VALORIZING CASSAVA PEEL WASTE FOR SUSTAINABLE BIO-PLASTICS PRODUCTION: MARKET DYNAMICS AND STARCH YIELD POTENTIAL IN KAMPALA, UGANDA

BY

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DECLARATION

This dissertation is my original work and has not been previously submitted for the award of any degree at any other university or institution. It is submitted in partial fulfillment of the requirements for the Master of Science in Conservation and Natural Resources Management.

Signature:____________________________Date: ____________________

GERALD BABI KIZITO

APPROVAL

This Research entitled '**Valorizing cassava peel waste for sustainable bio-plastics production: market dynamics and starch yield potential in Kampala, Uganda'** has been undertaken and submitted to the Directorate of Research and Graduate Training, Kyambogo University with the approval of the following supervisors:

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Dr. Karlmax Rutaro

DEDICATION

This work is dedicated to my beloved family, whose unconditional love, unwavering support, and endless encouragement have been my greatest source of strength. Your guidance, steadfast motivation, and unshakable belief in me gave me the courage to embark on this journey and the resilience to see it through. Without your patience, inspiration, and unwavering presence, this endeavor would not have been possible.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASTM:	American Society for Testing and Materials
DMA:	Dynamic Mechanical Analysis
DSC:	Differential Scanning Calorimetry
ft:	feet
H0:	Null Hypothesis
ISO:	International Organization for Standardization
KCCA:	Kampala Capital City Authority
MCC:	Microcrystalline Cellulose
MPa:	Megapascal
NACCRI:	National Crop Resources Research Institute
SDG:	Sustainable Development Goal
SPSS:	Statistical Package for Social Scientists
UBOS:	Uganda Bureau of Statistics
UK:	United Kingdom

ABSTRACT

This study confronts the global environmental crisis caused by non-biodegradable plastics by investigating the potential of bio-plastics as sustainable alternatives. It focuses on the valorization of cassava peel waste for bio-plastic production in Kampala, Uganda, employing a mixed-methods approach. Specifically, the study aimed: to quantify the mass of cassava peel waste generated and examine the cassava supply chain in selected Kampala markets; to evaluate the starch content of cassava peels from three improved varieties NASE 14, NASE 19, and NAROCCAS and a market sample, for use in developing biodegradable bioplastics; and to assess the properties and performance of the resulting bioplastic materials. Cassava peels were collected from pure varieties obtained at the National Crop Resources Research Institute (NACCRI), Namulonge, and randomly from Busega market. These samples were processed to extract starch, which was analyzed for suitability in bio-plastic formulation. Concurrently, field data were collected through a questionnaire survey administered to 35 end-users, 76 vendors and 35 transporters across Busega, Nakawa, and Kasubi markets. Data were collected electronically using questionnaires uploaded in KOBOcollect app installed on mobile phones, allowing for real-time digital capture of responses. Findings reveal that most respondents generate about 20 kg of cassava waste daily, with peels accounting for the largest proportion (73.6%). Busega market produced the highest amount of cassava peels waste, a trend linked to socioeconomic conditions such as poverty and slum settlements resulting into poor waste management. Mubende district was the primary cassava supplier (38.3%), followed by Hoima and Kibaale, NASE 19 consistently outperformed others in starch yield (3.40%) due to its genetic optimization for starch accumulation. It also demonstrated the highest water absorption and solubility when combined with additional cellulose, indicating that cellulose's hydrophilic nature enhances both properties. Additionally, NASE 19 showed the highest biodegradability in both buried and unburied conditions when cellulose was present, likely due to its high amylopectin content. Notably, the same variety exhibited the highest tensile strength in samples without additional cellulose, attributing it to a more cohesive molecular structure. The market sample, although produced the lowest starch yield (2.16%), performed well in solubility, water absorption, biodegradability, and tensile strength indicating its suitability for use in bioplastic production despite the lower starch content. In conclusion the study successfully quantified cassava peel waste, identifying Busega as Kampala's central hub for cassava trading and waste generation, the primary source of cassava was Mubende district while NASE 19 emerged as the most promising variety for bioplastic development, offering high starch yield, favorable mechanical properties, and enhanced biodegradability to support sustainable bio-plastic development, the study recommends expanding cultivation of high-starch varieties like NASE 19, implementing supportive policies such as tax incentives for biodegradable plastic producers. Encourage investment in bioplastic production facilities and promote collaboration among research institutions, government agencies and private sector players to scale up production.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Manihot esculenta crantz (Cassava) is an extensively grown starchy root crop and a major source of carbohydrates in many tropical and subtropical regions, (Campos *et al.,* 2017), With global production surpassing 280 million metric tons annually, cassava is primarily grown in Asia, Africa, and Latin America, with Nigeria, Thailand, and Indonesia being the largest producers (FAO, 2021). In Sub-Saharan Africa, cassava is vital for food security and economic stability, contributing significantly to the agricultural sector and providing essential carbohydrates for millions of people in the world (FAO, 2020). The region produces around 50% of the world's cassava, with Nigeria, the Democratic Republic of Congo, and Ghana leading in cultivation.

In Uganda, cassava is a key staple food, with annual production surpassing 3.5 million metric tons, and it has gained prominence due to its drought resistance and adaptability to poor soils (FAO, 2020). The crop is increasingly used in value-added products such as starch, flour, and ethanol, but its large-scale cultivation generates significant waste, particularly cassava peels, which are often discarded.

Cassava is processed for various products such as food, starch, flour, ethanol, and animal feed. However, the processing of cassava generates a significant amount of waste, particularly cassava peels, which can provide raw material for production of bio-plastics which are eco-friendly (Bamisaye *et al.,* 2022).

The improper disposal of these peels can lead to environmental degradation, including soil and water pollution (Bhatnagar *et al.,* 2015). Addressing this issue through innovative and sustainable approaches is crucial for both waste management and the potential economic benefits. Bioplastics are biodegradable alternatives to conventional petroleum-based plastics, offering environmental advantages in terms of reduced carbon footprint and waste management (Shamsuddin *et al.,* 2017). The utilization of cassava peels for bioplastics production could provide a dual benefit by converting waste into a valuable resource and reducing the dependence on fossil-fuel-derived plastics.

The escalating global concerns over environmental pollution, particularly from non-biodegradable plastics, have stimulated significant interest in the development of Environmentally friendly options. Bioplastics, derived from sustainable sources, have surfaced as a promising solution to this issue. Cassava peel waste, abundant in Kampala, Uganda, offers a potential resource for bioplastics production due to its high starch content (Magoola *et al.*, 2023). The volarization (value addition) of cassava peel waste involves the extraction of starch from the peels, which serves as the primary feedstock for bioplastics production. Starch is a natural polymer composed of glucose units (Adigwe *et al.*, 2022) and is widely used in bioplastic formulations due to its biodegradability and abundance (Hubbe *et al.,* 2021). Bioplastics produced from cassava peel starch could potentially replace conventional plastics in various applications, including packaging materials and single-use items.

The city of Kampala faces both waste management challenges and a growing demand for eco-friendly materials. By valorizing cassava peel waste into bioplastics, Kampala could simultaneously address waste-related issues and lead to the decrease in plastic pollution. Moreover, the production of bioplastics locally would reduce the reliance on imported petroleum-based plastics, thus bolstering the region's sustainability efforts (Elkaliny *et al.*, 2024). This agricultural residue is rich in polysaccharides, including starch and cellulose, rendering it a valuable feedstock for sustainable material production.

This study aimed to investigate the utilization of cassava peel waste valorization for bioplastics production in Kampala, Uganda. Through laboratory experiments, the study intended to establish optimal processing conditions for extracting polysaccharides from cassava peels and converting them into biodegradable bioplastics. By evaluating the characteristics related to mechanics, heat transfer, and ability to decompose naturally of the resulting bioplastics, the research aims to contribute to both scientific understanding and practical application.

1.2 Problem Statement

Kampala City, like many urban centers in Uganda, faces growing challenges in managing municipal waste. One significant component of this waste stream is cassava peels an abundant by-product of cassava processing mainly generated from markets and households. Large amount of cassava peels from Kampala markets and households are discarded as waste, contributing to environmental pollution. At the same time, the city faces a growing plastic pollution crisis due to widespread use of non-biodegradable plastics from the packaging materials. Despite the high starch content of cassava peels and their potential for bioplastics production, this resource remains largely untapped in Uganda. There is also lack of local research and innovation on converting cassava waste into biodegradable plastic. This study aimed at exploring the use of cassava peels for producing biodegradable plastics, offering a sustainable solution to both organic waste and plastic pollution challenges in Kampala.

1.3 Objective of the Study

1.3.1 General Objective

The general objective of this research was to valorize cassava peel waste for sustainable bio-plastics production: market dynamics and starch yield potential in Kampala, Uganda.

1.3.2 Specific Objectives

i. To quantify the amount of cassava peel waste generated and assess the supply chain of cassava in selected markets in Kampala.
ii. To analyze starch content of cassava peels from three distinct cassava varieties and the market sample, and use it to develop biodegradable bioplastics
iii. To assess the properties and performance of the developed biodegradable bioplastics

1.4 Research Questions

i. How much cassava peel waste is generated, and what are the characteristics of the cassava supply chain in selected markets in Kampala?
ii. What is the starch content of cassava peels from selected varieties and market samples, and how can it be utilized in the development of biodegradable bioplastics?
iii. What are the physical, mechanical, and biodegradability properties of the bioplastics developed from cassava peel starch?

1.5 Scope of the Study

The scope of the study was as follows:

1.5.1 Geographical Scope

The study was conducted in Kampala, the capital city of Uganda, with a focus on three major markets: Nakawa Market in Nakawa Division, Kasubi Market in Kawempe Division, and Busega Market in Rubaga Division. In addition to these market locations, specific crop varieties used in the study were sourced from the National Crops Resources Research Institute (NaCRRI) located in Namulonge, Wakiso District.

1.5.2 Content Scope

The study focused on determining the quantities of cassava peels produced in Busega, Nakawa and Kasubi markets, formulation of the film and determining the properties of the film formed.

1.5.3 Time Scope

The study was conducted during the cassava harvesting season, from November to December 2024. This period provided an accurate representation of cassava production.

1.6 Significance of the Study

This research explores the use of cassava peels for bioplastics production, addressing environmental sustainability, waste management, and material innovation. It aims to reduce waste disposal impacts, provide eco-friendly alternatives to petroleum-based plastics, and promote a circular economy. By creating value from waste, reducing plastic pollution, and improving the cassava supply chain, the study drives economic and environmental benefits. Bioplastics from cassava peels are biodegradable, aligning with SDG 9 that promotes Innovation and sustainable industrialization and SDG 12 that promotes Sustainable practices such as reducing food waste, while supporting Uganda’s National Development Plan III (NDP III). This research contributes to sustainable packaging solutions and inspires further innovation in waste valorization.

CHAPTER TWO

LITERATURE REVIEW

2.0 Cassava Production

Cassava is a widely cultivated crop in many tropical regions due to its high starch content and versatility in food processing (Parmar *et al.,* 2017). However, the processing of cassava into various products generates a significant amount of waste, particularly cassava peels (Ubalua *et al.,* 2007). This literature review aims to investigate the amount of cassava peel waste generated. Several studies have been conducted to estimate the amount of cassava peel waste generated during processing. For instance, a study by Anyanwu *et al.,* (2015) estimate that cassava processing plants in Nigeria produce approximately 2.5 million tons of cassava peel waste annually. Another study by Bayitse *et al.,* (2017) estimate that cassava peel waste from small-scale processing units in Ghana accounted for around 20-30% of the total cassava produced. Furthermore, research conducted by Odediran *et al.,* (2015) in Nigeria indicate that the amount of cassava peel waste generated varied significantly depending on the processing method employed. Traditional processing methods, such as sun-drying or open-air fermentation, often result in higher amounts of cassava peel waste compared to modern processing techniques (Nainggolan *et al.,* 2024). The amount of cassava peel waste generated depends on various factors, including the scale of processing, the techniques employed, and regional variations (Adekunle *et al.,* 2016). Additionally, the methods used for disposal, such as landfilling or natural decomposition, contribute to environmental concerns, including methane emissions and soil pollution (Yaashikaa *et al.,* 2022). The amount of waste generated is substantial and varies according to the processing methods used (Demirbas *et al.,* 2011). To mitigate the environmental impact of cassava peel waste, sustainable management strategies, such as composting, biogas production, and conversion into animal feed, have been proposed as potential solutions (Ubalua *et al.,* 2007). However, further research is needed to develop efficient and cost-effective technologies for the proper utilization and disposal of cassava peel waste.

