









COMMERCIALIZATION OF VALUE-ADDED BANANA PRODUCTS IN UGANDA

Banana fibres, Green Banana Resistant Starch, Fresh Peeled and Preserved Cooking Bananas, and Ethanol

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December 2021

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ACKNOWLEDGEMENTS

This report was prepared by Enoch Kikulwe, Joseph Kyanjo and Nasser Mulumba under the auspices of Knowledge-Wells Agricultural Consult. Special thanks go to the team at NARL: Priver Bwesigye, Jerome Kubiriba, Claire Nakimpi and Ali Kajubi for their inputs into the report. We benefited a lot from technical input from Abdullah Kaggwa, the Project Coordinator/Commercialization Manager FTF NARO Activity and his entire team. We thank the team of enumerators that were engaged in data collection for their valuable time and input into the tools. Special thanks go to all the key informants who provided us with the data. Lastly, we appreciate the support from URA by providing the data that greatly supported our estimations.

ABBREVIATIONS AND ACRONYMS

CAGR	Compound Annual Growth Rate
FAO	Food and Agricultural Organisation of the United Nations
KIIs	Key Informant Interview
MoH	Ministry of Health
NARL	National Agricultural Research Laboratories-Kawanda
NARO	National Agricultural Research Organization
NDA	National Drug Authority
RS	Green Banana Resistant Starch
UBoS	Uganda Bureau of Statistics
UNBS	Uganda National Bureau of Standards
URA	Uganda Revenue Authority
ENA	Extra-Neutral Alcohol

EXECUTIVE SUMMARY

Bananas and plantains (Musa spp.) are an important staple and food security crop to more than 3 million households in Uganda. The current production of bananas and plantains is estimated at 6.99 million tonnes of which 93% is the cooking type. Cooking bananas are grown by 45% of all agricultural households in Uganda on a land area of 579,000 Ha, with an annual production of 6.5 million tonnes. Banana produced is mainly for household consumption with per capita consumption estimated at 172 kg, the highest in the World. Bananas are mainly utilized for their fruit, leaving huge volumes of by-products and wastes which are mostly discarded due to lack of knowledge and suitable technology for their transformation into other value-added products. Efficient utilization of banana by-products and wastes through development of new products can potentially create additional income streams for small holder farmers, create employment opportunities for other value chain actors and increase foreign exchange earnings of the country. The Banana Program of the National Agricultural Research Organization (NARO) identified fresh, peeled, and preserved cooking bananas, banana fibre products, ethanol from corms, and resistant starch with potential for effective commercialization. This report provides results of the market study that was conducted to provide a comprehensive understanding of the market for the selected products to recommend the effective ways of increasing sales, market share and competitive advantage for those selected products.

Banana Fibres and Banana Fibre Products

Banana by-products and wastes such as peduncles and pseudo-stems can be converted into fibre which can act as a commercial and sustainable alternative fibre material for the fibre industry. Banana fibre has the potential to be the alternative sustainable fibre material because of the availability of banana pseudo-stems which are extensively produced all year round. Banana fibre is already used as a raw material in making composite boards, a raw material for textiles in the production of traditional handicrafts and clothes and in paper production. However, in Uganda, almost all farmers leave the banana pseudo-stems in their garden after harvest. Few individual entrepreneurs are currently involved in the extraction of banana fibre to make products such as carpets, hair extensions, and paper bags. They operate at a small scale and the quantities of stems used are negligible compared to the quantities of banana biomass generated in the country. Study results indicated that the level of supply of the three banana fibre products (carpets, paper bags and hair extensions) is very low despite the abundance of pseudo stems. This was attributed to the poor processing technologies currently employed. The demand for the three fibre products is projected to increase due to increasing awareness and interest in banana fibre. Regarding competitiveness, all the three banana fibre products were found to command a higher price than their direct substitutes. This is mainly attributed to their durability and unique appearance that make the consumers to stand out. The study further found that by utilizing only 10% of the

available pseudo-stems, 34,700 tons of fibre can be produced per annum, with a potential to increase to between 1.6 million tonnes and 4.6 million tonnes if the extraction efficiencies of Philippines and India are achieved. Furthermore, at the current extraction efficiency, the market value of banana fibres is USD 0.28 billion at local market prices and USD 0.47 billion at international market prices. Achieving extraction efficiency equivalent to that of India will generate additional USD 3.65 billion and USD 6.09 billion at local and international market prices, respectively. Findings also show that the banana fibre industry can make more money if processed products such as carpets, hair extensions and paper bags are sold instead of selling actual fibre. Additionally, higher value can be achieved if the fibre is processed into higher value products such as wearable textile and packaging boxes. The market study recommends that farmer groups are empowered to acquire the knowledge and extraction equipment such that extraction is done at farm level to reduce transportation costs of bulky pseudo-stems. It is also recommended that more investments in a more efficient fibre extraction technology to improve productivity of fibre extraction are made. Further research needs to be conducted on the wastes that are generated from the fibre extraction process to discover its potential uses.

