcing will be drawn from sweet potato clusters in Kano, Bauchi, and Plateau States, with local youth and farmer cooperatives integrated as supply chain partners.

Innovation & Impact:

This proposal builds on prior innovations including published studies on cold-water-soluble starch, conference presentations, and in-lab production of adhesives. The project aligns with NASENI's

Agricultural and Food Manufacturing Thematic Area and the Renewed Hope Agenda. It offers import substitution, rural employment, and sustainable agro-waste utilization.

Market & Sustainability:

Products will serve multiple end-users: households (CWSS sachets), packaging firms (adhesives), confectioners (syrups), and livestock producers (feed). Commercial channels will include distributors, B2B contracts, and retail packaging. The business targets a **₦36 million annual net profit** at full capacity with a 25% profit margin and breakeven within the first year.

Expected Outcome:

- A functional pilot plant ready for commercial expansion
- Scalable production of five product lines from sweet potatoes
- Strengthened local content in agro-processing value chains
- A commercially viable and socially inclusive enterprise model

1.0 Background and Rationale

1.1 Overview of Nigeria's Starch and Sweetener Industry Deficit

The starch processing industry in Nigeria stands at a critical juncture. Although the country possesses abundant starch-bearing crops including roots, tubers and cereals its capacity to convert these into industrial-grade starches and derivatives remains negligible. Adigwe *et al*. (2025) reports that "although all the starch crops are abundantly produced in Nigeria, only less than 1% is processed into high quality starch for industrial processes" (Table 1.1). A recent market study estimates the Nigerian starch-processing market to reach USD 574.11 million by 2030, yet still identifies a heavy reliance on imported starch and derivatives to meet food, pharmaceutical, feed and industrial applications (Data Bridge, 2023). Further, the market for starch derivatives (glucose syrups, maltodextrins, hydrolysed starches) is expanding, driven by urbanization, processed-food demand and functional-ingredient trends; however, domestic value-addition remains under-leveraged (6WResearch, 2024).

Table 1.1: Summarises the key supply-demand gap indicators.

Indicator	**Estimate**	**Implication**
Proportion of starch crops processed into industrial-grade starch	< 1% (Adigwe *et al.*, 2025)	Major under-utilisation of raw material
Projected starch-processing market value by 2030	USD 574.11 m (Data Bridge, 2023)	Strong market growth opportunity
Dominant uses of derivatives (food, pharmaceuticals, feed)	–	Broader value chain beyond staple uses

This disparity between raw-material abundance and industrial conversion underscores both a critical bottleneck and a significant opportunity for value-chain development, especially in root/tuber crops such as the sweet potato.

1.2 Summary of Sweet Potato's Agronomic and Biochemical Advantages

Sweet potato (*Ipomoea batatas L.*) is a versatile root crop with agronomic, nutritional and industrial attributes. Agronomically, it thrives in marginal soils with minimal inputs and relatively short growth cycles, making it attractive in smallholder contexts (Malhotra *et al*., 2022). Nutrition-wise, sweet potato roots are rich in starch, dietary fibre, protein and an array of micronutrients including β-carotene (Amagloh & Kang, 2021). In the Nigerian context, production statistics indicate that the crop had an agricultural production value of USD 954 million in 2010 and accounted for about 1.73% of total crop production value (EPAR-UW, 2014). Compared with other starch crops, sweet potato offers several advantages:

- Shorter maturation time and flexibility of harvest.
- High starch content relative to many traditional cereals.

- Potential for multi-product valorisation - starch extraction, syrup production, feed by-product utilisation.
- Adaptability across agro-ecological zones in Nigeria (Odebode, 2008).

Given these strengths, sweet potato becomes a highly promising feedstock for starch derivative processing and value-chain intervention.

1.3 Key Research Evidence from Prior Work

Previous investigation in Nigeria has established the feasibility of extracting starch from local sweet potato cultivars and modifying it to cold-water-soluble forms. Yusuf *et al.* (2022) extracted starch from sweet-potato tubers produced in Kano, achieving yields and modification profiles that support downstream functional applications. These results provide a robust scientific basis for scaling from laboratory to pilot and industrial levels. They demonstrate not only the viability of sweet potato as a starch source but also the potential for derivative modification, thus laying the groundwork for commercialization as addressed in this proposal.

1.4 Problem Statement: Post-Harvest Wastage, Low Industrial Utilization, and Over-Reliance on Imports

Despite the agronomic and nutritional merits of sweet potato and other starch crops in Nigeria, several structural challenges inhibit value-chain development. First, post-harvest losses in root and tuber crops remain high, shrinking the effective raw-material pool for processing. Secondly, industrial utilization of domestically produced starch is extremely limited (< 1% processed industrially) (Adigwe *et al*., 2025) resulting in lost value and missed employment opportunities. Thirdly, Nigeria continues to rely heavily on imported starch and derivatives (e.g., corn starch, potato starch) to meet local demand (Corn Starch import data, 2023)
This triad of raw-material wastage, low processing capacity, and import dependence forms a barrier to agricultural transformation, industrialization and job creation. There is, therefore, an urgent need to establish indigenous, scalable processing of sweet-potato starch derivatives, sweet syrups and feed formulations for domestic and agro-allied markets.

1.5 Strategic Alignment with NASENI's Agriculture & Food Manufacturing Thematic Area and the Renewed Hope Agenda

The proposed project aligns closely with the mandate of the National Agency for Science and Engineering Infrastructure (NASENI) to drive indigenous industrialization through research, development and commercialization of technologies (NASENI Watch, 2024). In particular, the Agency's focus on converting research innovations into market-ready solutions mirrors the thrust of this proposal.
Moreover, the project is congruent with the national policy direction set under the Renewed Hope Agenda of President Bola Ahmed Tinubu, which identifies "Boost agriculture to achieve food security" as a core priority (CDCU, 2025). The Federal Ministry of Agriculture and Food Security has likewise re-oriented policy to mechanization, value-addition and food-chain resilience.
By transforming sweet potato starch into high-value derivatives, syrups and feed products, this initiative supports industrialization, import-substitution, rural job creation and value-chain

revitalization thereby embodying both NASENI's commercial mandate and the Renewed Hope Agenda's vision for an agriculture-driven economy.

1.6 Theoretical Framework

The framework guiding this project is anchored on value addition**,** innovation diffusion**,** circular bioeconomy**,** and systems theory, all supporting its aim to develop and commercialize indigenous technologies for processing Nigerian sweet potatoes into starch derivatives, syrups, adhesives, and animal feeds. It emphasizes transforming raw tubers into high-value products, promoting technology adoption across industries, ensuring zero waste through residue conversion into animal feed, and integrating all processing stages into a cohesive, efficient system. Together, these principles drive industrial innovation, sustainability, and socio-economic impact in Nigeria's agro-processing sector.

The conceptual framework links the inputs, processes, outputs, and outcomes of the project, illustrating how indigenous technological innovation and value-chain integration can drive industrial and socio-economic development (Figure 1.1).

a. Key Components

- **Inputs:** Sweet potato tubers, local fabrication expertise, processing equipment, enzymes, chemicals, energy, and skilled technical staff.

- **Processes:**

    1. Starch extraction and purification.
    2. Modification to cold-water-soluble starch (CWSS).
    3. Enzymatic hydrolysis to produce sweet syrups.
    4. Adhesive formulation using CWSS and borax/alkali.
    5. Feed formulation from fibrous residues.
    6. Product testing, packaging, and regulatory certification.