2.1 Formation of a Bioplastic Film

Cassava peel, a readily available agricultural waste, contains a substantial amount of polysaccharides that can potentially be used to formulate bioplastic films (Zhang *et al.,* 2024). The composition of cassava peel includes cellulose (32–45%), hemicellulose (20–35%), and starch (15–25%), which serves as valuable raw materials for bioplastic production (Abel *et al.,* 2021). Various extraction methods have been explored to isolate polysaccharides from cassava peel. Acid hydrolysis, enzymatic treatment, and mechanical methods are widely used for processing cassava peel, each suited to specific applications (Barati *et al.,* 2019). Acid hydrolysis is efficient for producing fermentable sugars but involves higher costs and environmental concerns. Enzymatic treatment is environmentally friendly and ideal for high-purity products like bioplastics. Mechanical methods are cost-effective and scalable but often require combination with other techniques for complete conversion (Lynd *et al.,*2022). The choice of method depends on cost, scalability, and intended application. Modification processes, such as esterification and cross-linking, enhance the material properties for bioplastic formulation (Pooja *et al.,* 2024). Cassava peel polysaccharides can be used as a matrix material to formulate bioplastic films. Blending cassava peel polysaccharides with other biopolymers, such as cellulose, can improve the film properties (Zhang *et al.,* 2024). Processing techniques, including casting and compression molding, have been employed to produce films with desirable characteristics (Ciannamea *et al.*, 2014). These properties are crucial for determining the film's suitability for various applications. The addition of reinforcing agents, plasticizers, and nanomaterials has been explored to tailor the properties (Vieira *et al.*, 2011). The starch was processed into bioplastic films using casting technique (Fakhouri *et al.*,2013)

2.2 Properties of the Bio-Plastic Film

Bioplastics have gained attention as an eco-friendly alternative to conventional plastics due to their potential to mitigate environmental issues. One promising source for bioplastics is cassava peels, a byproduct of cassava processing. This review aims to explore the current state of research on the physical, mechanical, biodegradable, and thermal properties of bioplastic films derived from cassava peels. The physical properties of Cassava peels, often considered agricultural waste, possess cellulose and starch components, making them suitable for bioplastic production. The physical properties of resulting bioplastic films include tensile strength, elongation at break, density, and surface morphology (Ibrahim *et al.*, 2019). The mechanical properties of bioplastic films determine their usability and strength in various applications. Tensile strength, flexural strength, and impact resistance are key mechanical parameters. Research by (Zhang *et al.*, 2024) evaluated the impact of plasticizer content on the mechanical properties of cassava peel-based bioplastics. Their findings indicated an optimal plasticizer concentration for enhanced film flexibility and strength. The biodegradability of bioplastics is a crucial factor in assessing their environmental impact. Bioplastic films derived from cassava peels offer the advantage of being potentially biodegradable due to the natural origin of the raw material. The degradation behavior of cassava peel-based bioplastics under different environmental conditions, shows their potential role in providing an alternative that can reduce plastic waste (Zhang *et al.,* 2024). Thermal properties of bioplastics influence their processing, application, and stability. Cassava peel-based bioplastic films exhibit varying melting points, glass transition temperatures, and thermal stability. Researchers (Drzeżdżon *et al.,* 2019) have employed techniques such as Differential Scanning Calorimetry (DSC) to characterize these thermal properties, aiding in the determination of processing parameters. The utilization of cassava peels for bioplastic film production shows or promises an environmentally friendly approach. Studies on the physical, mechanical, biodegradable, and thermal properties of such films contribute to a comprehensive understanding of their potential applications. Further research is required to optimize processing techniques, enhance mechanical performance, and assess real-world biodegradability

2.2.1 Tensile Strength of the Biofilm

The growing concern over environmental sustainability has led to increased interest in the development of biodegradable materials, such as bio-plastics (Moshood *et al.*, 2021). One promising source for bio-plastics is cassava peels, a byproduct of cassava processing. To assess the mechanical properties of cassava peel bio-plastics, tensile strength testing has been a commonly employed method. American Society for Testing and Materials (ASTM) standards (ASTM D638) for tensile testing are widely adopted in bio-plastic research (Goel *et al.,* 2021). Tensile strength, modulus of elasticity, and elongation at break are crucial parameters evaluated to determine the material performance under tension (Davis *et al.*, 2004). The starch extraction method, plasticizer type and concentration, and processing conditions are critical parameters. Additionally, the incorporation of reinforcing agents, such as fibers or nanoparticles, has been explored to enhance tensile strength (Mishra *et al.,* 2022). Despite the promising aspects of cassava peel bio-plastics, challenges such as moisture sensitivity and limited mechanical strength have been identified (Bamisaye *et al.*, 2022). Research is ongoing to address these challenges and optimize the formulation for enhanced tensile strength and overall performance. Literature reveals a growing body of research focused on determining the tensile strength of bio-plastics derived from cassava peels. Researchers have explored various extraction and processing methods, testing standards, and influencing factors. While challenges persist, ongoing efforts aim to optimize cassava peel bio-plastics for improved mechanical properties, moving towards a more sustainable and environmentally friendly alternative.

2.2.2 Elasticity of the Biofilm

This literature review aims to explore existing research on determining the elasticity of bioplastics derived from cassava peels. Cassava peels are rich in starch, making them a promising feedstock for bioplastic production (Abel *et al.,* 2021). Starch-based bioplastics offer environmental advantages, but their mechanical properties, particularly elasticity, require thorough investigation. Researchers like (Fauziah *et al.*, 2025) have studied the impact of varying cassava peel starch concentrations and plasticizers on the elasticity of resulting bioplastics. Plasticizers play a crucial role in modifying the elasticity of bioplastics. Research by Tamara *et al.* (2020) demonstrated the effects of different plasticizers, such as glycerol and sorbitol, on the tensile properties and elasticity of cassava peel starch-based bioplastics. To enhance the mechanical properties of cassava peel bioplastics, researchers have explored reinforcement with natural fibers. A study by (Abotbina *et al.,* 2022) investigated the impact of incorporating bamboo fibers on the elasticity and tensile strength of cassava peel bioplastics. Characterizing the elasticity of cassava peel bioplastics requires advanced techniques. Researchers have employed methods such as tensile testing and dynamic mechanical analysis (DMA). (González *et al.*, 2023) utilized DMA to assess the viscoelastic behavior and elasticity of cassava starch-based bioplastics. Elasticity is not the sole parameter to consider; the environmental impact and biodegradability of cassava peel bioplastics are also critical. Research by (Rossi *et al.,* 2015) explored the relationship between elasticity and biodegradation rates, emphasizing the importance of sustainable end-of-life options. The elasticity of bioplastics derived from cassava peels is a multifaceted aspect influenced by various factors, including formulation, plasticizers, reinforcement, and characterization techniques. Researchers continue to explore and optimize these parameters to develop cassava peel bioplastics with desirable elastic properties, aiming for sustainable alternatives in diverse applications.

2.2.3 Water Absorption

Cassava peel bioplastics generally exhibit moderate water resistance but tend to absorb water more readily than conventional plastics due to their high starch content (Abel *et al.*, 2021). Studies report that water absorption in these bioplastics is influenced by factors such as film composition, the addition of plasticizers, and the degree of starch modification. Films with unmodified starch show higher water uptake compared to those where starch has been hydrolyzed or acetylated, as starch modification can increase hydrophobicity and thus reduce water absorption. The material's porosity and density also play critical roles, where higher densities are associated with lower water absorption rates, enhancing the film's structural integrity (Repka *et al.*, 2000).

Blending cassava peel-derived starch with additives like eggshell powder has been shown to affect water absorption properties. For example, bioplastic films with a 1:0 (cassava peel to eggshell) ratio demonstrated optimal water resistance, maintaining flexibility without excessive brittleness. However, increasing eggshell content to ratios like 1:3 or 1:5 reduces flexibility, resulting in brittle films with increased water absorption due to poor adhesion between elements in the matrix (Mohammadi *et al., 2018*).

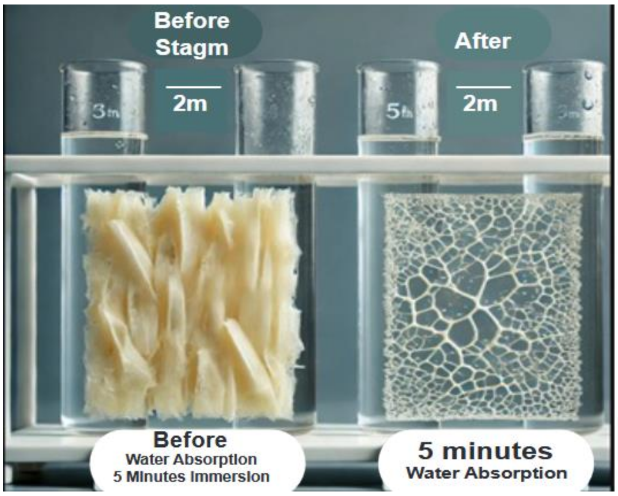

Figure 2.1: Cassava peel-based bioplastic film before and after a water absorption test

Illustration depicting a cassava peel-based bioplastic film before and after a water absorption test. The image (figure 2.1) shows the differences in structure and flexibility, highlighting the film's water absorption properties over a short immersion period. This serves as a visual reference for understanding how cassava peel bioplastics react under conditions that test water resistance.

2.2.4 Solubility in Water

Cassava (*Manihot esculenta Crantz*) has gained significant attention in recent years as a viable source for bioplastic production, especially due to its high starch content and biodegradability (Abotbina *et al.,* 2022). As environmental concerns over petroleum-based plastics rise, bioplastics derived from agricultural waste such as cassava peels are seen as sustainable alternatives.

Cassava peels, which are often discarded as agricultural waste, are a rich source of starch, which constitutes up to 30-40% of the dry weight of the peel (Fronza *et al.,* 2023). Cassava starch has been widely used in bioplastic production due to its high amylose content, which contributes to the mechanical strength and flexibility of bioplastic films (Oluwasina *et al.,* 2019). The presence of amylose and amylopectin in cassava starch influences its water solubility, with higher amylose content generally leading to lower solubility due to its linear structure (Charles *et al.,* 2005).

Bioplastic films from cassava peels are generally prepared by extracting starch from the peels and mixing it with plasticizers such as glycerol. The mixture is then gelatinized and cast into thin films. The addition of plasticizers is crucial, as they influence the flexibility, tensile strength, and water solubility of the resulting film (Suderman *et al.,* 2018). Studies have shown that the plasticizer concentration affects water solubility, with higher concentrations increasing water absorption due to enhanced molecular mobility and increased hydrophilic interactions between glycerol and water (Fundo *et al.,* 2015).

Water solubility is a key property, especially for packaging applications, as it impacts the shelf life and functionality of bioplastics. The solubility of cassava peel bioplastic films is influenced by several factors, including the ratio of starch to plasticizer, degree of gelatinization, and any additional components or fillers. A study by Abotbina *et al.* (2021) highlighted that increasing the plasticizer concentration to 30% resulted in a bioplastic film with increased water solubility, reaching up to 45% in water immersion tests. Similarly, Zhang *et al.* (2023) observed that cross-linking agents, such as citric acid, reduced water solubility by creating stronger intermolecular bonds within the starch network, enhancing film stability in aqueous environments.

In recent years, research has focused on enhancing the durability and reducing the water solubility of cassava-based bioplastic films through the use of additives such as cellulose and lignin. These fillers not only improve the mechanical properties of the films but also reduce solubility by creating a more hydrophobic matrix. Zhao *et al.* (2021) found that adding 5% lignin reduced water solubility by 20%, suggesting that lignin's hydrophobic nature restricts water penetration into the starch matrix. In another study, cellulose fibers were added to cassava peel bioplastic, resulting in a composite material that exhibited reduced water solubility due to the formation of a denser polymer network (Edhirej *et al.,* 2016).

2.2.5 Biodegradability

The environmental impact of synthetic plastics has spurred the search for biodegradable alternatives. Cassava peel-derived bioplastic films have emerged as a sustainable substitute due to their natural biodegradability and ability to decompose into harmless byproducts. Cassava, a rich source of starch, provides an ideal material for bioplastic production due to its availability, low cost, and low environmental footprint.

The biodegradability of cassava peel bioplastics results from their organic composition, which can be broken down by microorganisms in natural environments. Cassava starch contains amylose and amylopectin, polysaccharides that are digestible by bacteria and fungi, resulting in carbon dioxide, water, and biomass without the release of toxic residues (Ubalua *et al.*, 2007). According to Bamisaye *et al.* (2022), bioplastic films from cassava peels degrade significantly faster than conventional plastics, with up to 80% degradation within six months under controlled composting conditions.