Green Banana Resistant Starch

Production of bananas fluctuates between surplus and scarcity seasons. During the surplus season, the production increases by up to 70% which leads to physical post-harvest losses as high as 10% and economic losses of 8%. The quantities of bananas lost due to excess supply can be used economically through processing of the excess supply into high value-added banana products such as Resistant Starch. Resistant starch is a natural fibre that is not broken down or absorbed when consumed, rather converted by intestinal bacteria short chain fatty acids which benefits the body in many ways such as: lowering blood cholesterol and fats and restricting the production of new fat cells, keeping appetite stable, improving insulin sensitivity and digestion, assisting in rehydration process of body, and improving immunity. RS is also helpful in preventing diseases like colon cancer, diabetes and heart disease and boost immune system. The quantity of bananas lost during excess supply can be used to produce 3.8 tonnes of resistant starch worth USD 217 million/year. The USD 217 million value is estimated based on the price of an already marketed RS product which contains only 38% of resistant starch. Results indicated that NARL can produce an RS product that contains more than 60% resistant starch. This suggests that Uganda will be able to market RS products with the highest proportion of RS on the world market. Such products are more likely to fetch a premium price and have a potential to generate more value than currently estimated. Results further estimate the potential demand for RS in Uganda at 3.3 tonnes/year, valued at USD 68.2 million. With a potential supply of 3,784 tonnes/year of RS, there will be a surplus of 2,595 tonnes/year, valued at USD 149 million. This surplus can potentially be exported to generate foreign exchange for the country and contribute to import substitution. Because of the potential of RS to be exported, its recommended that international

regulations such as those from Food and Drug Administration (FDA) of the US. and regulations of dietary supplements by European Union should also be followed during its production processes to meet the quality requirements for export. It is also recommended that for successful commercialization of RS, NARO can licence the technology to private sector firms and sign an agreement that gives rights to the firms to produce and market RS and RS products. In turn, the firms will pay NARO a royalty on net sales and NARO provides technical support that maybe required in the production process. Finally, there is a need for substantial investments in research to identify the potential effectiveness of RS in the prevention and control of human diseases. Further, with a wider range of possible applications of RS, more research is needed to better understand if and how RS can be effectively used in pharmaceutical, bakery and confectionary industries.

Fresh Peeled and Preserved Cooking Bananas

The cooking banana value chain actors incur high postharvest losses due to the short green life of bananas and damage arising from poor handling after harvest. PHL reduction strategies can offer unique opportunities to contribute to sustainable food systems for increased food security and farm incomes. Innovations such as the use of ripening control chemicals like ethylene and offering peeled and packed bananas at increased shelf life and as convenience food can drastically reduce PHL. NARO has developed a technology that uses Nano technology to preserve and extend the shelf life of fresh and cooking bananas. The technology involves application of an edible coating to the fruit surface to regulate moisture transfer, gas exchange, and prevent oxidation processes which eventually increases the shelf life of fresh and peeled bananas. The findings from the market study show that Nano technology has great potential in reducing post-harvest losses by increasing the shelf life of fresh perishable fruits like bananas. However, based on the study findings, the demand for fresh peeled and preserved matooke in Uganda is low mainly because local consumers can easily access fresh matooke from the numerous markets. The demand for peeled matooke is mostly in the urban centers due to the high costs of garbage management and moreover it is mostly among the middle class and university students who account for only a small proportion of the urban population. Additionally, many of the consumers of peeled matooke prefer that the retailers peel the bananas in their presence since that is the best way to be certain of the variety and quality of the bananas. On the export side, the level of export of cooking bananas from Uganda have remained low overtime and this has mainly been attributed to the small targeted market among the Ugandans in diaspora. The potential local demand for fresh peeled nanotechnology preserved cooking banana at 16% market share stands at 24,299 tons per annum valued at USD 10.2M million. The potential value of exports for fresh peeled and preserved banana is approximately USD 0.84million and has a potential to increase with increasing banana exports. On a positive note, the unit value of banana exports has increased over time which can act as an incentive for increased banana exports from Uganda.