- **Outputs:**

    1. Industrial-grade native starch
    2. Cold-water-soluble starch (CWSS)
    3. Sweet syrups (glucose/maltose)
    4. Corrugated packaging adhesives
    5. Animal feed formulations

- **Outcomes/Impacts:**

    1. Import substitution for starch and adhesives
    2. Reduction in post-harvest losses

3. Job creation and rural industrialization
4. Support for NASENI's agro-industrial mandate
5. Enhanced food security and economic diversification

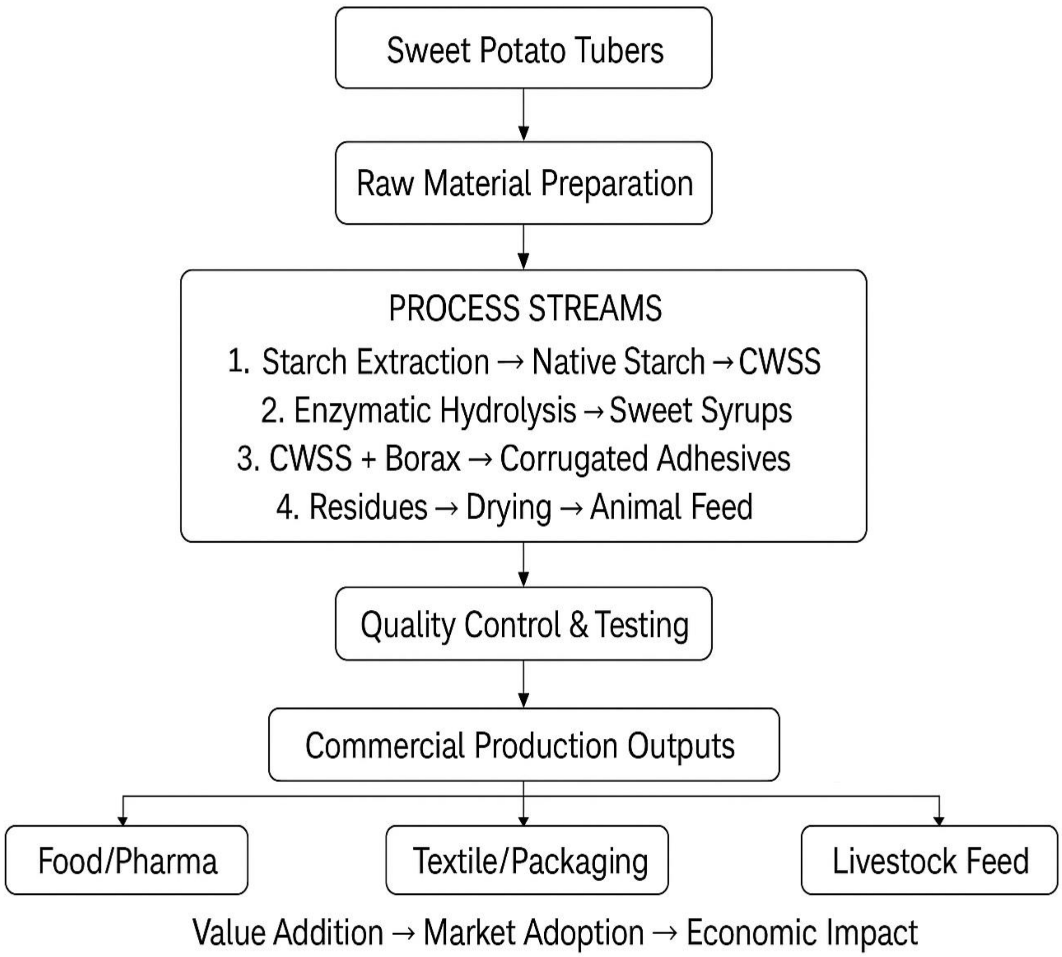

Figure 1.1: Depicts the conceptual framework of the project

Summary of Relationships

Variable Type	Elements	Description
Independent Variables	Sweet potato availability, technology adoption, R&D input	Drive the processing chain
Intervening Variables	Process optimization, equipment efficiency, regulatory support	Affect conversion rate and quality

Variable Type	Elements	Description
Dependent Variables	Industrial output, economic viability, job creation	Reflect project success and sustainability

2.0 Literature Review

2.1 Starch Extraction

Starch, the second most abundant biomass in nature, offers a highly versatile polymer that is readily modified chemically, physically, enzymatically, and biologically (Ghasemlou *et al*., 2013). The rationale for focusing on the starch industry is that it is under-exploited in Nigeria and has great potential for driving agribusiness development based on its low-cost availability, high calorific value, excellent inherent physicochemical properties, and the ease of its modification to other derivatives. Nigeria is one of the largest producers of sweet potato (*Ipomoea batatas*) in the world, and the largest in sub-Saharan Africa, producing about 4 million metric tons of sweet potato annually. Yet, ironically, Nigeria contributes less than 2% of global starch production because of its fragmented, unsophisticated agricultural, industrial, research and development structure. In fact, over 95% of Nigerian industrial starch needs are met through imports, with about $580 million spent annually (Okojie, 2017).

Starch can be modified to enhance its functional properties to suit the needs of various industries-pharmaceutical, paper, textile, food and beverage, etc, and to create bio-products like bioplastics for packaging, construction, and design (Table 1). It may be modified to enhance stability (e.g., by adding antioxidants or UV absorbers), optimize or modify drug release (using disintegrants, hydrophilic polymers, wetting agents, biodegradable polymers), provide essential manufacturing functions (as binders, glidants, lubricants), or enhance consumer acceptance or product identification (using flavours, colorants) (Mohammed, 2017). In the pharmaceutical industry, without non-toxic, inert filler materials like starch, it would be almost impossible to produce acceptable potent drug forms suitable for patient administration. Modified starches are thus critical to the design of drug delivery systems and play a major role in their quality and performance (Mohammed, 2017).

On the other hand, food-grade starches are chemically modified mainly to increase paste consistency, smoothness, and clarity, and to impart freeze-thaw and cold storage stabilities (Singh *et al*., 2007). Bio-products produced from starch include bioplastics, nanoparticles, biomedical products, and drug-delivery materials (Xie *et al*., 2013). Starch-based plastics and films have advantages in food applications because of their transparency, high oxygen barrier, and lack of flavour and odour (Acosta *et al.*, 2016). Starch is used to sweeten and to influence or control characteristics such as texture, moisture, consistency, and shelf stability. It can be used to bind or to disintegrate; to expand or to densify; to clarify or to opacify; to attract or to inhibit moisture; to produce a smooth or pulpy texture; to create soft or crisp coatings; and to stabilize emulsions or to form oil-resistant films (Miyazaki *et al.*, 2006).

Sweet potato starch has immense potential for growth through innovation and competitiveness in both industrial and human applications. The unique properties of its starch suggest uses in specialty markets such as baby foods, non-allergenic products, and foods for hospitalized patients. Its starch can be modified to provide required characteristics and can compete with other starch sources in producing value-added products for various industries, including paper and textile sizing, glues and adhesives, monosodium glutamate (MSG), sweeteners, pharmaceutical tablet disintegrants, biodegradable plastics, butanol and acetone solvents, explosives, corrugated board adhesives, and bioplastics (Jonhed, 2006).

2.2 Starch Modification

Each starch needs to be modified to increase its usefulness and value. Starch modification involves altering the physical and chemical characteristics of native starch to improve its functional properties for specific applications. Possibilities for new modified starch products beyond simple physical modifications are offered by controlled reaction sites within granules, controlled reaction sites on molecules, and biological modification of existing commercial base starches (BeMiller, 1997). In its native form, without modification, starch has a limited number of applications and is used mainly as a binder or thickener. However, upon heating in water, the helices within the amylopectin regions of starch melt and the granule starts to swell, increasing the viscosity of the solution. Further heating and stirring lead to disintegration of the granule structure, solubilization of the starch, and a loss of viscosity. Upon cooling, the linear chains re-associate into aggregates, precipitate, and set to form a gel. Its low shear resistance, poor thermal stability, thermal decomposition, and high tendency towards retrogradation limit its use in some industrial food applications. Controlling these processes is a key factor in starch functionality and is achieved mainly by modifying the starch while it is in the granular state (Jobling, 2004).