The biodegradation rate of cassava peel bioplastics is influenced by environmental factors, including temperature, humidity, pH, and microbial diversity. Research by Zoungranan *et al.* (2020) demonstrated that cassava-based films degraded faster in humid and high-temperature conditions, which promote microbial activity. The researchers also noted that composting environments with high moisture levels accelerated the biodegradation rate by facilitating enzymatic breakdown of the starch matrix.

Plasticizers and fillers, such as glycerol and cellulose, are commonly added to improve the mechanical properties of cassava peel bioplastics but can also influence their biodegradability. Glycerol enhances flexibility but can slightly slow down biodegradation as it forms a more compact matrix that resists microbial attack (Ben *et al.*, 2022). On the other hand, natural fillers like cellulose improve both mechanical strength and biodegradability. Bamisaye *et al.* (2022) found that cassava peel bioplastic with 10% cellulose degraded by 95% in 120 days in soil, compared to 70% for films without additional cellulose. The cellulose creates a more porous structure, which increases water absorption and microbial colonization, accelerating degradation.

2.2.6 Density

Bioplastics have garnered substantial interest as environmentally friendly alternatives to conventional plastics. These materials, derived from renewable biological sources such as starch, cellulose, and proteins, offer advantages including biodegradability and reduced dependence on fossil fuels. Among the various physical and mechanical properties used to characterize bioplastics, density stands out as a critical parameter. Density plays a significant role in determining a material’s structural integrity, compatibility with other materials, and suitability for specific applications (Ali *et al.,* 2020).

The importance of density in bioplastics is multifaceted. It directly correlates with structural and mechanical properties, influencing the material’s tensile strength, rigidity, and impact resistance. Higher densities typically indicate better mechanical performance, which is essential for load-bearing applications (Piggott 2002). Density also affects application-specific suitability, with lightweight bio-plastics being ideal for packaging and disposable products, while denser materials find use in construction and durable goods. Additionally, density influences the biodegradability of bio-plastics, as materials with lower porosity and higher density may degrade more slowly in the environment. Furthermore, density matching is crucial when combining bioplastics with other materials in composite applications to ensure uniform mechanical properties and prevent delamination.

Several factors influence the density of bio-plastics. The composition of the base polymer, such as polylactic acid (PLA) or polyhydroxyalkanoates (PHA), determines the inherent density of the material. Additives like plasticizers and cross-linking agents modify density by altering the material's porosity and flexibility. For instance, plasticizers such as glycerol and sorbitol reduce density by increasing porosity, but excessive use may compromise mechanical strength. Processing conditions, including temperature, pressure, and cooling rate, also play a significant role by affecting polymer chain alignment and porosity. Furthermore, the inclusion of fillers like natural fibers or mineral additives increases density by introducing compact structures into the polymer matrix.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was carried out in three markets of Busega (0.31008° N, 32.51630° E) in Rubaga division, Nakawa (0.33015° N, 32.61151° E) in Nakawa division, and Kasubi (0.33373° N, 32.55618° E) Kawempe division from Kampala capital city (Fig 3.1), which were selected using purposive sampling. Kampala, the primary urban center and most populous city in Uganda, is located on a cluster of hills approximately 3,900 feet (1,190 meters) above sea level. As of 2024, Kampala has a population of 4,050,830 people (UBOS 2024).

3.1.1 Climate

Kampala has a tropical rainforest climate under the Köppen-Geiger climate classification system (Kabano, 2019). A facet of Kampala's weather is that it features two annual wetter seasons. While the city does not have a true dry season month, it experiences heavier precipitation from August to December and from February to June. However, it is between February and June that Kampala sees substantially heavier rainfall per month, with April typically seeing the heaviest amount of precipitation at an average of around 169 millimeters (6.7 in) of rain (Katasi, 2021).

3.1.2 Topography

The City of Kampala covers a total area of 189 km^2 (73 square miles), comprising 176 km^2 (68 square miles) of land and 13 km^2 (5.0 square miles) of water. Kampala is a hilly place with its valleys filled with sluggish rivers/ swamps. The highest point in the city proper is the summit of Kololo hill at 1,311 metres (4,301 ft), located in the center of the city and the lowest point at the shores of Lake Victoria south of the city center at altitude of 1,135 metres (3,724 ft).

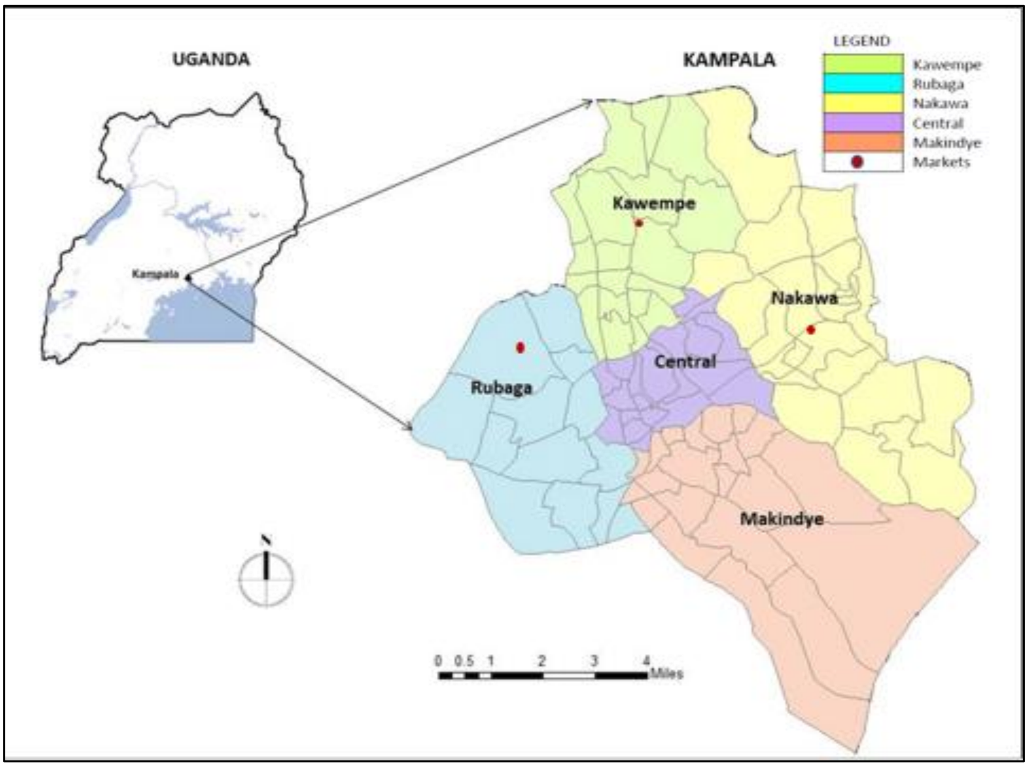

Figure 3.1: Map of Kampala city illustrating the locations of the Study sites

3.2 Research Design

This study utilized a cross-sectional research design, combining both quantitative and qualitative approaches to provide a holistic assessment of cassava waste valorization for bio-plastic production. Laboratory experiments were conducted to extract and analyze starch from cassava peels, while field surveys, using structured questionnaires, gathered data from end-users (Appendix A) and vendors (Appendix B) across three markets of Busega, Nakawa and Kasubi. Simple random sampling was applied to ensure representative participation. This design facilitated a detailed exploration of both the technical and market aspects of bio-plastic production.

3.2.1 Experimental Design

To formulate a biofilm from Cassava peel waste, three varieties of cassava were used from National Crop Resources Research Institute farm, Namulonge. For the biofilm for the first experiment, starch from the cassava peels was used with a plasticizer without additive while for the second objective starch from the cassava peels was used with a plasticizer and cellulose was added for each experiment multiple samples were done for consistence. For each of the biofilm formed water absorption, solubility in water, biodegradable and tensile strength test properties were carried out.

3.3 Sampling and Sample Size

For the field surveys, data was collected from 146 participants, comprising 35 end-users,76 vendors and 35 transporters which were purposively selected, from the three markets Busega, Nakawa, and Kasubi. The sample size was carefully chosen to balance statistical reliability and logistical feasibility while ensuring a diverse and representative cross-section of stakeholders within the cassava supply chain. By targeting 35 end-users, 76 vendors and 35 transporters, the study acknowledged the differing contributions and perspectives of each group, reflecting their unique roles in the supply chain. This segmentation provided a nuanced understanding of cassava waste generation, market dynamics, and the feasibility of bio-plastic production (Tanyela et al., 2022). The selected sample size was also guided by prior studies in similar contexts, which demonstrated that 100–150 respondents are often sufficient to capture meaningful trends and behaviors in local supply chains.

Consequently, the 146 participants provided a robust foundation for drawing reliable and generalizable insights while maintaining practical efficiency in data collection.

For the starch extraction portion of the study, cassava samples were selected from three varieties NASE 19, NASE 14, and NAROCAS sourced from the National Crop Resources Research Institute (NACCRI) Farm, Namulonge along with a market sample from Busega market. These specific varieties were chosen because they represent commonly cultivated and widely used cassava types in Uganda, each with distinct agronomic and biochemical properties. NASE 19 and NASE 14 are high-yielding varieties known for their resistance to cassava mosaic disease, while NAROCAS is recognized for its adaptability and high starch content, making it ideal for both food and industrial purposes. Including a random market sample ensured that the study also captured variations in cassava quality and properties as encountered in local trade.

For biofilm formation, starch-to-sorbitol ratios of 10:10, 12:8, and 14:6 were chosen based on (Maulida *et al.*, 2016) research, which demonstrated that varying these ratios influences key bioplastic properties like flexibility, tensile strength, and water resistance. The selected ratios represent different trade-offs: 10:10 for rigidity, 14:6 for flexibility, and 12:8 as a balanced middle ground. These ratios are essential for optimizing biofilm performance across various applications. In the second experiment, microcrystalline cellulose (MCC) was added to reinforce the films by enhancing their tensile strength and stability without compromising biodegradability (Maulida *et al.*, 2016).

3.4 Data Collection on Cassava Peel Waste Amount and Supply Chain Dynamics

Data collection was conducted using the KOBOcollect mobile application, which was installed on smartphones. Structured questionnaires were uploaded into the app, allowing for electronic data capture through face-to-face interviews. The software facilitated both the collection and management of data efficiently. During the interviews, cassava waste present at each participant's site was measured using a calibrated digital weighing scale. This was done for every respondent across the three markets Busega, Nakawa, and Kasubi to estimate the average daily cassava waste generated per individual. Traders and suppliers of cassava were selected purposively to ensure relevant input on the cassava supply chain. The structured questionnaire used in the KOBOcollect app included a mix of open and closed-ended questions, designed to gather both quantitative data and qualitative insights.

3.5 Limitations

The study may have been limited in the frequency of collection of the cassava peel waste might not have captured long-term fluctuations.

3.6 Approval and ethical consideration

The project received clearance from Uganda Christian University Research Ethics Committee (UCUREC): registration number UCUREC-2023-694 and Uganda National Council for Science and Technology (UNCST) registration number: NS681ES. Emphasizing its purely academic nature. The researcher treated all individuals encountered during the study with the utmost respect and refrain from seeking any financial or other benefits from them. Additionally, the researcher upheld intellectual property rights throughout the research process. Informed consent from participants was used in the survey study. The participants were fully informed about the research objectives, potential risks, and benefits. Language and cultural considerations were considered to ensure participants understood the implications of their involvement

3.7 Sample Preparation

Fresh cassava peels, weighing 100 grams and sourced from the National Crop Resources Research Institute (Namulonge), were thoroughly washed with water before being finely chopped. The chopped peels were blended and soaked in 100 milliliters of water to produce a starch slurry, which was then filtered and allowed to settle in a beaker for 30 minutes. The settled white starch was rinsed with distilled water, and left to settle again. After the second settling period, the starch sediment was dried in an oven at 70°C to remove residual moisture. Once dried, the starch was ground into a fine powder, sieved to achieve a uniform particle size, this was weighed and stored in airtight, moisture-proof bags to prevent humidity absorption and maintain quality (Maulida *et al.,* 2016).