Regarding marketing channels, the actors interviewed suggested that due to the hygiene standards and the consumer segment for peeled matooke, this product would be better suited for the supermarkets and other online marketing channels like Jumia. The exporters also suggested that the product would be most suited for the formal marketing channels where it would command premium prices unlike the green bananas that are traded in the informal marketing channels. Based on the study results, the potential demand for peeled bananas locally stands at 40,498 tons per year valued at USD 17 million while the potential demand of peeled bananas for export stands at 307 tons/annum valued at USD1million. To achieve this potential, first, massive investment in awareness campaigns is needed to foster attitude change and build consumer confidence in ready peeled bananas. Second, strong attention needs to be given to the type of branding and packaging to make the product more appealing to the targeted consumers. Finally, more studies need to be conducted to compare the unit cost of producing peeled banana products with the value consumers are willing to pay for them. Moreover, there is need for more research centred on incorporating the protective Nano coating in the acceptable packaging materials especially for the export markets.

Ethanol from banana corms

Banana production and trade generates huge amounts of wastes and by-products which are not used in an economical way. One of the value-added products that can be made from banana wastes is ethanol. Scientists at NARO have already proved that ethanol can be made from banana corms. Ethanol/alcohol/ethyl alcohol is an industrial chemical used as a solvent in the synthesis of other organic chemicals, as an additive to automotive gasoline, and as the intoxicating ingredient of many alcoholic beverages such as beer, wine, and distilled spirits. Ethanol can be made synthetically from petroleum or by microbial conversion of biomass materials through fermentation. Ethanol made from plant biomass is called bioethanol. Among the leading producers of bioethanol (USA and Brazil), the main use of bioethanol is blending with gasoline. Globally, corn grain and sugar cane are the main feedstocks for bioethanol production. However, there are concerns that there will be limits to the supply of these raw materials. As a result, there is growing focus on utilization of cellulosic biomass such as crop residues, wood residues and industrial wastes as a sustainable alternative feedstock for bio-ethanol production. Cellulosic feedstocks are considered more advantageous over starch and sugar-based feedstocks because they are abundant, often cheap, and they are not used for human food. One of the most abundant materials that has a potential to be an alternative for starch and sugar-based feedstocks in production of ethanol is the banana corm. While scientists at NARO have proved that ethanol can be produced from corms, most banana farmers still leave their corms in the ground after harvest and there have been no commercial efforts to produce ethanol from corms in Uganda. Results from the market study show that with the current production efficiencies at NARO proof of concept, Uganda can generate 158 million liters of ethanol per year from banana

corms, worth USD 281 million. With improvements in the production efficiency to reach that at Kakira Sugar Works, the potential annual supply of ethanol can increase up to 1,134 million liters worth USD 2,016 million per year. Using only 27% of all usable corm in Uganda, the actual ethanol that can be generated from banana corms is 43 million litres, worth USD 76 million. With the same percentage of 27% and production efficiencies at KSW, the quantity of ethanol that can be generated will increase to 306 million litres, worth USD 544 million. The potential local demand for ethanol in Uganda is estimated at 7.4 million litres (2.6 million liters for alcoholic beverages and 4.8 million liters for hand sanitizer) worth USD 13.3 million (4.6 million from alcohol beverages and USD 8.7 million for hand sanitizer). Considering the potential supply of 306 million litres per year (when considering efficiency at KSW), this leaves a surplus of 299 million litres of ethanol that will need to be exported. If this surplus is exported, it can generate USD 535 million in foreign exchange per year. The study identified four potential market segments that commercialization of ethanol can focus on. These include: Extra-Neutral Alcohol for alcoholic beverages, Biofuels, Ethanol Fuel for Clean Cook Stoves, and Ethanol-based Hand Sanitizers. The best entry point is ethanol for alcoholic beverages and ethanol-based hand sanitizers. This is because there is an existing market demand in the two segments. The study however notes that the oligopoly structure of the current ethanol industry in Uganda and the industry may not have sufficient competition among actors, with a possibility of price-setting and other anticompetitive behavior. These conditions together with high initial investment cost may be hard for companies that may want to invest into commercialization of ethanol from corms hard.