Starch modification is generally achieved through derivatization (such as etherification, esterification, cross-linking, or grafting of starch); decomposition (acid or enzymatic hydrolysis and oxidation of starch); or physical treatments (using heat, moisture, etc.). Chemical modification involves the introduction of functional groups into the starch molecule, resulting in markedly altered physicochemical properties. Such modification of native granular starches profoundly alters their gelatinization, pasting, and retrogradation behaviour. For example, cross-linking treatment is intended to add intra- and inter-molecular bonds at random locations in the starch granule that stabilize and strengthen the granule (Choi & Kerr, 2003). This restriction of swelling, along with the addition of charged groups to the chains to stabilize gel formation, makes cross-linked starches more tolerant of extreme heat and cold, as well as high or low pH, allowing their use under a wide variety of processing conditions (Jobling, 2004). Thus, starch pastes from cross-linked starches are less likely to break down under extensive heating, increased acidity, or severe shear conditions. Cross-linking is generally performed by treating granular starch with multifunctional reagents capable of forming ether or ester inter-molecular linkages between hydroxyl groups on starch molecules (Singh *et al*., 2007). The only naturally occurring covalent modification of starch is phosphorylation, and the level of phosphate substitution strongly influences the physical properties of starch, such as its high swelling power and stable paste properties. The enzyme responsible for incorporating phosphate groups into starch was discovered in potato and has been identified as an α-glucan water dikinase (GWD) (Jobling, 2004).

Physical modification methods can be safely used in food products since they do not involve chemical reagents. There has been a wave of new methods in the physical modification of starches. Some of the new physical modification techniques investigated in the last two decades include:

- Osmotic-pressure treatment – Pukkahuta *et al*. (2007)
- Deep freezing – Szymońska *et al*. (2000)
- Multiple Deep Freezing and Thawing – Szymońska *et al*. (2003)
- Instantaneous Controlled Pressure Drop (DIC) process – Zarguili *et al*. (2006)
- Mechanical Activation (Stirring Ball Mill) – Huang *et al*. (2007)
- Micronization in Vacuum Ball Mill – Che *et al.* (2007)
- Pulsed Electric Fields Treatment – Han *et al.* (2009)
- Corona Electrical Discharges – Nemtanu & Minea (2006)

The adoption of various starch modifications has led to an evolution of new processing technologies and market trends. These highly functional starch derivatives have been tailored to create competitive advantages in new products, improve product aesthetics, simplify product labelling, lower formulation and production costs, increase product throughput, eliminate batch rejects, ensure product consistency, and extend shelf-life, all of which clearly demonstrate the relevance of starch at every stage of a product's lifecycle (Murphy, 2000; Wurzburg, 1986). Starch modification is an ongoing process with numerous possibilities, and there is a huge market for the many new functional properties and added-value products resulting from these modifications (Kaur, 2012).

Enzymatic modification of starch has primarily employed hydrolysing enzymes, and one major class of products from such modification is syrups (e.g., glucose syrup or high fructose corn syrup). With ongoing research, more enzymes are being identified for use in starch modification. Because the glycaemic index (GI) of foods is linked to diseases like diabetes, prediabetes, cardiovascular disease, and obesity (Ludwig, 2002), it is becoming important to develop more low-GI foods to help control these conditions. One approach is to produce foods containing starch that is digested slowly. In one study, there was a significant reduction in rapidly digested starch by 14.5%, 29.0%, 19.8%, and 31.0% when maize starch was modified with β-amylase; β-amylase and trans glucosidase; maltogenic α-amylase; and maltogenic α-amylase with trans-glucosidase, respectively. An increase in starch branch density and crystalline structure in the modified starches was thought to contribute to the slower digestion (Ao *et al.,* 2007).

It should be noted that native starch, without any modification, has limited uses primarily as a binder or thickener as mentioned earlier. Upon modification, however, starch can play many roles: for instance, it can sweeten; it can influence or control texture, moisture, consistency, and shelf stability; it can bind or disintegrate; expand or densify; clarify or opacify; attract or repel moisture; produce smooth or pulpy textures; create soft or crisp coatings; and stabilize emulsions or form oil-resistant films (Miyazaki *et al.,* 2006).

In its native form, starch's limitations (low shear and thermal resistance, etc.) restrict its industrial applications as noted. However, upon heating and gelatinization, followed by cooling, starch undergoes retrogradation, which can negatively affect product quality. Controlling these processes through modification is crucial, as discussed, and is typically done when starch is in granular form (Jobling, 2004). Starch modifications via derivatization (chemical means like cross-linking) introduce new bonding or functional groups, and as noted, cross-linked starches resist breakdown under extreme processing conditions (Singh et al., 2007; Jobling, 2004). Phosphorylation within starch granules, as occurs naturally at low levels in some starches (e.g., potato starch), greatly enhances swelling and paste stability, and the discovery of the GWD enzyme has provided insight into this modification (Jobling, 2004).

Advances in genetic engineering have made the genetic modification of starch *in planta* possible by targeting enzymes in the starch biosynthetic pathway. This transgenic approach has the potential to produce novel starches that reduce or eliminate the need for environmentally hazardous post-harvest chemical and enzymatic modifications (Davis *et al.*, 2003).

The Nigerian starch industry has several strengths, including a huge domestic market (perhaps its greatest strength), a suitable climate, ample arable land, widespread familiarity with sweet potato cultivation, and high-yielding sweet potato varieties. However, the unrelenting environmental impact of plastic wastes and the unsustainability of their fossil-fuel origins have led to widespread global concern and interest in bioplastics (Gutiérrez & Álvarez, 2016; Podshivalov *et al.*, 2017; Tian *et al.*, 2017). In Nigeria, a country of approximately 200 million people, solid waste is generated at an average rate of 0.43 kg per person per day, with about 40% of this waste consisting of plastics (Sridhar, 2006; Ogwueleka, 2009). This reality prompted the Nigerian House of Representatives to pass a bill banning the use of plastic bags in May 2019. Bioplastics are emerging as a highly sought-after innovative material in response to the ever-increasing demand for more environmentally friendly solutions.

Considering the implications for our economy and environment, it is clear that we need to initiate and support domestic research in this vital area, with the aim of adopting and optimizing current global trends using local raw materials and resources to suit local needs and capacities. By doing so, Nigeria can eventually claim its rightful place in the $9 billion global starch market. This literature review highlights ways in which two of our most abundant yet underutilized crops could help address some of our most pressing challenges unemployment, lack of economic diversification, insecurity, poverty, and environmental degradation.

2.3 Sweet Potato Starch: Extraction, Modification, and Industrial Applications

2.3.1 Extraction of Starch from Sweet Potato Tubers

Sweet potato (Ipomoea batatas) tubers are a rich source of starch (roughly 24–27% of fresh weight is carbohydrate, with starch comprising the majority) (Rezvanian, Jafarinejad, & Bovell-Benjamin, 2022) To extract this starch, industry typically employs a wet milling process: the tubers are washed, peeled, and finely grated or pulverized in water, releasing starch granules which are then separated from fibre by filtration or centrifugation). The crude starch is repeatedly settled or centrifuged, washed to remove impurities, and dried to yield a fine white powder Under conventional methods, the starch recovery from fresh sweet potato can range around 10–20% by weight, though variations are large depending on cultivar and extraction efficiency (yield values of ~9.5% up to ~27% of fresh tuber weight have been reported). Such variability underscores the importance of optimizing extraction conditions and sweet potato varieties for higher starch output (Dorantes-Fuertes *et al.*, 2024).