3.8 Starch Extraction

A total of 10 kg of cassava waste was collected from Busega Market and carefully sorted to separate cassava peels from other materials such as leaves and stems. The cassava peels were then thoroughly washed to remove soil and impurities. After cleaning**,** 3,000 g of clean peels were measured and set aside for starch extraction. Additionally, for each pure cassava variety NASE 14**,** NASE 19, and NAROCAS peels were manually removed from the tubers using a knife. These peels were also thoroughly washed**,** and 3,000 g of clean peels from each variety were measured and set aside for starch extraction. The starch extraction process (Figure 2.2) started with grating washed cassava peels into coarse pieces using a flat, generic handheld grater. The grated material was thoroughly washed with clean water and strained through a sieving cloth bag, which was then squeezed to extract starch milk into a collection bucket. This washing and squeezing process was repeated until the liquid appeared clear, indicating complete starch removal. The extracted liquid was left undisturbed for 24 hours to allow the starch to settle at the bottom, after which the supernatant was carefully decanted. The starch was repeatedly washed and settled until the decanted liquid was completely clear, ensuring a high level of purity.

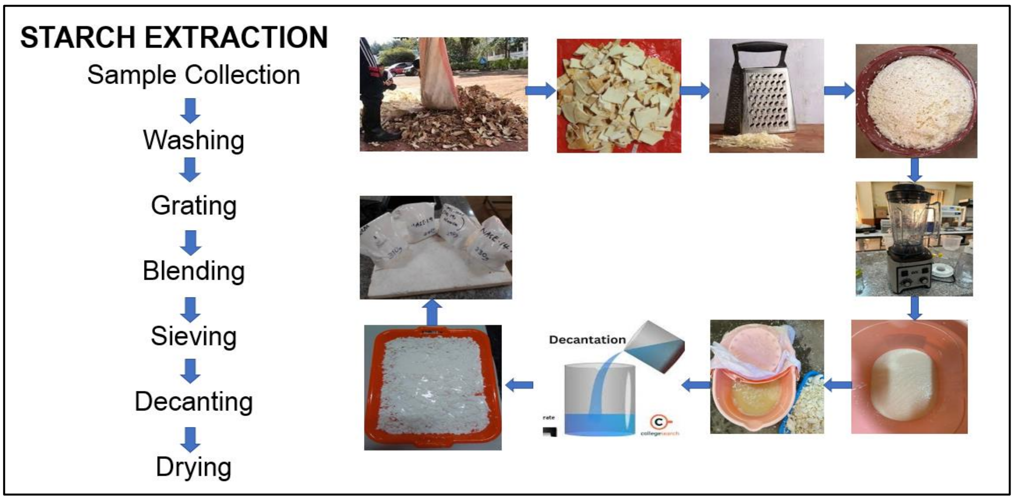

Figure 2.2: Starch extraction process; (Source: Field and Laboratory experiment)

3.9 Bioplastic Film Formulation

The outlined method by Maulida *et al.*, 2016 was adopted for this study with some modifications. Initially, a mixture of starch and sorbitol as a plasticizer in three different ratios: 10:10, 12:8, and 14:6, without any additives. These formulations were tested on three cassava varieties (NASE 19, NASE 14, and NAROCAS) sourced from the National Crop Resources Research Institute (NACCRI) Farm, in addition a random market sample collected from Busega market was tested. The cassava varieties were selected for their high starch content, specifically: NAROCAS (84.42 ± 1.98%), NASE 14 (75.25 ± 1.40%), and NASE 19 (66.72 ± 3.65%) (Manano *et al.,* 2017). To ensure consistency, three samples were prepared for each variety and the market sample. Sorbitol was used to enhance the flexibility of the bioplastic and prevent brittleness. Additionally, 20% vinegar was added to help dissolve and blend the biopolymers.

The second phase of analysis, microcrystalline cellulose (MCC) was added to the formulations. Starch-to-MCC ratios of 10:10, 12:8, and 14:6, along with 40% sorbitol, were employed to improve the water absorption properties of the bioplastic (Salim *et al.,* 2018). The same cassava varieties and market sample were used, with three replicates for each, ensuring consistency across experiments. MCC served to reduce the density of the bioplastic and minimize water absorption.

The preparation process began by dissolving the starch composition in distilled water at a 1:10 (w/v) ratio. The solution was heated to 70°C and stirred continuously on a hotplate for 10 minutes, with sorbitol (40%) gradually added during the heating process. The resulting gel was spread evenly on a flat surface to form a uniform film. This film was then left to dry under the sun to remove moisture. Once dried, the bioplastic was peeled off the surface (Figure 3.3).

Each experiment (with and without MCC) involved a total of 24 samples three replicates for each of the three cassava varieties and the market sample. These replicates ensured reliability and consistency in the results across both experimental setups.

Figure 3.3: Samples of Biofilms developed

3.10 Determination of Properties

3.10.1 Tensile Test

The tensile strength of the biofilm derived from cassava peels waste was determined using a Testometric materials testing machine (Testometric M350-10CT, Rochdale, UK). The machine was calibrated prior to testing, following the manufacturer's instructions to ensure accuracy and reliability of the measured forces and displacements (Testometric Company Ltd. 2024). Appropriate grips designed for thin film testing were attached to the machine to ensure secure holding of the sample without causing slippage or premature failure. Biofilm samples were carefully cut to a width of 2 mm and length of 30 mm using a precision cutter to minimize irregularities along the edges. Each sample was mounted between the upper and lower grips of the Testometric machine, ensuring proper alignment and elimination of any initial tension or slack (ISO 527-1:2012. 2012). The gauge length, defined as the distance between the grips, was adjusted to 50 mm in accordance with standard testing procedures, such as those outlined in ASTM D882 for thin plastic films (ASTM D882-18. 2018).

The testing parameters were set to a crosshead speed of 30 mm/min, which is a commonly used speed for testing thin films to capture both the elastic and plastic deformation behaviors of the material (Atanacio *et al.,* 2005). The testing procedure involved applying a uniaxial tensile force along the length of the biofilm until sample rupture. This force was applied at a constant rate by the Testometric machine, generating a stress-strain curve in real time. During the test, the Testometric machine automatically recorded the force applied to the sample and the corresponding displacement. The peak stress value, representing the maximum force applied before rupture, was recorded in kPa. This value was subsequently converted to MPa to represent the tensile strength of the biofilm

$$\text{Tensile strength} = \frac{\text{Peak stress}}{1000}$$

3.10.2 Water Absorption

The absorption of water in film samples was studied by measuring the weight of film samples measuring around 2 X 2 cm². These samples underwent drying at 70 ºC for 3 hours, followed by cooling and immediate weighing. Subsequently, the film samples were immersed in distilled water for 3 hours without any agitation. Upon completion of the immersion period, the samples were taken out of the water and weighed again. The percentage of water absorbed was calculated as described by Maulida *et al.* 2016.

$$\text{Water Absorption (\%)} = \frac{(\text{Final weight} - \text{Initial Weight})}{\text{Initial Weight}} \text{ X } 100$$

3.10.3 Solubility in Water

Dried samples with an area of approximately 2 X 2 cm^2 were weighed. Each sample was subsequently immersed in 50 mL of distilled water under constant agitation for 3 hours at room temperature. Insoluble portion of the film was air dried for 24 hours and reweighed. The water solubility (%) of the films was calculated as by Maulida *et al* 2016.

$$\text{Solubility (\%)} = \frac{(\text{Weight before submersion} - \text{Weight after submersion})}{\text{Weight before submersion}} \text{ X } 100$$

3.10.4 Biodegradability Test

The biodegradation assessment technique outlined by Edhirej *et al.* in 2016 was employed. This involves analyzing bioplastic film pieces measuring 2 X 2 cm2 to observe changes in weight and physical appearance before and after burying them in soil under natural environmental conditions. Half of the film samples were buried in 1.5 cm of soil, while the other half was left exposed to the open air. After one week, the samples were extracted from the soil and delicately cleaned using a soft brush. They were then air-dried for an additional week, re-inspected, and weighed. The percentage weight loss was determined using a specific formula.

$$\text{Weight loss (\%)} = \frac{(\text{Initial Weight} - \text{Final Weight })}{\text{Initial Weight}} \text{ X } 100$$

3.10.5 Density Test

The Gravimetric Method (Mass and Volume Measurement) was used to determine the density. This method involved measuring the mass and volume of a bioplastic sample: Weighed the bio-plastic sample using a precision balance to determine its mass. Measured the sample's volume.

Calculate density using the formula:

$$\text{Density} = \frac{\text{Mass (g)}}{\text{Volume (cm3)}}$$

3.11 Data Analysis

To quantify the amount of Cassava Peel waste generated and the supply chain of cassava in selected Markets in Kampala data was analyzed using SPSS version 29. Descriptive analysis such as the frequencies and percentages were employed to examine the data concerning the quantity of cassava peel waste gathered and the data regarding the cassava supply chain in the chosen markets. The results were presented using graphs, tables and figures.

To analyze starch content of cassava peels from three distinct cassava varieties and the market sample, and use it to develop biodegradable bioplastics data was analyzed using SPSS version 29. Descriptive analysis such as the frequencies and percentages were employed to examine the data. The results were presented using graphs.

To assess the properties and performance of the developed biodegradable bioplastics data analysis was performed using Microsoft Excel (version 16) and GraphPad Prism (version 8.0.1) to calculate measures of central tendency and variation, for the observed parameters of water absorption, tensile strength, solubility, density and biodegradability.

CHAPTER FOUR

PRESENTATION OF RESULTS

4.1 Determine the Amount of Cassava Peel Waste Generated and the Supply Chain of Cassava in Selected Markets in Kampala

4.1.1 Cassava waste Generation at the Markets

The study revealed that a majority of participants, 83 individuals (75.0%), generate cassava peel waste daily, ensuring a consistent supply. Additionally, 19 participants (17.5%) reported generating waste on a weekly basis, while 9 participants (7.5%) indicated rare involvement in waste generation (Figure 4.1).

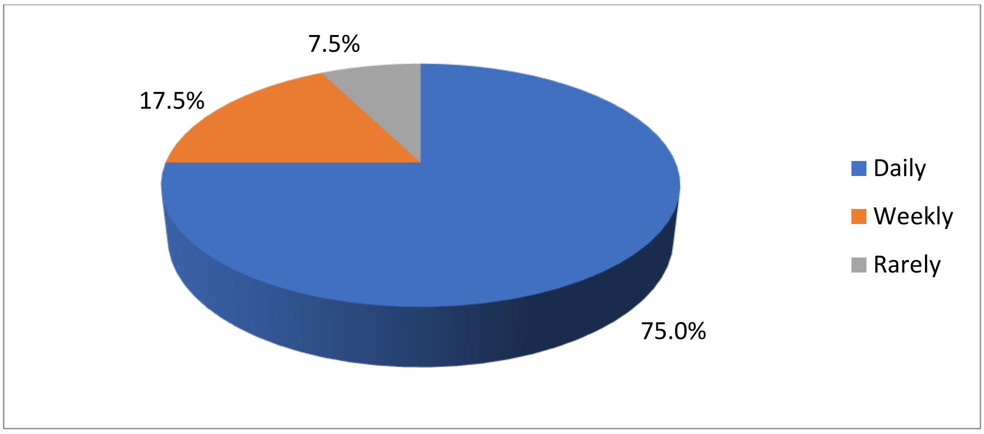

Figure 4.1: Frequency of waste generation

4.1.2 Forms of Cassava Waste Generated by End-Users

Regarding the types of cassava waste generated by end-user's, peels accounted for the largest proportion at 73.6%. Residues were moderately generated, contributing 17.0%, while stems represented the smallest share, comprising only 9.4% of the total waste (Figure 4.2).

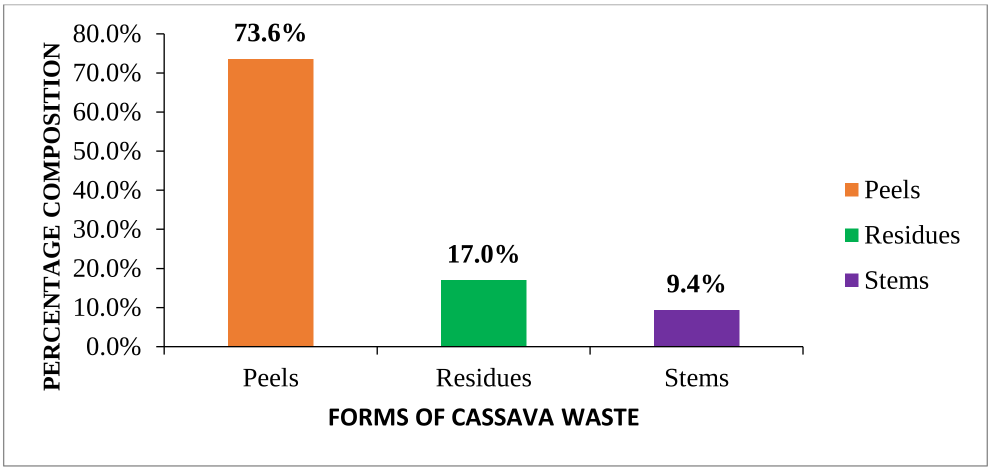

Figure 5.2: Forms of cassava waste generated by end-users

4.1.3 Amount of Cassava Waste Generated

The majority of the participants (32.5%) generated < 10 kg of waste, followed by 17.5% of the participants who generated 41 to 50 kg of waste while 5.0% of the participants generated > 50 kg of waste (Figure 4.3).