1.0 INTRODUCTION AND RATIONALE

1.1 Overview of the banana sub-sector in Uganda

Bananas and plantains (Musa spp.) are an important staple and food security crop to more than 3 million households in Uganda. The current production of bananas and plantains is estimated at 6.99 million tonnes of which 93% is the cooking type. Cooking bananas are grown by 45% of all agricultural households in Uganda on a land area of 579,000 Ha, with an annual production of 6.5 million tonnes and a yield of 12.3 MT/Ha (UBOS, 2020). The banana produced is mainly used for household consumption with per capita consumption estimated at 172 kg though higher daily consumption exceeding 500 grams per day has been reported in the main banana producing regions including the Southwestern, Western, Central, and Eastern, where it is a primary staple emphasizing its great contribution to food security (Schnurr and Addison 2017; Geberewold &Yildiz, 2018). The crop also doubles as a key source of income for the farmers earning each cultivating household approximately USD 1244 per year through sales in fresh fruit and value-added products such as wines and juices (Kikulwe et al., 2018; Namanda *et al*., 2019; Kikulwe and Asindu, 2020). Approximately 70% of cooking banana production is consumed at household level with the remaining 30% sold through agents/brokers, wholesalers, and retailers to urban consumers in form of bunches, clusters, or fingers (Akankwasa et al., 2013).

Production of bananas generates huge volumes of biomass which are mostly discarded due to lack of knowledge and suitable technology for their transformation into other value-added products. Efficient utilization of this biomass through development of products that respond to market demand can potentially create additional income streams for small holder farmers and create employment opportunities for other value chain actors.

Therefore, the Banana Program of the National Agricultural Research Organization (NARO) identified fresh, peeled and preserved cooking bananas, banana fibre products, ethanol from corms, and resistant starch with potential for effective commercialization. Through commercialization of these products, NARO will create opportunities to be self-reliant and also support government of Uganda to build an expanded industrial sector through agro-processing and value addition. Moreover, trade in peeled and preserved bananas has great potential in reducing the urban garbage problem in Ugandan cities. As a result, a detailed market study was conducted to provide a comprehensive understanding of the market for the selected products to recommend the effective ways of increasing sales, market share and competitive advantage for those selected products.

1.2 Banana Fibres and Banana Fibre Products

Bananas and plantains are cultivated mainly for their fruits. This leaves several tonnes of underused by-products and wastes. The by-products and wastes include damaged fruits, peels, peduncles, leaves, fibres, pseudo-stem, and corms. More than three million tonnes of banana waste were estimated by Spilsbury *et al*., (2002) to be generated and lost annually in Uganda in 2002. The by-products and wastes such as peduncles and pseudo-stems can be converted into fibre which can act as a commercial and sustainable alternative fibre material for the fibre industries.

Banana fibre has the potential to be the alternative sustainable fibre material because of the availability of banana pseudo-stems which are extensively produced all year round. The fibre can be used to develop a wide range of products that help farmers financially and have a wide scope to create new markets (Vigneswaran et al., 2015). Banana fibre is already used as a raw material in making composite boards (Chattopadhyay et al. 2010), a raw material for textiles in the production of traditional handicrafts and clothes and paper production (Kennedy 2009). Papers made from banana fibres have a very low water absorption capacity making them more water-resistant and stronger than wood-pulp paper (Jacob and Prema 2008).

However, in Uganda, almost all farmers leave the banana pseudo-stems in their garden after harvest. This practice is not economical given the economic value that can be generated from the fibre from the pseudo-stems. Few individual entrepreneurs are currently involved in the extraction of banana fibre to make products such as carpets, hair extensions, and paper bags. They operate at a small scale and the quantities of stems used are negligible compared to the quantities of banana biomass generated in the country.

1.3 Green Banana Resistant Starch

Production of bananas in Uganda fluctuates between surplus (in June-August and December-February) and scarcity seasons (March-May and September-November) (Nalunga et al., 2015). During the surplus season, the production increases by up to 70% which leads to physical post-harvest losses as high as 10% and economic losses of 8% (Nalunga *et al*., 2015). The quantities of bananas lost due to excess supply can be used economically through processing of the excess supply into high value-added banana products such as Resistant Starch (RS).