Recent research has improved extraction techniques to increase yield and starch quality. Pre-treatments like soaking cut sweet potato in dilute sodium bisulfite (≈1500 ppm) help prevent enzymatic browning and oxidation during processing. Mild alkaline treatments (e.g., NaOH digestion) have been used to soften cell walls and speed starch release. Enzymatic methods are particularly effective- adding cell wall-degrading enzymes such as cellulase and xylanase can break down the pectin-cellulosic matrix of the tuber, freeing more starch granules and significantly boosting extraction yield. For example, one enzymatic process combining cellulase and xylanase yielded high starch recovery and high-purity product from sweet potato. Use of such "green" extraction aids, as well as novel mechanical techniques (ultrasound, pulsed electric field, etc.), is helping make starch isolation more efficient and sustainable.

In summary, the literature shows that by carefully selecting sweet potato varieties and applying optimized pre-treatment (chemical or enzymatic) during wet milling, producers can obtain improved starch yields while maintaining purity (sweet potato starch typically has low protein, fat, and ash content, indicating high purity) (Ghoshal & Kaur, 2023). These advancements in extraction are crucial for making sweet potato starch a competitive raw material in industry (Azadi *et al.*, 2024)

2.3.2 Cold-Water-Soluble Modified Starch for Textile Applications

Native sweet potato starch, like other starches, is only sparingly soluble in cold water due to its granular crystalline structure. In textile processing (e.g., warp sizing and fabric finishing), starch is traditionally used to impart temporary stiffness, strength, and smoothness to yarns and fabrics (Puri et al., 2025). However, using unmodified starch requires heating to gelatinize it into a usable paste, which can be energy-intensive. To address this, researchers have developed modifications that render sweet potato starch cold-water-soluble or cold-water-swellable, so it can be used in textile applications without high-temperature cooking. One common approach is physical pre-gelatinization: heating the starch in water (or rolling/drying it) to disrupt granule structure, then drying it. Pregelatinized sweet potato starch can disperse in cold water, forming a viscous solution useful for "steeping" fabrics or yarns (i.e. saturating them with starch solution for sizing) (Li et al., 2024) (Puri et al., 2025).

Chemical modifications can also produce cold-water-soluble starch derivatives. For instance, carboxymethylation (etherification of starch with chloroacetic acid) introduces hydrophilic carboxymethyl groups. Carboxymethylated sweet potato starch dissolves readily in cold water and has been widely used as a textile sizing and printing agent. This modified starch can be applied to cotton or polyester warp yarns at room temperature, forming a film upon drying that protects the yarn during weaving and adds stiffness to the fabric finish. Another strategy is oxidation of starch (using agents like sodium hypochlorite or hydrogen peroxide) to cleave some glycosidic bonds and add carbonyl/carboxyl groups. Oxidized sweet potato starch has lower molecular weight and pasting temperature, making it partially soluble in cold water and giving it good film-forming properties for yarn sizing. Mild oxidants such as hydrogen peroxide tend to preserve more viscosity while still improving cold-water dispersibility.

Chemical substitutions that add ionic or bulky groups can greatly enhance cold-water solubility. For example, sulfosuccinylation (esterification with sulfosuccinic anhydride) was found to improve starch’s adhesion to fibres and allowed a sizing formulation usable at ~40 °C (Li et al., 2024). In practice, a combination of modifications may be used.

Starch manufacturers often produce proprietary “instant soluble” starches for textiles by dual methods (e.g., mild acid hydrolysis followed by etherification). The result is a starch that swells or dissolves in cold water to the desired viscosity. Such cold-water-soluble sweet potato starch derivatives can be directly mixed into a sizing bath or fabric finishing solution without heating, saving energy and simplifying the process on an industrial scale. Studies report that textiles treated with these modified starches have comparable performance to those sized with traditional hot-prepared starch, providing adequate strength and abrasion resistance to the yarns during weaving (Moore, 1941). Overall, through physical and chemical modifications (pre-gelatinization, oxidation, etherification, etc.), sweet potato starch can be converted into a cold-water-soluble form that is highly convenient for textile applications, combining the renewable, biodegradable nature of starch with modern processing efficiency (Puri *et al.*, 2025).

2.3.3 Conversion of Sweet Potato into Glucose and Maltose Syrups

Beyond native starch uses, sweet potato can be further processed into sweeteners. In fact, the high starch content and the presence of sugars (glucose, fructose, sucrose) in sweet potato roots make them suitable feedstock for syrup production) (Rezvanian *et al.*, 2022*)*. Glucose syrup (a mixture of glucose and oligosaccharides) can be produced from sweet potato starch via hydrolysis processes similar to those used for corn syrup. Typically, the starch is first gelatinized with water (by heating), then liquefied by α-amylase enzyme, which breaks starch into shorter dextrins. After liquefaction, a saccharification step uses glucoamylase (amyloglucosidase) to convert dextrins fully into D-glucose. Rezvanian *et al*. (2023) describe this multi-step enzymatic hydrolysis as the standard route for sweet potato glucose syrup: starch gelatinization, α-amylase liquefaction, and enzymatic saccharification yield a high-glucose solution, which is then refined and concentrated into syrup. Enzyme-based processes are preferred because they give high yields of dextrose equivalent with minimal by-products; in contrast, acid hydrolysis of sweet potato starch, while possible, can produce unwanted flavours and a darker coloured syrup. Early attempts using acid or acid-enzyme combinations noted issues of bitter taste and colour unless further purification (e.g. activated carbon treatment) was applied. Modern enzyme technologies have largely overcome these issues, producing clear, high-purity syrup from sweet potato that is acceptable for food use.

Research has also explored making maltose-rich syrup from sweet potato starch. By using β-amylase enzymes (which release maltose disaccharides from starch) instead of or in addition to glucoamylase, the hydrolysate can be tailored to a high-maltose content. However, because β-amylase alone cannot bypass starch branch points, debranching enzymes like pullulanase or isoamylase are often added to assist in converting amylopectin into maltose units. This approach yields a syrup where maltose is the predominant sugar, which is useful for certain confectionery and brewing applications. For instance, one study reported that using β-amylase on liquefied sweet potato starch (with debranching enzyme support) produced a maltose syrup efficiently, whereas a glucoamylase route produced mainly glucose. The flexibility of enzymatic hydrolysis means sweet potato can generate various saccharide profiles (maltodextrins, glucose syrup, high-maltose syrup, or even high-fructose syrup after glucose isomerization) depending on enzyme selection and process conditions. Johnson et al. (2009) demonstrated a direct conversion technique on sweet potato roots to produce glucose and high-fructose syrup, finding that sweet potato's efficiency was comparable to cassava in yield and easily could be enzymatically isomerized to fructose syrup if desired. This suggests sweet potato is a viable alternative raw material for producing syrups in regions where corn or cassava may be less available.

A 2023 review by Rezvanian and colleagues highlights that sweet potato syrup production is attracting interest for its potential economic and nutritional benefits. Sweet potato-based syrups could offer a sustainable sweetener source that adds value to surplus or sub-grade roots, reducing waste. Moreover, sweet potato has a lower glycemic index than some other starches, and research into syrup characteristics continues (e.g., optimizing enzyme doses, reaction pH/temperature, and addressing syrup storage stability).

Overall, converting sweet potato starch into glucose or maltose syrups is a well-demonstrated process in the literature, and ongoing studies aim to refine these processes for cost-effectiveness and product quality. With appropriate enzymatic technology, sweet potato can yield high-glucose syrups that are virtually indistinguishable from conventional corn syrup, as well as specialty syrups like high-maltose, thereby broadening the industrial use of this crop.