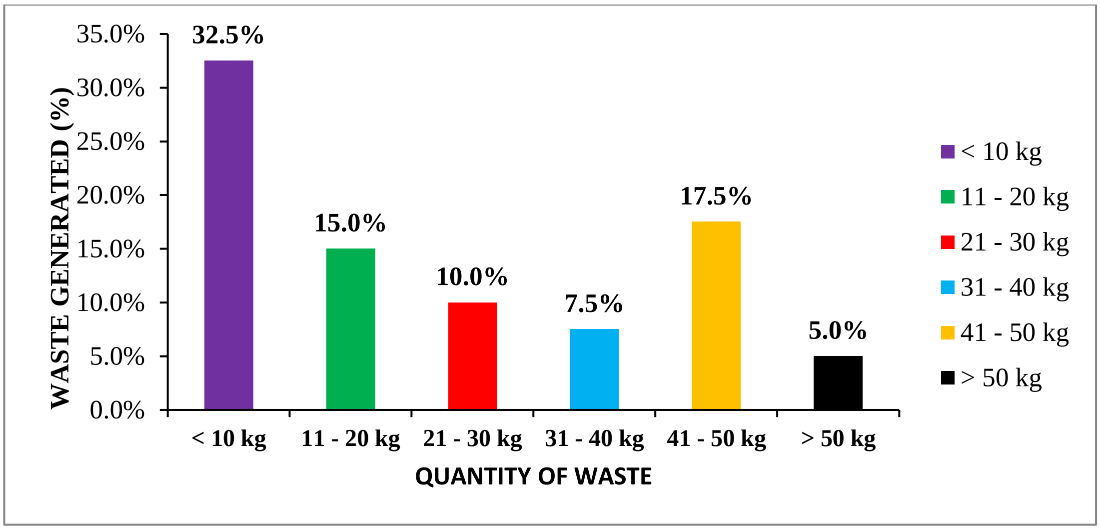

Figure 6.3: Quantity of waste generated

4.1.4 Cassava Waste Management by the End-Users

The primary end-users of cassava products included cassava processors (commonly known as "cassava fryers"), local food vendors referred to as "Toninyira" (Meaning a local dining place), households located near markets, and nearby schools. Data from 68 participants indicates that cassava waste is predominantly managed through composting, often used as mulch, with 31 participants (45.6%) adopting this method. This is closely followed by 29 participants (42.6%) who utilize the waste as animal feed. A smaller portion of respondents reported disposing of cassava waste in landfills via waste collectors (6 participants, 8.8%), while just 2 participants (2.9%) reported recycling it as a binder in charcoal briquettes. When asked about challenges in cassava waste management, half of the respondents (50.8%, n=35) identified the lack of designated dumpsites as the most significant barrier. This was followed by 26 participants (37.7%) who cited the high cost of waste collection services. The least reported challenge was the absence of waste management companies, mentioned by only 8 participants (11.5%). To address these issues, the majority of participants (54.0%, n=37) recommended the establishment of accessible dumpsites. An additional 26 participants (37.7%) suggested reducing waste collection costs, while 8 participants (11.1%) proposed expanding the coverage of collection services (see Table 4.1).

Table 4.1: Waste management by the end-users

Variable	Categories	Frequency	Percentage
Current management of cassava waste	Compositing	31	45.6
	Animal feeds	29	42.6
	Disposal in landfills	6	8.8
	Recycling	2	2.9
Challenges encountered in cassava waste management	Lack of dumpsite	35	50.8
	High cost of waste collection	26	37.7
	Lack of waste management company	8	11.5
Suggestions for better cassava waste management	Reducing waste collection costs	24	34.9
	Make dumpsite available	37	54.0
	Increase waste collection service coverage	8	11.1

4.1.5 Amount of Waste Generated by Vendors

The majority of the participants (73.7%) generated < 20 kg of waste, followed by 11.8% of the participants who generated > 80 kg of waste while 2.6% of the participants generated 20 to 40 kg and 40 to 60 kg of waste (Figure 4.4).

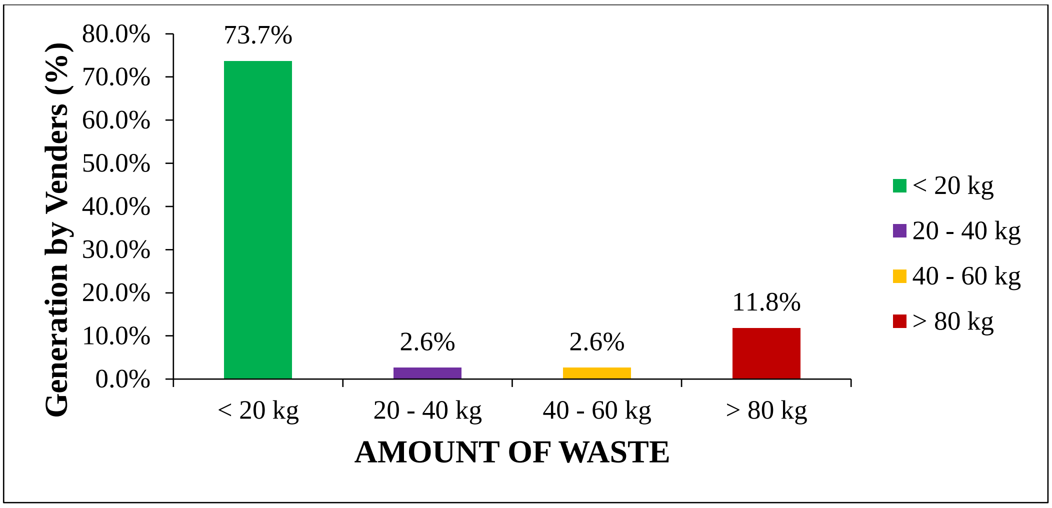

Figure 7.4: Amount of waste generated by Vendors on a daily basis

4.1.6 Districts that Supply Cassava to the Markets

Concerning the supply of cassava to the markets' Mubende district made up the largest percentage at 38.3% followed by Hoima district with 18.3% while Lira had the least supply of the cassava produce to the markets (Table 4.2).

Table 4.2: Districts that supply cassava to the markets

District	Frequency	Percentage
Mubende	44	38.3
Hoima	21	18.3
Kibaale	15	13.0
Masaka	12	10.4
Fortportal	8	7.0
Gomba	7	6.1
Kyegegwa	4	3.4
Mityana	3	2.6
Lira	1	0.9

4.1.7 Cassava Supply Chain

The cassava supply chain originates from farmers across key districts, including Mubende, Hoima, Kibaale, Masaka, Fort Portal, Gomba, Kyegegwa, Mityana, and Lira, who cultivate high-starch varieties such as NASE 19, NASE 14, and NAROCAS. Among these districts, Mubende emerged as the leading supplier with 38.3% of the total cassava delivered to markets, followed by Hoima at 18.3%, while Lira accounts for the smallest proportion. Transporters, who function as intermediaries, manage 75% of cassava deliveries. Direct deliveries by farmers without intermediaries constitute 10% of the supply, and 13% is sourced by traders who purchase directly from farmers. Additionally, 2% of cassava originates from traders who cultivate their own farms and deliver produce to the markets (Figure 4.5).

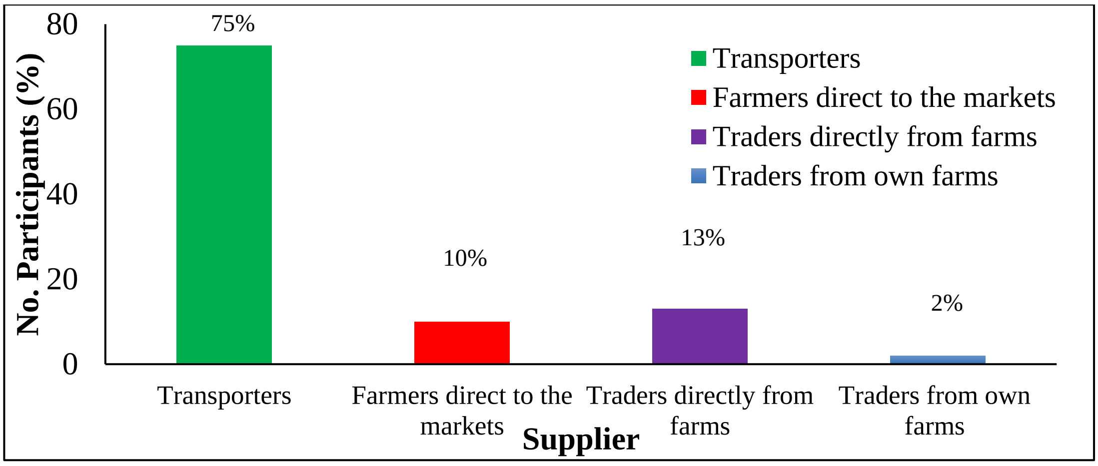

Figure 8.5: Supply of Cassava to the Markets

4.1.8 Quantities of Cassava Received (kg)

Majority of the cassava was received from Busega market while the least quantity was received from Nakawa market (Table 4.3).

Table 4.3: Average daily quantity of cassava received

	Kasubi	Nakawa	Busega
	n (%)	n (%)	n (%)
Average daily quantity	476.4 (32.9)	261.1 (18.1)	709.1 (49.0)

4.1.9 Average Cassava Waste Generated Daily Per Trader (kg)

Majority of the cassava waste was generated from Busega market while the least quantity was generated from Kasubi market (Table 4.4).

Table 4.4: Daily average waste generated per trader

	Kasubi	Nakawa	Busega
	n (%)	n (%)	n (%)
Average waste	12.9 (22.0)	19.2 (32.8)	26.5 (45.2)

4.2 Starch Extract from Cassava Peels

The highest starch yield was from NASE 19 (3.4%), indicating that it has the best performance in terms of starch yield followed by NASE 14 (3.0%) and Naroccas (2.8%). The lowest starch yield was from the Market sample (2.16%), showing it performed the least well in starch production. The error bars on the graph also indicated the variability associated with each percentage, but the trend clearly showed NASE 19 as the best and Market sample as the lowest in terms of starch yield (Figure 4.6).

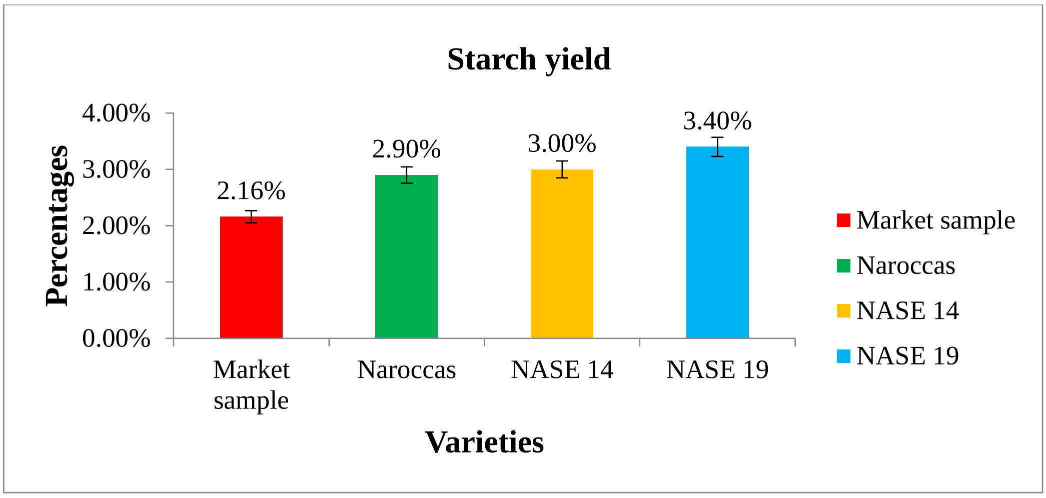

Figure 9.6: Level of starch yield for cassava varieties and market sample

4.3 Water Absorption, Solubility, Biodegradability and Tensile Strength of the Bioplastic Film

4.3.1 Water Absorption

Water absorption for NASE 19 samples was consistently high especially in those without additional cellulose. Samples with NASE 14 showed the lowest water absorption (51.2%), for samples without additional cellulose where the gap between the highest (NASE 19) and the lowest (NASE 14) is the most pronounced. Samples containing cellulose exhibited minimal variation, with all values ranging closely between 98% and 99%. Statistical analysis using Mann–Whitney U test revealed that the 75th percentile of water absorption was significantly higher in cellulose-containing samples (70.27) compared to those without additional cellulose (66.06), indicating a meaningful group effect ($p < 0.05$). As shown in Figure 4.7, bars annotated with the same letter are not significantly different, while those with different letters represent statistically significant differences.