Resistant starch is a natural fibre that is not broken down or absorbed, rather converted into fatty acids by intestinal bacteria (Birt *et al*., 2013). There are five types of RS: Type 1, 2, 3, 4, and type 5 (Sullivan, 2020). Banana starch falls into type 2 starch. This starch has the B- or C-type polymorph, which are highly resistant to enzymatic hydrolysis. However, after cooking, most of the starch becomes highly digestible as a result of starch gelatinization and loss of the B- and C-type crystallites (Birt et al., 2013).

RS is not fully absorbed in small intestine. Instead, it progresses to the large intestine where bacteria ferment it and produce short-chain fatty acids which benefit the body in many ways including: (i) lowering blood cholesterol and fats and restricting the production of new fat cells, (ii) keeping appetite stable, (iii) improving insulin sensitivity and digestion, (iv) assisting in rehydration process of body, and (v) improving immunity. RS is also helpful in preventing diseases like colon cancer, diabetes and heart disease and boosting the immune system (Malcomson et al., 2015; Hylla et al., 1998; Maki et al., 2012; Birt et al., 2013; Sullivan, 2020).

Resistant Starch has a wide range of applications. It can be consumed exclusively, as an additive to other foods and in the baking process. This shows the potential of RS to be incorporated into food systems to convey a wide range of health benefits from reducing the risk of colon cancer to managing weight loss and diabetes type two.

The demand for RS is on the rise primarily due to factors such as an increase in the awareness of non-communicable diseases, an increase in disposable income, and a rise in the population. Global Market Insights (2018) estimated the global RS market size to be more than USD 8.4 billion in 2018 and is likely to increase by 6.1% between 2018 and 2025. This market size represents a huge opportunity for countries that have large production of commodities with high levels of resistant starch.
There are several sources of RS such as potatoes, rice, and whole intact grains. However, green un-ripened finger bananas contain the highest percentage of RS at 38% (The Source Bulk Foods, 2021). Uganda being one of the leading producers of bananas and plantains in the world, there is a big potential to commercially produce RS and tap into its growing global demand.

1.4 Fresh Peeled and Preserved Cooking Bananas

The cooking banana value chain actors incur high postharvest losses due to the short green life of bananas and damage arising from poor handling after harvest. The damage leads to direct food and income losses for both farmers and consumers (Kikulwe et al., 2018). In Uganda, 14.9% (1.1 million tonnes) of all the cooking bananas that are produced suffer postharvest deterioration along the value chain. About 7.2% of them deteriorate completely with no residual value, while 7.7% deteriorate partially and are sold at discounted prices which reduces the profit margins for retailers (Kikulwe et al., 2018).

PHL reduction strategies can offer unique opportunities to contribute to sustainable food systems for increased food security and farm incomes for more than 75% of farmers who grow bananas in Uganda. It is suggested that at the transportation stage, moving bananas in boxes would protect against bruising, minimizing both physical and economic losses while at retail level, innovations such as the use of ripening control chemicals like ethylene and offering peeled and packed bananas at increased shelf life and as convenience food would drastically reduce PHL (Kikulwe et al., 2018). On the other hand, solid waste management is a significant environmental health problem that continues to affect local authorities and Governments as the rates of urban migration continue to rise (Mukama et al., 2016). In Uganda, Komakech et al. (2014) reported that in Kampala alone, about 28,000 tons (40%) of waste is collected every month with organic wastes accounting for approximately 88.5% and 94.8% during the wet and dry season respectively. Moreover, Bananas as one of the most eaten foods is a big contributor to this garbage problem (Kinobe et al., 2015).

On a positive note, trading in already peeled bananas presents an opportunity of reducing urban waste generation in addition to satisfying an emerging consumer segment foe peeled bananas from markets. Nalunga et al. (2015) reported an increasing demand for peeled bananas among urban consumers possibly as a garbage management strategy. Therefore, to exploit the potential value in utilization of banana-based by-products and reduce post-harvest losses during excess supply, National Agricultural Research Organization (NARO) identified fresh, peeled and preserved cooking bananas. Through commercialization of these products, NARO will create opportunities to be self-reliant and also support government of Uganda to build an expanded industrial sector through agro-processing and value addition.