2.3.4 Starch-Based Adhesives from Sweet Potato for Packaging

One of the oldest and most widespread industrial uses of starch is in the production of adhesives, particularly for paper and packaging. Starch-based adhesives are predominantly used in corrugated cardboard manufacture, where a suspension of starch is applied to bond the layers of paper (linerboard and fluted medium) (Kruger & Lacourse, 1990 (Luo *et al*., 2011). Upon heating and subsequent cooling, the starch paste gelatinizes and then sets into a firm adhesive layer. While most corrugation plants historically use corn starch, other starches like tapioca (cassava) and potato are also common, and sweet potato starch can likewise be used as the base for these adhesives (Hasna, 2003. In fact, patents for corrugating adhesives explicitly list **sweet potato starch** as a suitable raw material alongside corn, wheat, and cassava starches (Onusseit, 1992). Sweet potato starch has relatively high amylose content (often around 20% or more (Cereda, 2024), which is beneficial for adhesive strength since amylose contributes to strong gel formation. Research on starch gels indicates that higher-amylose starches produce adhesives with greater cohesive strength and better paper bonding performance (Liu et al., 2023). Even unmodified sweet potato starch, when cooked with the typical additives (alkali and borax), yields a glue with good tack and bond strength suitable for corrugated board production. A mid-20th-century study found sweet potato starch equal or superior to maize starch for warp yarn sizing, suggesting its adhesive film-forming quality is high.

In practice, corrugated starch adhesives are prepared either by the traditional Stein-Hall (two-step) process or a simpler no-carrier process. Both methods use a portion of the starch that is chemically gelatinized (the carrier or alpha starch) and a portion that remains granular (raw starch) to achieve the desired viscosity and tack. Typically, starch (e.g., sweet potato starch) is mixed with water and caustic soda (sodium hydroxide); the alkali partially swells and gelatinizes the starch, greatly increasing the mixture's viscosity (Liu *et al.*, 2023). Borax (sodium tetraborate) is then added to cross-link and stabilize the paste, and the remaining raw starch granules are suspended in this carrier gel (Mentzer, 1984). When the adhesive is applied to the heated paper during corrugation, the raw starch granules quickly gelatinize, and the whole adhesive mass sets on cooling, creating a strong paper-to-paper bond. Sweet potato starch can undergo this process in the same equipment used for corn starch, with only minor adjustments (its gelatinization temperature and viscosity profile may differ slightly). Industry sources in Asia note that corrugating adhesives are indeed formulated from corn or sweet potato starch interchangeably, combined with NaOH and borax in specified ratios (Koyakumaru & Nakano, 2016).

The performance of sweet potato starch adhesives in packaging is comparable to other plant starches. They provide high initial tack and bond strength for paper joints (Gedik & Lav, 2016), and the cured adhesive is fully biodegradable – a growing advantage for sustainable packaging. One challenge of starch adhesives is their water sensitivity, so recent research has focused on improving water resistance and bonding strength via modified starch adhesives. For example, cross-linking the starch or grafting synthetic polymers onto it can make the adhesive more moisture-resistant.

In the context of sweet potato starch, chemical modifications (such as oxidation or acetylation) can be applied prior to adhesive formulation to tailor viscosity or tack. A recent review by Maulana *et al.* (2022) highlights that starch (from various botanical sources) is a promising eco-friendly adhesive base and that ongoing advances in starch modification are enhancing its properties for high-performance uses (Maulana *et al*., 2022). Sweet potato starch fits within this trend as a readily available, renewable feedstock that can be converted into industrial adhesives. Its use in corrugated packaging adhesive aligns with industry's move toward sustainable materials, since these starch glues replace synthetic petrochemical adhesives. In sum, both historical usage and current innovations affirm that sweet potato starch can be effectively used to produce corrugation adhesives with strong bonding quality, especially when optimized with proper chemical additives or modifications. This adds another important outlet for sweet potato starch in industrial applications, contributing to the value chain of this crop beyond food products.

3.0 Project Objectives

3.1 Aim

To develop, optimize, and commercialize indigenous technologies for the integrated industrial processing of Nigerian sweet potatoes into starch derivatives, sweet syrups, corrugated board adhesives, and animal feed formulations, thereby unlocking high-value consumer and agro-allied market opportunities.

3.2 Specific Objectives

1. To establish a pilot-to-commercial scale processing facility for the efficient extraction of native starch from Nigerian sweet potato varieties, ensuring high yield, purity, and cost competitiveness with imported starches.
2. To optimize multi-step modification techniques including pre-gelatinization, oxidation, and carboxymethylation for converting native sweet potato starch into cold-water-soluble starch suitable for industrial use in fabric stiffening, cap finishing, and textile steeping applications.

3. To develop a parallel processing stream that isolates and concentrates sweet potato’s aqueous supernatant (post-starch extraction) into high-quality sweetening syrups (glucose/maltose) via enzymatic hydrolysis, aimed at replacing imported corn and cassava syrups in food and beverage formulations.
4. To formulate corrugated board adhesives using sweet potato starch and standard chemical additives (e.g., caustic soda, borax), thereby producing biodegradable, cost-effective alternatives to synthetic adhesives for packaging industries.
5. To valorise all processing residues including peels, pulp fibres, and enzymatic by-products into balanced animal feed formulations, targeting ruminants and monogastric livestock systems through nutritional fortification and pelletization technologies.
6. To design, fabricate, and deploy scalable, locally adaptable processing machinery capable of handling raw material throughput at commercial capacities for each product line, with considerations for modularity, energy efficiency, and operator safety.
7. To develop sustainable value chains and off-take arrangements by fostering industrial partnerships, securing regulatory certifications, and engaging agro-processors, textile manufacturers, packaging companies, and feed mills in co-creation and early adoption pathways.

4.0 Methodology

This project progresses through an advanced Development–Commercialization methodology, building upon prior laboratory research, product validation, and existing proof-of-concept outputs which includes published cold-water-soluble starch-based adhesive and syrup prototypes. The project’s current focus is industrial piloting and process upscaling of sweet potato-derived products, ensuring alignment with Nigeria’s agro-industrial transformation agenda.

4.1. Pilot Facility Setup and Equipment Specification

A miniaturized production line (Table 4.1) will be deployed with a capacity of 500 kg/day native starch output, integrating:

i. Imported drum dryer - for cold water-soluble starch production.
ii. Locally fabricated units – with pulper, hydraulic press, filtration tanks, centrifugal separator, hydrolysis tanks, syrup evaporators, and stainless-steel mixers.

Flow Logic: Raw roots → washing/rasping → starch filtration → drying (native/CWSS) → hydrolysis or blending → packaging.

Table 4.1: Shows the various units, equipment types and their functions

S.no	Unit Operation	Equipment Type	Function
1.	Rasping	High-speed stainless rasper	Cell rupture and starch release
2.	Separation	Paddle screen + centrifuge	Fiber removal, starch milk isolation
3.	Drying (native starch)	Flash dryer (indirect gas)	Fast drying to <12% moisture
4.	CWSS Conversion	Drum dryer (imported)	Pre-gelatinization of starch slurry
5.	Hydrolysis (syrups)	Jacketed tanks + heaters	Acid/enzyme starch conversion
6.	Adhesive Blending	Agitated tanks	Addition of modifiers to CWSS
7.	Feed Drying	Rotary dryer	Pulp drying for feed formulation

4.2 Cold-Water-Soluble Starch (CWSS) for Fabric and Cap Stiffening

Using the drum drying method, optimized starch slurries will be spread on the heated drum surface (~130 °C) and instantly dried to form thin flakes, then ground into powder. Performance specifications (e.g., solubility index, flow properties, and binding strength) will be benchmarked against commercial textile stiffeners.

4.3 Sweet Syrup Recovery from Supernatant

Post-starch extraction supernatant (filtrate) will be filtered, decolorized, and evaporated to concentrate native sugars into high-brix syrups (target: ~70° Brix) (Table 4.2). No enzymatic saccharification is required at this stage; native reducing sugars (primarily glucose, maltose, fructose) will be quantified and the product pasteurized.