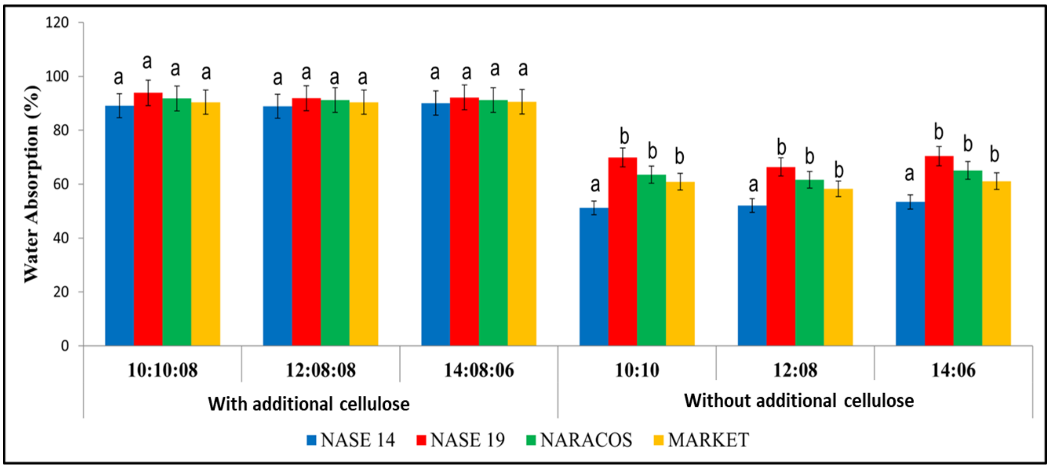

Figure 4.10: Level of water absorption of the bio plastic film made from cassava peels of the cassava varieties and the market sample

4.3.2 Solubility

The NASE 19 samples consistently exhibited the highest values among those with additional cellulose, reaching up to 56.0%. In contrast, the NASE 14 samples consistently showed the lowest values across all conditions. For samples with additional cellulose, the NASE 14 values were 40.4%, 42.7%, and 45.2% for the ratios 12:08:08, 10:10:08, and 14:08:06, respectively. Without additional cellulose, the values for NASE 14 were 30.6%, 32.4%, and 34.3% for the ratios 12:08, 10:10, and 14:06, respectively. A Mann–Whitney U test revealed that the 50th percentile for solubility was higher in samples with additional cellulose (50.6) compared to those without additional cellulose (33.6), Showing a significant difference in the two groups ($p < 0.001$). As shown in Figure 4.8, bars annotated with the same letter are not significantly different, while those with different letters represent statistically significant differences.

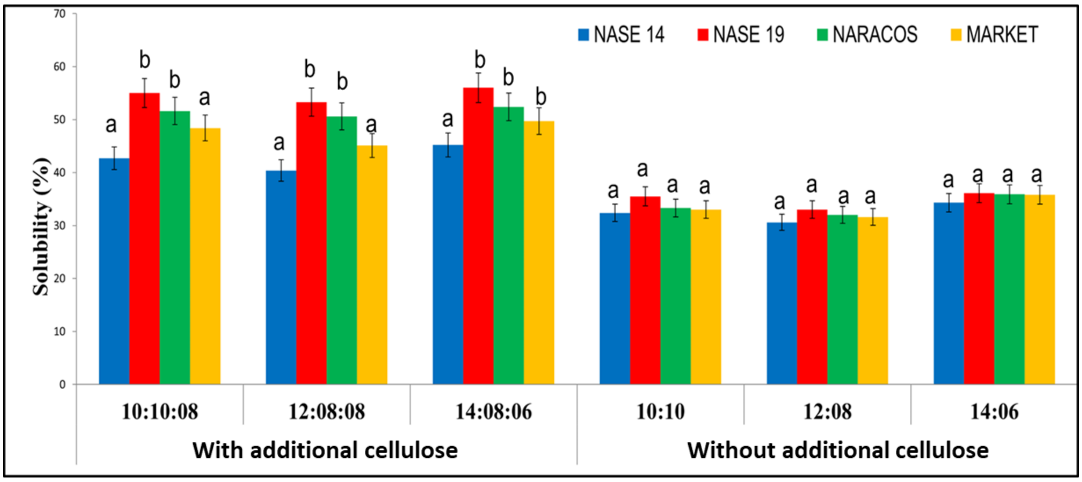

Figure 4.11: Level of solubility in water of the bio plastic film made from cassava peels of the cassava varieties and the market sample

4.3.3 Biodegradability

The NASE 19 samples consistently displayed the highest values in 10:10:08 (buried and unburied), 12:08:08 (buried and unburied) and 14:08:06 (unburied) while the NARACOS samples consistently displayed the highest values in 14:08:06 (buried). The NASE 14 samples consistently displayed the lowest values throughout the categories, the NASE 19 sample seems to perform better in buried and unburied categories. A Mann–Whitney U test revealed that the 75th percentile for biodegradability was lower in buried samples with additional cellulose (65.8) compared to unburied samples (75.9). Showing a significant difference in both conditions, ($p < 0.001$). As shown in Figure 4.9, bars annotated with the same letter are not significantly different, while those with different letters represent statistically significant differences.

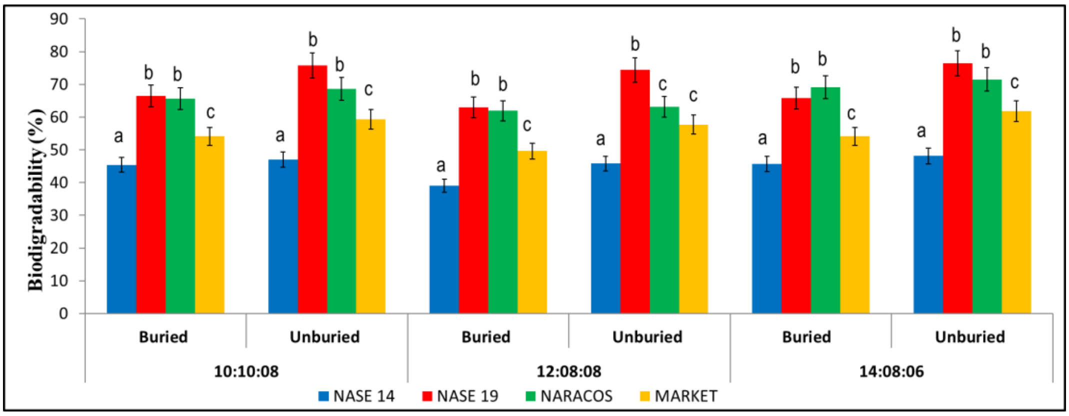

Figure 12.9: Level of biodegradable of the bio plastic film made from cassava peels of the cassava varieties and the market sample

4.3.4 Tensile Strength

The market sample under the 14:06 without additional cellulose condition has the highest tensile strength value (381.571) while the NASE 14 under the 14:08:06 with additional cellulose condition has the lowest tensile strength. Without additional cellulose, tensile strength values are generally higher, particularly for the market sample. NASE 19 shows consistently high values in both "with additional cellulose" and "without additional cellulose" conditions, except in the 14:08:06 Market sample. NASE 14 generally shows the lowest values (55.217) across most conditions. A Mann–Whitney U test revealed that the 25th percentile for tensile strength was high in samples without additional cellulose (10.08) compared to those with additional cellulose (5.85). Showing a significant difference between the two groups ($p < 0.05$). As shown in Figure 4.10, bars annotated with the same letter are not significantly different, while those with different letters represent statistically significant differences.

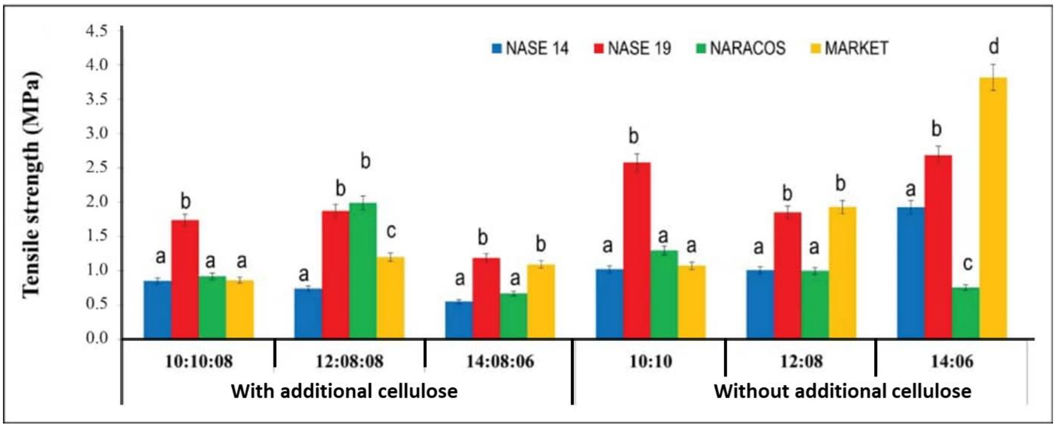

Figure 13.10: Level of tensile strength of the bio plastic film made from cassava peels of the cassava varieties and the market sample

4.3.5 Density

The NASE 19 under the 14:06 without additional cellulose condition shows the highest value (1.4) while the NASE 14 under the 10:10:08 with additional cellulose condition has the lowest value (1.05). The differences between the varieties are relatively small across both "with additional cellulose" and "without additional cellulose" conditions. NASE 19 consistently has the highest values, especially in the without additional cellulose condition. NASE 14 tends to have the lowest values across most conditions. A Mann–Whitney U test revealed that the 75th percentile (Q3) of density in samples without additional cellulose is 1.3225, while in samples with additional cellulose is 1.2725, indicating that the upper quartile of densities decreases with the addition of cellulose. A Mann–Whitney U test revealed that this difference is statistically significant with ($p<0.001$). As shown in Figure 4.11, bars annotated with the same letter are not significantly different, while those with different letters represent statistically significant differences.

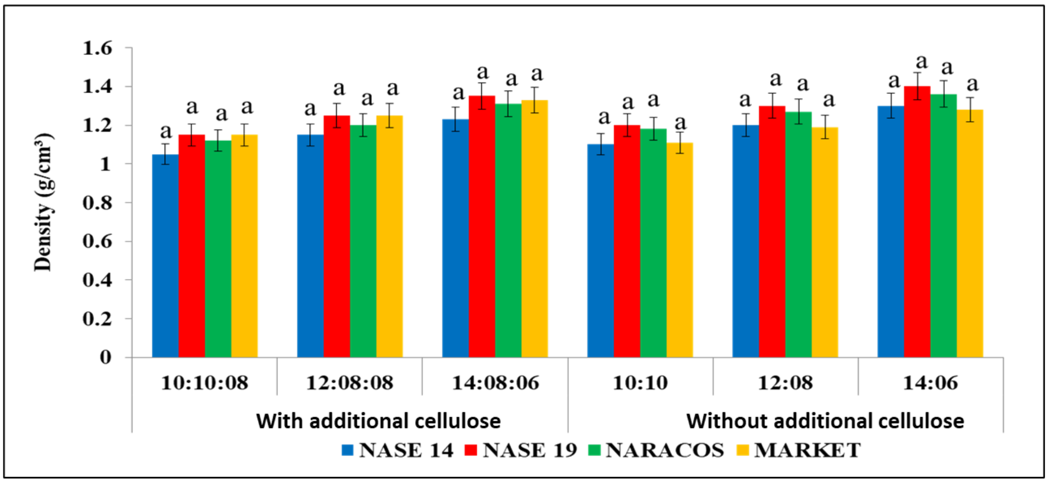

Figure 14.11: Level of density of the bio plastic film made from cassava peels of the cassava varieties and the market sample

CHAPTER FIVE

DISCUSSION

5.1 The Amount of Cassava Peel Waste Generated and the Supply Chain of Cassava

5.1.1 Waste Generation Patterns

The study results indicated that most of the participants generate cassava waste daily, this is similar to the study by Falade *et al.* (2010) which indicated that due to the perishable nature of cassava and its widespread use. Additionally, cassava waste is underutilized for value-added products like animal feed, bioenergy, or bioplastics. This also aligns with the research by Padi *et al.* (2022), which highlighted the challenges of poor infrastructure and limited awareness that hinder the effective use of cassava waste, leading to environmental inefficiencies and missed economic opportunities.