Table 4.2: Shows the various physicochemical parameters for sweet syrup recovery

Property	Expected Value	Method
Brix	65–72°	Digital refractometer
pH	3.8–4.2	Electrometric
Reducing sugars	>60% (w/w)	DNS or HPLC
Shelf stability	≥3 months	Accelerated storage trial

4.4 Corrugated Board Adhesive from Sweet Potato CWSS

The CWSS, optionally crosslinked with borax or urea-formaldehyde resin, will be used to produce adhesives for corrugated packaging. Rheological properties (viscosity, tack time) and bonding performance will be evaluated against NIS standards.

Adhesive Prototype Composition:

- CWSS: 85%
- Borax: 2–5%
- pH stabilizer: Citric acid/NaOH
- Water: q.s.

Performance Parameters:

- **Viscosity**: 500–1200 cP (Brookfield)
- **Gel point**: 55–60°C
- **Adhesion**: ≥3 N/mm² (Pin adhesion)

4.5. Animal Feed Formulation Using Residual Pulp

Residual fibrous pulp will be sun/rotary-dried to ≤12% moisture and ground for incorporation into pelleted ruminant and monogastric feeds (up to 25% inclusion). Proximate profiling confirms high digestible fiber and residual starch content (Table 4.5).

Table 4.5: Shows the parameters and their values for animal feed formulation

Parameter	**Sweet Potato Pulp (% DM)**
Residual starch	30–40
Crude fibre	15–20
Crude protein	4–6
Metabolizable energy	~2,800 kcal/kg

Feeds will be formulated with soybean meal and premix to meet livestock nutritional requirements.

4.6 Quality Control and Regulatory Readiness

All product lines (CWSS, syrups, adhesives, and feeds) will undergo routine NAFDAC and SON regulatory assessments, including:

- Microbial testing
- pH and moisture analysis
- Functional performance evaluation
- Packaging labelling and batch tracking

4.7 Equipment Design and Fabrication for 500 kg/day Pilot Plant

To achieve a 500 kg/day native starch output, a mini pilot line is designed with robust, food-grade equipment covering all unit operations from tuber processing to derivative production. Key processing machines including a pulper, hydrolyser, mixing tanks, and reactors will be engineered and fabricated to suit the throughput, while certain specialized equipment (notably the drum dryer) is procured off-the-shelf for quality and reliability. All construction materials are stainless steel **(SS)** at food-contact points to ensure hygiene and corrosion resistance. The design emphasizes energy efficiency, ease of cleaning (CIP), and compliance with food safety standards. Table 4.5 summarizes technical parameters for the major equipment.

4.7.1 Pulper (Root Grinder/Rasper): A high-speed rasping machine will be fabricated to disintegrate washed sweet potatoes and release starch. The rasper consists of a rotating drum lined with abrasive stainless-steel blades, driven by a ~7.5–10 kW motor. It can process ~300–500 kg tubers per hour, achieving a crushing rate ~94% (starch liberation efficiency). Water spray nozzles will be integrated to form slurry and cool the grating surface. All contact parts will be SS304 for food safety, and the design allows easy blade replacement and CIP cleaning. This pulper design draws from cassava/sweet potato rasper practices, targeting ≥90% starch extraction yield.

4.7.2 Hydrolyzer (Enzymatic Conversion Reactor): Starch-to-syrup conversion occurs in a jacketed stainless steel reactor tank with an agitator. A 500 L insulated SS316 tank to handle ~100 kg starch per batch in ~40% slurry). It features steam/thermal oil heating in the jacket to raise mash to gelatinization temperature (~85–90 °C) and maintain it, plus cooling capability (or cold-water flush) to bring temperature down for enzyme saccharification is included in the design. A top-mounted agitator (~3 kW motor) provides thorough mixing. The reactor includes ports for enzyme dosing, pH adjustment, and sampling. All wetted parts are SS316 to resist mild acids/enzymes. A condenser vent manages steam during boiling. The hydrolyser is fabricated to withstand slightly elevated pressures and continuous 90 °C operation, enabling gelatinization, liquefaction, and saccharification steps (detailed under syrup process) within a single vessel. Safety valves and digital controllers (for temperature and agitation speed) are installed to ensure precise control of the enzymatic reactions.

4.7.3 Mixing Tanks: Several auxiliary mixing tanks (100–200 L, SS304) with low-speed agitators (~1.5 kW) are to be provided for ingredient preparation and intermediate handling. For example, a mixing tank will be used to suspend native starch in water to feed the drum dryer, forming a uniform slurry. Another may be used to pre-mix chemicals or additives (e.g., for pH adjustment, or in case of chemical modifications). These tanks are simple cylindrical vessels with baffles and bottom discharge, designed for easy cleaning. While not complex, they are essential for homogenization tasks and are locally fabricated from stainless steel sheets.

4.7.4 Reactors for Starch Modification: In addition to the enzymatic hydrolyser, a chemical reactor is planned for any chemical modifications (such as producing adhesive-grade dextrin or modified starches). This reactor is similar in construction to the hydrolyser – SS316 vessel with heating and agitation, but sized for smaller batches and capable of reaching higher temperatures (up to ~150 °C) if needed for processes like acid conversion or cross-linking. It is equipped with a reflux condenser when handling volatile reagents and has robust temperature and pressure controls. For safety, any chemical reactor operation (e.g., alkaline-alcohol treatment for cold soluble starch or dextrinization for adhesives) is done in a closed vessel with ventilation. Notably, drum drying is chosen over chemical modification for cold-water-soluble starch to avoid handling large volumes of solvents; thus, the primary "reactor" for pregelatinized starch is the drum dryer itself (for physical modification).

4.7.5 Drum Dryer (Commercially Procured): A single-drum dryer (at least 1 m drum width, chrome-plated smooth surface) will be procured rather than fabricated, due to its precision requirements. The drum dryer operates with internal steam heating (up to ~150 °C surface temperature) and a doctor blade to scrape off dried product.

In our design, the drum dryer produces pregelatinized (cold-soluble) starch by cooking a starch slurry on the hot drum and drying it in a thin film. This yields a flaked product that is milled into powder. The unit can evaporate ~20–30 kg water per hour, sufficient for ~100–150 kg/day pregelatinized starch output per 8 h shift. Commercial units come with variable drum speed and gap controls to adjust drying time and product moisture. We specify a unit with feed roll or spreader to ensure a uniform thin layer of starch slurry on the drum. Using a proven commercial dryer guarantees the cold-water-soluble starch will have high solubility and swelling power, as drum-dried starch typically shows minimal granule integrity and readily hydrates in cold water. By purchasing this unit, we avoid technical risks in fabrication and ensure the dryer meets safety and performance standards. The drum dryer will be installed with a steam boiler (electric or diesel-fired) and condensate return system.

Other supporting equipment includes a rotary washing machine for root cleaning, centrifugal sieve or vibrating screen for fibre separation, a filter press or peeler centrifuge for dewatering starch, a flash dryer for quick drying of native starch, and a hammer mill and pelletizer for feed (if pellets are made). These are described in the process flow below. All equipment will be laid out to minimize material handling distances, with pumps and screw conveyors moving intermediates between units. The entire pilot line will be housed under roofing with good drainage (for wash water) and shall comply with Good Manufacturing Practices.

Table 4.6: Key Equipment Specifications (500 kg/day Starch Plant)

Equipment	**Materials (Product Contact)**	**Motor/Power**	**Throughput/Capacity**	**Design Features / Notes**
Washing Unit (Drum Washer)	SS perforated drum, mild steel frame	2 kW rotary motor + water pump	~500 kg tubers/h input	Removes dirt/stones; dry sieve + rotary wash combo for efficient cleaning.
Pulper (Rasper Grinder)	SS blades & casing	7.5–10 kW motor	~500 kg/h grating capacity	Grates tubers to pulp; ~94% starch release efficiency; water injection for slurry.
Centrifugal Sieve (Fiber Separator)	SS mesh (120–250 µm) screen	3 kW motor (vibrating/rotary)	~0.5 m³/h slurry throughput	Separates fiber from starch milk; multi-stage fine screening to

				maximize starch recovery.
Starch Refining Unit (Hydrocyclones or Settling Tanks)	Polyurethane cones (food-grade) or SS tanks	Feed pump ~5 kW (if cyclones)	~0.3 m^3/h per cyclone stage	Removes fine fiber & impurities; 15+ cyclone stages concentrate starch to ~38% w/w; alternatively, settling tanks used in series.
Dewatering Device (Filter Press or Peeler Centrifuge)	SS filter plates or basket	Hydraulic pump or 4 kW motor	Produces starch cake ~35–40% moisture	Removes free water before drying; vacuum filter can also be used (produces ~38% moisture cake).
Flash Dryer (for native starch)	Mild steel with SS contact parts	15 kW hot air blower & heater	~100 kg/h wet cake input (evap. 50 kg H_2O/h)	Dries dewatered starch to <13% moisture in 2–3 s (inlet air ~150 °C, outlet ~45 °C to keep starch <40 °C).
Drum Dryer (for CWS starch) – Procured	Chrome-plated cast iron drum, SS feed tray	Steam heated (~120–150 °C drum surface)	~20 kg H_2O evaporation/h (feeds ~50 kg/h slurry)	Double-drum or single-drum design with adjustable gap; yields pregelatinized starch flake (high cold-water solubility). Not

				fabricated in-house.
Hydrolyzer Tank (Enzyme Reactor)	SS316 jacketed vessel, insulated	3 kW agitator; steam boiler ~50 kW	Batch ~500 L (for ~100 kg starch)	For liquefaction (α-amylase at ~90 °C) and saccharification (glucoamylase ~60 °C); temp and pH controlled.
Mixing/Buffer Tanks	SS304 tank, agitator	1–2 kW motor	100–200 L each (x2–3 units)	Slurry make-up tank for drum dryer, chemical mixing or pH adjustment tank, etc. Simple design with bottom discharge.
Feed Dryer (Residue Dryer)	SS304 trays (if oven) or small flash dryer	5 kW heater/blower	~50 kg wet fiber per batch	Dries fiber pomace from ~60% to ~10% moisture for storage. Could be solar-assisted or electric cabinet dryer.
Hammer Mill (Feed Grinder)	Carbon steel or SS hammers	5 kW motor	~100 kg/h dry fiber milling	Grinds dried fiber to fine meal for animal

				feed incorporation.
Pelletizer (Feed) optional	Hardened steel die, SS hopper	7.5 kW motor (flat-die type)	~50–100 kg/h pellet output	Compresses fiber meal (with binders like molasses) into pellets for feed. Optional unit if pelleted feed is desired.

4.7.6 Materials, Machines & Tools for Piloting and Scale-Up

A. End-to-End Process Train (ordered flow)

Table 4.7: Core Process Equipment

S/N	Unit Operation (Flow order)	Equipment / Tool	Key Capacity & Specs	Material (product contact)	Acquisition	Product Stream(s)
1	Raw root receiving & inspection	Platform scale, sorting tables, crate trolleys	2–3 t/day throughput; food-grade tables	SS304 tops	Fabricate/Buy locally	All
2	Washing & destoning	Rotary washer + stone trap, spray manifold	≥500 kg/h roots; recirculating water	SS304 drum, PVC piping	Fabricate locally	All
3	Peeling (optional)	Knife/abrasive peeler (manual or small rotary)	300–500 kg/h	SS304	Fabricate/Buy	All
4	Size reduction (rasping)	High-speed pulper/rasper	500 kg/h; ~7.5–10 kW motor	SS304 housing & grater	Fabricate locally	All
5	Slurry transfer	Hygienic centrifugal pump	5–10 m^3/h	SS316 wetted parts	Procure	All

6	Fiber separation (primary)	Centrifugal/paddle sieve (120–250 µm)	0.3–0.5 m³/h slurry	SS304 screen	Fabricate locally	All
7	Fiber separation (polish)	Vibratory fine screen (75–120 µm)	0.2–0.3 m³/h	SS304 screen	Fabricate locally	All
8	Starch milk refining	Hydrocyclone bank (or settling tanks)	10–16 stages; ~0.3 m³/h/feed cone	PU cones & SS headers	Procure/Fabricate	All
9	Dewatering	Peeler centrifuge or plate-and-frame filter	Cake ~38–40 % m.c.	SS304	Procure/Fabricate	Starch/CWSS/Adhesive
10	Drying — native starch	Flash/cabinet dryer	Wet cake 60–80 kg/h; outlet <12 % m.c.	SS contact parts	Fabricate/Procure	Starch
11	Pregel CWSS conversion	Steam-heated drum dryer (procured)	Evap. ≈20–30 kg H_2O/h; surface 120–150 °C	Chrome drum, SS product path	Procure	CWSS
12	Milling/classification	Pin/hammer mill + sieve	100–200 kg/h	SS304 liner	Fabricate/Procure	Starch/CWSS
13	Syrup line—clarification	Jacketed settling tank + coarse filter	300–500 L/batch	SS316	Fabricate locally	Syrup
14	Syrup line—polish	Carbon treatment + cartridge filter	5–10 L/min	SS316 housings	Procure	Syrup
15	Syrup concentration	Vacuum kettle/evaporator	To 68–72 °Brix	SS316	Fabricate/Procure	Syrup
16	Adhesive compounding	Agitated mixing reactor (heat optional)	100–300 L/batch; 0–90 °C	SS316	Fabricate locally	Adhesive
17	Residue handling	Screw press (optional) + tray/solar dryer	30–60 kg/h wet pulp → ≤12 % m.c.	SS304 trays	Fabricate locally	Feed
18	Feed finishing	Hammer mill + (optional) flat-die pelletizer	50–100 kg/h pellets	CS/SS contact	Fabricate/Procure	Feed
19	Bulk packaging (starch)	25 kg bagging scale + stitcher	6–10 bags/min	SS304 spout	Procure	Starch/CWSS
20	CWSS retail sachet pack	VFFS pillow packer + auger filler	see Table B2	Food-grade SS	Procure	CWSS (consumer)
21	Syrup packaging	Food-grade drums/jerrycans; hot-fill	20–200 L	HDPE/SS	Procure	Syrup

22	Adhesive packaging	Tight-head pails/buckets or bulk IBC	20–1000 L	HDPE/IBC	Procure	Adhesive

Table 4.8: Prime Power: 40 kVA Diesel Generator (reputable OEM)

Item	Recommended Model	Prime/Standby Rating	Frequency / Speed	Engine / Alternator	Voltage	Tank (typ.)	Highlights
Diesel genset	FG Wilson P40 (P40-4S/P40-3S)	36 kVA prime / 40 kVA standby (50 Hz)	50 Hz / 1500 rpm	Perkins engine, Leroy-Somer alt.	230–400 V (site-config)	~180–194 L (site option)	Fuel-optimized set, industrial enclosure, ComAp/DeepSea control, e-stop; suited for continuous plant duty

Table 4.9: Consumer Pillow Pack (VFFS) for CWSS Powder

Item	Recommended Model	Dosing	Bag/Sachet	Throughput	Utilities	Footprint/Notes
Vertical Form-Fill-Seal (VFFS)	Viking Masek M250 (powders)	Auger filler (accurate for starch)	Pillow sachets/flat pouches; typical 10 g–1 kg	Up to ~100 BPM (format-dependent) *	6 kVA power, 6 bar air	Roll dia 500 mm; roll width 545 mm; rugged for food/non-food.