Additionally, the study reported a high level of waste generation, which contrasts with findings by Dou *et al.* (2018), who found lower waste levels in rural areas where subsistence lifestyles, including mixed farming, focus on minimizing food waste. These results also contradict the study by Wilson *et al.* (2012), which observed even lower waste generation in urban areas due to the presence of robust recycling programs and waste management systems. These discrepancies underscore the role of urbanization, policy enforcement, and local consumption habits in waste generation patterns. Regions with advanced waste management infrastructure and practices tend to produce less waste, highlighting the significant influence of regional context and infrastructure on cassava waste generation.

5.1.2 Quantity of Waste Generated

The study found significantly high levels of waste generation, influenced by a complex interplay of socioeconomic factors and awareness of waste reduction practices. These findings are consistent with those by Zohoori *et al.* (2017), which noted that inefficient waste management systems in low-income urban areas contribute to higher waste levels, despite efforts to use affordable, disposable products. This suggests that the dependence on inexpensive, disposable goods in certain low-income settings, combined with ineffective waste management systems, may exacerbate waste generation rather than mitigate it.

Additionally, Grazhdani *et al.* (2016) demonstrated that recycling efforts can significantly lower waste levels, which may explain some of the variation in waste generation patterns observed in this study, these contrasting findings underscore the regional disparities in waste generation, with socioeconomic factors, waste awareness, and infrastructure playing significant roles in shaping the levels of waste produced. The study highlights how these variables interact differently across regions, suggesting that both economic and infrastructural dynamics are key to understanding waste generation patterns.

5.1.3 Cassava Supply Chain Dynamics

The study results indicated that cassava supplies primarily come from districts like Mubende, Hoima, and Kibaale, which thrive due to their favorable agro-climatic conditions similar to the observations of Bazimya *et al.* (2004). The study also confirms the significant role of intermediaries, particularly transporters, in overcoming market access issues, which aligns Nkuba *et al.* (2020), though concerns about high transaction costs remain. This calls for improvements in infrastructure and direct market linkages, as emphasized by Adebayo *et al.* (2018). In terms of market distribution, the dominance of household consumption (60%) and the limited industrial use (6%) aligns with findings from Kamara *et al.* (2019), highlighting cassava's role as a staple food, with industrial demand still emerging. The importance of Busega as a central distribution hub, further reflects the underdeveloped cassava processing sector, underscoring the need for investments in value-added processing, as discussed by Mezera *et al.* (2013).

Due to the highly perishable nature of cassava, stakeholders in the supply chain facilitate daily deliveries to major urban markets, including Busega, Nakawa, and Kasubi, with Busega market serving as the primary hub. At the point of sale, cassava is distributed to various end-users, including households, hotels, schools, and industrial processors. Households account for 60% of cassava purchases, hotels for 25%, schools for 9%, and small-scale industries for 6%. The latter utilize cassava primarily for starch production. However, the study also contradicts with the findings by Kelly *et al.* (2003), which emphasized challenges related to land access, agricultural inputs, and farmer support in districts like Mityana and Lira, the study found out that cassava production in these areas remains significant, though disparities exist.

5.2 Extract Starch from Cassava Peels of Three Distinct Cassava Varieties and Develop Biodegradable Bioplastics

The study results revealed that NASE 19 exhibited superior performance, likely attributable to its genetic traits specifically optimized for high starch accumulation. Improved cassava varieties, such as NASE 19, are strategically bred to boost productivity, which aligns with the findings of Ceballos *et al.* (2020), who observed that these varieties consistently outperform local ones due to focused breeding strategies. Additionally, NASE 19′s environmental adaptability plays a crucial role in its resilience under various stress conditions, such as poor soils and pest infestations, supporting the conclusions of Devi *et al.* (2022). Furthermore, NASE 19, along with other improved varieties, delivers up to 30% higher starch yields compared to traditional varieties, attributed to its enhanced photosynthetic efficiency and improved carbohydrate storage, consistent with the studies by Ceballos *et al*. (2020). These combined traits make NASE 19 particularly well-suited for both consumption and industrial applications, such as starch extraction and bioethanol production.

In contrast, Sime *et al*. (2018) presented differing findings, reporting no significant difference in starch yields between improved and local varieties in regions with suboptimal farming practices. Additionally, the study by Wei *et al.* (2024) who found out that local varieties outperformed improved ones in marginal soil conditions due to their better adaptation to harsh environments also contravenes with the study findings. These discrepancies emphasize the importance of contextual factors such as farming methods, postharvest processes, and environmental conditions in determining starch yields.

Several other cassava varieties are also valued for their high starch content. TME 419, with a starch content of around 28–30%, is widely cultivated in Nigeria, one of the largest producers of cassava in Africa (Uchechukwu-Agua *et al.,* 2015). TMS 30572, with a starch content of approximately 28%, is primarily cultivated in West Africa, particularly in Nigeria and Ghana, where it is recognized for its resilience and high starch extraction potential. TME 7, with a starch content of about 27%, is also widely grown in Nigeria, where it is known for its adaptability. Additionally, IITA 90/0237, developed by the International Institute of Tropical Agriculture (IITA), is cultivated in Nigeria and other parts of West Africa, where it is valued for both its high yield and starch content, making it suitable for industrial applications. NASE 14, with a starch content of 25–28%, is cultivated mainly in Uganda, where it is recommended for both fresh consumption and processing. Like NASE 19, NASE 19 is predominantly grown in Uganda, where it is preferred for its higher starch content, resilience, and adaptability to environmental stressors, making it a preferred variety for both local use and industrial processing.

5.3 Water Absorption

The study revealed that NASE 19 consistently demonstrated the highest water absorption capacity, particularly in samples without additional cellulose. This superior performance is likely due to its structural properties, including granule porosity and high amylopectin content. Amylopectin’s branched structure enhances water uptake by forming hydrated networks, which is similar to the study by Luo *et al*. (2021). The addition of cellulose reduced variability in water absorption, likely due to its hydrophilic nature, which promotes water retention and masks differences between starch varieties. This aligns with the study by Agarwal *et al.* (2019), who found that cellulose incorporation stabilizes water absorption across samples. Several studies support these findings. Zou *et al*. (2012) emphasized the role of amylopectin in boosting water absorption, while Sun *et al.* (2023) highlighted the superior structural traits of improved cassava varieties and the stabilizing effect of cellulose, respectively.

However, conflicting studies exist. Li *et al.* (2020) reported higher water absorption in traditional varieties, citing their lower amylopectin content as advantageous for water diffusion. Müller *et al*. (2009) argued that cellulose addition had minimal impact on water absorption differences, emphasizing the dominance of intrinsic starch properties. Khalil *et al*. (2015) suggested that environmental factors such as soil type and growth conditions may play a more significant role than genetic traits in determining water absorption capacity.

The findings have practical applications in food processing and industry. NASE 19's high water absorption capacity makes it ideal for industries requiring strong water-binding properties, such as baking and thickening agents. Additionally, the stabilizing effect of cellulose offers value in products requiring consistent hydration. These results underscore the need to optimize the interplay between starch properties and additives for enhanced functionality in industrial applications.

5.4 Solubility in Water

The study found that NASE 19 consistently exhibited the highest water solubility, particularly when combined with additional cellulose, reaching up to 56.0%. This exceptional solubility is attributed due to the stabilizing effect of cellulose, which reduces aggregation and enhances solubility (Burchard 2003), and NASE 19 is characterized by high amylopectin content that promotes solubility through its branched structure (Tetlow *et al.,* 2014). The study findings are similar to the study by Tavares *et al.* (2019), where cassava starch carboxymethyl cellulose (CMC) films showed enhanced solubility, emphasizing the functional potential of starch-cellulose composites in industrial applications.

These findings align with Van Soest *et al.* (1997), who reported increased solubility in amylopectin-rich starches, particularly in the presence of cellulose. However, Burchard (2003) noted that cellulose can occasionally hinder solubility by forming overly stable complexes, which could explain the variability in NASE 14*'s* performance. In contrast, Xie *et al.* (2009) found that amylose-rich starches might exhibit higher solubility under specific conditions, challenging the observed lower solubility of NASE 14 and highlighting the complex interplay of starch composition and external factors in determining solubility.

The study's findings have significant implications for both agricultural and industrial sectors. NASE 19**,** with its higher solubility, is well-suited for food and pharmaceutical applications where starch solubility is crucial. Understanding starch-cellulose interactions can inform product development in industries like food processing, where texture and digestibility matter. The observed solubility differences highlight the need to consider molecular structure and chemical interactions in optimizing starch-based products. Additionally, the findings could guide research into starch modifications to enhance solubility for specific industrial uses, with further exploration of starch-cellulose mechanisms offering potential for improved starch varieties.

5.5 Biodegradability

The study revealed that NASE 19 consistently exhibited the highest biodegradability across various mixtures, both buried and unburied. This superior performance is likely due to its starch composition and structure. Starches with more amorphous structures, like NASE 19, are more accessible to microbial degradation, as supported by Gallant *et al.* (1992). Additionally, NASE 19 may foster favorable conditions for microbial activity, enhancing its breakdown under different environments, aligning with Guan *et al.* (2017). Starches with lower amylose content, which degrade faster (Chen *et al.*, 2017), might explain NASE 19's advantage over NASE 14 and NAROCOS.

However, conflicting studies suggest that higher amylose content can also enhance biodegradability (Aburto *et al.*, 1999), and starches with higher crystallinity are more resistant to degradation (Gallant *et al.*, 1992). Phetwarotai *et al.* (2013) found that burial conditions may not always improve biodegradation, contradicting the consistent performance of NASE 19. These findings have significant implications for developing biodegradable products, such as packaging, where rapid environmental breakdown is critical. Understanding the influence of starch composition and environmental factors on biodegradability can guide the design of sustainable, eco-friendly materials optimized for various applications.

5.6 Tensile Strength

The study highlighted significant differences in tensile strength across starch varieties and the impact of cellulose addition. The market sample in the 14:06 mixture without additional cellulose exhibited the highest tensile strength, possibly due to a more cohesive molecular structure. In contrast, the addition of cellulose generally reduced tensile strength by introducing rigidity and disrupting the starch matrix, as observed in NASE 14. This aligns with Gutiérrez *et al.* (2017), who noted that cellulose fibers often decrease tensile strength in starch-based materials. However, NASE 19, likely with higher amylopectin content, consistently showed strong tensile properties, supporting findings by Li *et al.* (2020) that amylopectin-rich starches are more flexible and mechanically resilient.

While Picolotto *et al*. (2024) similarly found that cellulose-free starch materials often exhibit superior mechanical properties, other studies, such as Avérous *et al.* (2001), reported that cellulose can enhance tensile strength by reinforcing the starch matrix under specific conditions. Dos Santos *et al.* (2025) further noted that processing conditions play a critical role, suggesting that cellulose’s impact on tensile strength is context-dependent.

These findings are crucial for designing starch-based materials, particularly for applications like packaging where mechanical strength is vital. NASE 19's consistent performance makes it a versatile candidate for both flexible and high-strength applications, while NASE 14 may be less suitable for uses requiring enhanced mechanical properties, especially when combined with additional cellulose.

5.7 Density

The study found that NASE 19 consistently exhibited the highest density, particularly in the 14:06 mixture without additional cellulose. This could be attributed to its molecular composition, as starches with higher amylose content, like NASE 19, tend to form more compact structures, resulting in higher density values. In contrast, NASE 14, likely richer in amylopectin, forms more loosely packed structures, leading to lower density. This supports findings by Xie *et al.* (2009), who linked higher amylose content to increased density. The presence of cellulose can also influence density, though its effects vary. In this study, the addition of cellulose to NASE 14 may have reduced packaging efficiency, lowering its density. Li *et al*. (2020) noted that the interaction between cellulose and starch can either increase or decrease density depending on how cellulose is dispersed within the matrix. This is further supported by Xie *et al.* (2009), who found that amylose-rich starches exhibited higher density without additional cellulose.