Table 4.9: Utilities & Site Services

Utility	Specification	Notes
Steam	6–8 bar saturated (for drum dryer; ~150 °C surface)	Package steam boiler (diesel/gas) sized for ~250–350 kg steam/h; trap & condensate return for drum dryer.
Compressed air	6 bar, 300–500 L/min	Drives VFFS pneumatics, valves; use food-grade dryer/filter.
Process water	2–4 m³/day, potable	Washing, slurry, CIP. Simple treatment (sand/carbon) suggested.
Power distribution	3-phase 415 V + single phase	Fed by 40 kVA genset; ATS to grid where available.
CIP	Mobile SS CIP cart	Hot water/caustic rinse for tanks, lines.

Wastewater	Settling + screen + pH neutralization	Reuse for non-critical washing where possible.

Table 4.10: Quality Control Instrument

Area	Instrument	Purpose
Starch/CWSS	Moisture analyser; Brookfield/RVA; Colorimeter	Spec: ≤12 % moisture; viscosity profiling; whiteness
Syrup	Refractometer; DE/ pH meter	68–72 °Brix; DE target per spec; pH 4.5–6
Adhesive	Brookfield; Pin-bond tester; pH	500–1200 cP; adhesion vs spec; pH ~7–9
Feed	Proximate kit (moisture, CP, CF, ash); sieve	Verify nutrient targets; pellet durability (if pelleted)
Micro	TPC/yeast-mold plates (as needed)	Food/feed hygiene checks

5. Expected Outcomes

The implementation of this industrial commercialization project will result in a range of tangible technical, economic, and socio-environmental outcomes that reflect both its innovation-driven foundation and its alignment with Nigeria's national industrialization and food security priorities. These outcomes span across production efficiency, market expansion, skill development, technology transfer, and sustainable development.

5.1 Establishment of a Functional Pilot and Modular Agro-Industrial Facility

- A fully equipped, pilot-scale sweet potato processing facility with a daily production capacity of 500 kg of native starch will be commissioned and operational.
- The facility will demonstrate modular, adaptable designs suitable for replication across sweet potato-producing zones in Nigeria and sub-Saharan Africa.
- Integration of locally fabricated stainless-steel machinery will reduce equipment import dependency and boost indigenous engineering capabilities.

5.2 Commercial Production and Market Availability of Value-Added Products

- Consistent and scalable production of five industrial and consumer products:
    - Native sweet potato starch
    - Cold water-soluble starch (CWSS) for laundry use
    - Concentrated sweet syrup for sweetening and confectionery
    - Corrugated board adhesive for packaging industries

- Nutrient-rich animal feed formulated from agro-residues

- Introduction of packaged CWSS sachets and bottled syrups into local markets for consumer use, backed by proper NAFDAC registration and SON compliance.

5.3 Technology Validation and Industrial Process Optimization

- Development of optimized and documented standard operating procedures (SOPs) for:
  - Starch extraction, purification, and cold modification
  - Syrup concentration via thermal evaporation
  - Adhesive formulation through starch hydrolysis
  - Feed formulation using residue blending
- Demonstration of scalable enzymatic and physicochemical process parameters applicable to other root-based agro-derivatives.

5.4 Economic and Employment Impact

- Creation of direct employment for at least 25 skilled and semi-skilled workers in operations, quality control, logistics, and administration.
- Indirect employment and income generation for over 300 rural sweet potato farmers and transporters engaged through structured off-take agreements.
- Daily net profit projection of ₦300,000 at full operation, contributing to rural economic growth and investor confidence in agro-industrial ventures.

5.5 Capacity Building and Knowledge Dissemination

- On-site training of local fabricators, technicians, and researchers in pilot processing, machine maintenance, and product quality assurance.
- Publication of findings in policy briefs and journals, and presentation at national and regional innovation forums.
- Establishment of the project as a demonstration model for knowledge transfer to other states and stakeholders.

5.6 Environmental Sustainability and Circular Economy Practices

- Significant reduction in post-harvest sweet potato wastage through full-plant utilization.
- Zero-waste processing design, ensuring the valorization of all processing residues into animal feed or biocompatible co-products.
- Use of borehole water systems and diesel generator with plans to transition to hybrid solar systems in scale-up phase.

5.7 Strengthened Industry-Academic-Government Collaboration

- A live example of translating academic research (including published journal articles and validated product prototypes) into industrial commercialization.
- Enhanced cooperation between Bayero University Kano (BUK), NASENI, and private sector partners to drive agro-based technology diffusion.
- Policy-level visibility and potential for scaling under national food security and job creation programs

6.0 Project Team and Management Structure

The success of this commercialization project depends on a technically competent, multidisciplinary team with proven experience in industrial research, agro-processing, and project management. The team brings together experts from Bayero University Kano, local fabrication workshops, and private-sector collaborators, ensuring a balance between academic innovation and industrial execution.

A. Organizational Structure

The project adopts a functionally integrated management structure for efficiency, innovation, and accountability.

- **Project led/Principal Investigator (PI)** provides overall leadership
- **Co-Principal Investigator** leads product development and day to day activities, liaises with NASENI/NRCG.
- **Operations and Technical Units** oversees all technical aspects of the project.
- **Quality, Finance, and Marketing Teams** ensure compliance, profitability, and outreach.

B. Project Team Composition

Position/Role	Name / Expertise	Responsibilities
Project lead/ Principal Investigator	**Prof. Hafiz Abubakar** – Professor of Biochemistry	Provides overall leadership, strategic direction and process standardisation.
Co-Principal Investigator	**Dr. Zulaiha Gidado Mukhtar** – PhD Biochemistry. Analytical Biochemist, Food Safety and Security Specialist, Project Management.	Leads product development, liaison with NASENI and partners. Oversees research-to-market transition, stakeholder engagement, and technical staff training.

Position/Role	Name / Expertise	Responsibilities
Technical Coordinator	**Yusuf Ibrahim –** Industrial Biochemistry Industrial Process Optimization Specialist, Regulatory Compliance Specialist.	Supervises the starch modification, and overall R&D scale-up process. Oversees quality testing, regulatory certification (SON/NAFDAC), and process documentation for all product lines. Represents the team at technical sessions and bootcamps.
Process / Production Manager	**Engr. Sani Yusuf** – Mechanical Engineer, Design and Fabrication Specialist	Designs processing and production lines; fabrication and maintenance of equipment. Ensures operational efficiency, safety, and continuous improvement in production flow.
Control Systems Manager	**Engr Mariya Mustapha** –Electrical Engineer, COREN - Electrical Systems Specialist	Lead Electrical/Control Systems design and maintenance

C. Advisory and Partnership Network

As the project progresses, to strengthen and support the project team- an Advisory and Technical Committee will guide project implementation, policy alignment, and commercialization expansion.

Advisory Member	Affiliation / Expertise	Advisory Role
Representative, NASENI NRCG	NASENI Headquarters, Abuja	Provides oversight, monitoring, and reporting guidance.
Representative, Technology Incubation Centre	Federal Ministry of Science, Technology and Innovation	Facilitates technology transfer and industrial incubation.
Representative, Bayero University Kano	Faculty of Science/Engineering	Academic support, research validation, and student training.
Representative, Private Sector Partner	Agro-Industrial Manufacturer	Supports product marketing, quality benchmarking, and investment linkage.

D. Capacity Strength and Experience

- Over 10 years of laboratory and pilot-scale R&D in starch modification and agro-industrial processing.
- Peer-reviewed publications and patentable outputs on cold-water-soluble starch, sweet syrups, and biodegradable adhesives.
- Hands-on fabrication capability for industrial-grade, food-safe processing equipment.
- Multidisciplinary expertise in biochemistry, engineering, food science/technology, and entrepreneurship.
- Established collaborations with farmer cooperatives and industry end-users for raw material sourcing and product adoption.

E. Governance and Accountability

The project will operate under strict monitoring, ensuring transparency, gender inclusion, and performance-based accountability.

- Monthly progress meetings for technical review.
- Quarterly reports submitted to NASENI NRCG.
- Annual audit and impact assessment to track commercialization performance and social returns.

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