However, some studies, such as those by Khoshkava *et al.* (2014), suggest that cellulose typically increases density when well-dispersed and finely milled, contrasting with the findings for NASE 14. Avérous *et al*. (2001) also pointed out that processing conditions could affect the density of starch-cellulose composites, which may explain the small density differences observed in this study.

These findings are significant for designing starch-based materials, particularly in biodegradable applications. NASE 19’s higher density, especially without additional cellulose, makes it more suitable for applications like packaging and structural components, while NASE 14’s lower density limits its use in such contexts. Additionally, the study underscores the importance of controlling cellulose dispersion to optimize material properties in starch composites.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

6.1.1 Amount of Cassava Peel Waste

Most participants generate small-scale cassava peel waste due to limited preservation technologies, household/business size, and disposal practices. This highlights the need for improved waste management and infrastructure to enhance efficiency and reduce waste along the supply chain.

6.1.2 Supply Chain of Cassava

Regional production, intermediaries, and urban distribution are key to the cassava supply chain. Mubende leads in supply, with household consumption dominating the market. Inefficiencies due to reliance on intermediaries point to opportunities for optimizing logistics and reducing costs.

6.1.3 Starch Extraction from Cassava Peels for Bioplastics

NASE 19 demonstrated the highest starch yield, making it the best candidate for starch-intensive applications. Intermediate starch levels in NAROCAS and NASE 14 suggest their potential for moderate-use applications, while low starch yields from market samples indicate variability in commercially sourced varieties. These findings support prioritizing improved cassava varieties like NASE 19 for consistent, high-starch production.

6.1.4 Bioplastic Properties and Performance

NASE 19 is best suited for biodegradable packaging due to its superior starch content, mechanical properties, and biodegradability. Market samples showed inconsistent properties, limiting their industrial application potential.

6.2 Recommendations

6.2.1 Cassava Supply Chain

Strengthen farmer access to markets through cooperatives, improved infrastructure, and digital platforms. Investments in processing facilities and logistics can reduce post-harvest losses and support regional growth in cassava production.

6.2.2 Amount of Cassava Peel Waste Generated

Research institutions, government agencies and private sector players should develop a data collection system to track the amount of cassava peel waste, sources, and disposal methods, focusing on the small-scale patterns identified. This will address inefficiencies related to household/business size and regional disparities while guiding targeted waste management solutions. The system will also support scalable recycling strategies and optimize the cassava value chain.

6.2.3 Starch Extraction and Bioplastic Development

National Agricultural Research Organization (NARO) should prioritize NASE 19 for high-starch applications, explore genetic and cultivation improvements for NAROCAS and NASE 14, and investigate processing factors impacting market sample yields. Develop guidelines to match cassava varieties with industry needs.

6.2.4 Bioplastic Properties and Performance

Capitalize on NASE 19’s strengths for applications requiring durability, biodegradability, and solubility. Further research on improving NASE 14’s properties and leveraging NAROCAS for compostable products is necessary.

6.2.5 Additional Recommendations

Advocate for policies and incentives that support the bioeconomy including subsidies or tax relief for industries investing in biodegradable plastics.

Encourage investment in bioplastic production facilities and promote collaboration among research institutions, government agencies and private sector players to scale up production.

6.3 Areas for Further Research

Enhance cassava-based bioplastics with sustainable additives like rice bran or agricultural fibers.

Assess environmental impacts of cassava-based plastics on soil health and ecosystem functions.

Investigate the potential toxicity of cassava-based bioplastics when used for packaging ready to eat foods.

Evaluate the suitability of cassava-based bioplastics for use in potting and raising nursery plants.

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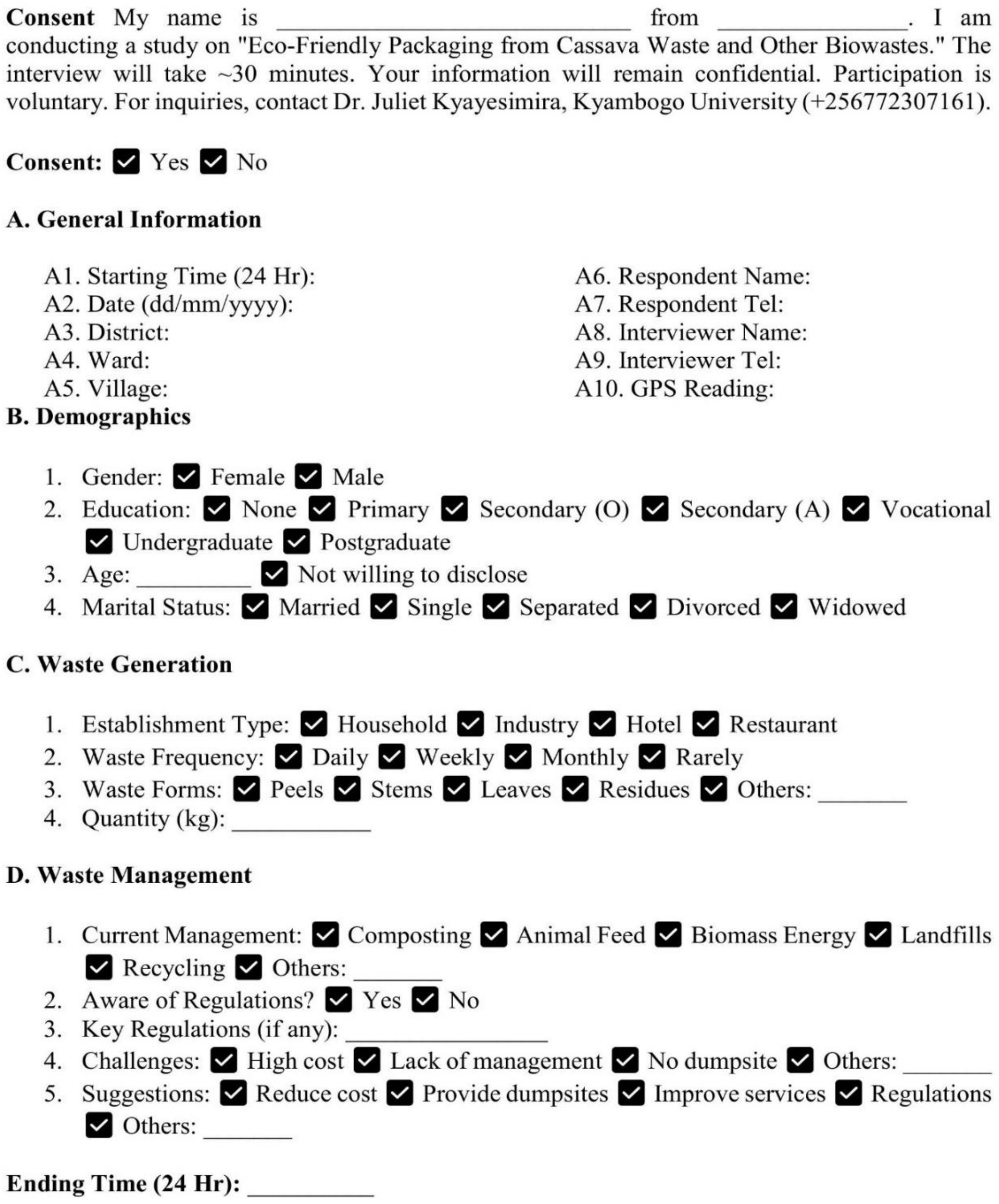
APPENDIX

Appendix A: End-Users Questionnaire



Consent My name is ______________________________ from ________________. I am conducting a study on "Eco-Friendly Packaging from Cassava Waste and Other Biowastes." The interview will take ~30 minutes. Your information will remain confidential. Participation is voluntary. For inquiries, contact Dr. Juliet Kyayesimira, Kyambogo University (+256772307161).

Consent: ☑ Yes ☑ No

A. General Information

A1. Starting Time (24 Hr):
A2. Date (dd/mm/yyyy):
A3. District:
A4. Ward:
A5. Village:
A6. Respondent Name:
A7. Respondent Tel:
A8. Interviewer Name:
A9. Interviewer Tel:
A10. GPS Reading:

B. Demographics

1. Gender: ☑ Female ☑ Male
2. Education: ☑ None ☑ Primary ☑ Secondary (O) ☑ Secondary (A) ☑ Vocational ☑ Undergraduate ☑ Postgraduate
3. Age: __________ ☑ Not willing to disclose
4. Marital Status: ☑ Married ☑ Single ☑ Separated ☑ Divorced ☑ Widowed

C. Waste Generation

1. Establishment Type: ☑ Household ☑ Industry ☑ Hotel ☑ Restaurant
2. Waste Frequency: ☑ Daily ☑ Weekly ☑ Monthly ☑ Rarely
3. Waste Forms: ☑ Peels ☑ Stems ☑ Leaves ☑ Residues ☑ Others: ________
4. Quantity (kg): ____________

D. Waste Management

1. Current Management: ☑ Composting ☑ Animal Feed ☑ Biomass Energy ☑ Landfills ☑ Recycling ☑ Others: ________
2. Aware of Regulations? ☑ Yes ☑ No
3. Key Regulations (if any): __________________
4. Challenges: ☑ High cost ☑ Lack of management ☑ No dumpsite ☑ Others: ________
5. Suggestions: ☑ Reduce cost ☑ Provide dumpsites ☑ Improve services ☑ Regulations ☑ Others: ________

Ending Time (24 Hr): ___________

Appendix B: Vendors Questionnaire

Consent My name is ____________________________ from _______________. I am conducting a study on "Eco-Friendly Packaging from Cassava Waste and Other Biowastes." The interview will take ~30 minutes. Your information will remain confidential. Participation is voluntary. For inquiries, contact Dr. Juliet Kyayesimira, Kyambogo University (+256772307161).

Consent: ☑ Yes ☑ No

A. General Information

A1. Starting Time (24 Hr):
A2. Date (dd/mm/yyyy):
A3. District:
A4. Ward:
A5. Village:

A6. Respondent Name:
A7. Respondent Tel:
A8. Interviewer Name:
A9. Interviewer Tel:
A10. GPS Reading:

B. Demographics

1. Gender: ☑ Female ☑ Male
2. Education: ☑ None ☑ Primary ☑ Secondary (O) ☑ Secondary (A) ☑ Vocational ☑ Undergraduate ☑ Postgraduate
3. Age: _________ ☑ Not willing to disclose
4. Marital Status: ☑ Married ☑ Single ☑ Separated ☑ Divorced ☑ Widowed

C. Business Information

1. Years in cassava trade: ☑ <1yr ☑ 1-5yrs ☑ 6-10yrs ☑ >10yrs
2. Run alone? ☑ Yes ☑ No
3. Source: ☑ Own farm ☑ Farmers ☑ Suppliers ☑ Others: _______
4. Supply frequency: ☑ Daily ☑ Weekly ☑ Monthly
5. Quantity (kg): __________
6. Selling time (days): ______
7. Varieties: ☑ Yes: ☑ Sweet ☑ Bitter ☑ No
8. Similar traders: _________
9. Other uses: ☑ Animal feed ☑ Income ☑ Fabrics ☑ Paper ☑ Plywood ☑ Alcohol ☑ Starch ☑ Biofuel ☑ Glucose ☑ Others: _______

D. Waste Management

1. Generate waste? ☑ Yes ☑ No
2. Quantity (kg): ___________
3. Type: ☑ Wet ☑ Dry ☑ Other: _______
4. Separation: ☑ Yes: ☑ Peels ☑ Leaves ☑ Tubers ☑ Others: _______ ☑ No
5. Collection payment? ☑ Yes: Amount: _______
6. Market waste use: ☑ Compost ☑ Animal feed ☑ Others: _______

E. Waste Opportunities

1. Market for waste? ☑ Yes ☑ No
2. Value-added products: ☑ Yes ☑ No. Recommend: ☑ Packaging ☑ Animal feed ☑ Biofuel ☑ Bioplastics ☑ Composite ☑ Others: _______
3. Environmental concerns? ☑ Yes ☑ No
4. Challenges: ☑ High collection cost ☑ No company ☑ No dumpsite ☑ Others: _______
5. Suggestions: ☑ Reduce cost ☑ Dumpsite access ☑ Service coverage ☑ Regulations ☑ Others: _______
6. Regulations in market? ☑ Yes ☑ No

End Time: __________

Appendix C: Photographs of Laboratory Procedures

i Blending of the cassava peels

ii. settling of the starch

iii Preparation of starch for drying

iv Gel spread on the mould

v Dried bioplastic films

Vi Solubility and water absorption tests

Vii Tensile strength test

viii Biodegradability test