NARO proposes the use of Nano technology as the preservation technology for the fresh and preserved cooking bananas. Besides, Nanotechnology, there are conventional preservation methods but with several limitations including high production costs, unsatisfactory shelf-life and/or undesirable residue. However, owing to a number of unique properties, nanotechnology-related shelf-life extension strategies have the potential to compensate the shortcomings of traditional preservation methods (Liu et al., 2019). Basically, nanotechnology involves any material or nanoparticle having one or more dimensions to the order 100 nm or less (Auffan et al. 2009; He et al. 2019). The technology is favoured as it possesses different properties like slow-release action, target specific nature, precise action on active sites and high surface area (Joshi et al. 2019).

Senna et al. (2014) reported that popular Nano technology method used in prevention of fast ripening of the fruits involves the use of an edible coating. This edible coating is a thin layer made of components that are safe for consumption, which are applied to the fruit surface as an addition or substitute for natural waxy coating (Baldwin et al., 1999; jafarizadeh et al., 2011). These edible films and coatings help in regulating moisture transfer, gas exchange (as a barrier to CO2and O2), and prevent oxidation processes (Rojas-Graü et al., 2009; Sa et al., 2015). Additionally, the edible coating is a favorite choice for post-harvest treatment because of its safeness and environment-friendliness (Senna et al., 2014; Mustafa et al., 2011) and the edible coating can also be used as a media to incorporate active substances, such as antimicrobial agents, antioxidants, enzymes or probiotics, and vitamins (Rojas-Graü et al., 2009).

1.5 Ethanol from banana corms

Uganda is one of the leading producers of bananas and plantains in the world. However, bananas and plantains are cultivated mainly for their fruits. This leaves several tonnes of underused by-products and wastes. The by-products and wastes include damaged fruits, peels, peduncles, leaves, fibres, pseudo-stem, and corms. These wastes and by-products have a potential to act as raw materials to produce other value-added products that can create jobs and increase farmers' incomes.

One of the value-added products that can be made from banana wastes is ethanol. Scientists at NARO have already proved that ethanol can be made from banana corms. Ethanol/ alcohol/ethyl alcohol (C_2H_5OH) is an industrial chemical used as a solvent in the synthesis of other organic chemicals, as an additive to automotive gasoline, and as the intoxicating ingredient of many alcoholic beverages such as beer, wine, and distilled spirits. Ethanol has the same chemical formula regardless of whether it is produced from starch- or sugar-based feedstocks, such as corn grain, sugar cane, or cellulosic feedstocks.

Ethanol can be made synthetically from petroleum or by microbial conversion of biomass materials through fermentation. Ethanol made from plant biomass is called bioethanol. Among the leading producers of bioethanol (USA and Brazil), the main use of bioethanol is blending with gasoline. For example, more than 98% of U.S. gasoline contains ethanol (EERE, 2021).

Corn grain and sugar cane are the main feedstocks for bioethanol production among the world leading producers. However, there are concerns that there will be limits to the supply of these raw materials soon. As a result, there is growing focus on utilization of cellulosic biomass such as crop residues, wood residues and industrial wastes as a sustainable alternative feedstock for bio-ethanol production (Aden et al., 2002). Cellulosic feedstocks are considered more advantageous over starch and sugar-based feedstocks because they are abundant, often cheap, and they are not used for human food.

One of the most abundant materials that has a potential to be an alternative for starch and sugar-based feedstocks in production of ethanol is the banana corm. While scientists at NARO have proved that ethanol can be produced from corms, most banana farmers still leave their corms in the ground after harvest and there have been no commercial efforts to produce ethanol from corms in Uganda.

1.6 The rationale for the market study

Whereas bananas in Uganda are mainly utilized for their fruits and wasting other parts, there is a big potential to utilize other by-products and wastes such as peels, peduncles, leaves, fibres, pseudo-stem, and corms more efficiently and commercially. Developing new products from the banana by-products has the potential to create new jobs, increase banana farmers' incomes, contribute to foreign exchange earnings, and contribute to import substitution.
Banana fibres, resistant starch, fresh peeled and preserved cooking Bananas, and ethanol have been identified by National Agricultural Research Organization (NARO) as products that can be developed from banana by-products and wastes and have a potential for commercialization. This market study was commissioned to provide a comprehensive understanding of the market dynamics of the four products and recommend effective ways to increase sales, market share, and competitive advantage of the four products.

1.7 Specific objectives of the market study

1. Identify local and imported products that compete with the selected banana products and document their characteristics.

2. Determine the supply, demand, market share, structure, and marketing channels for the selected banana products.

3. Identify the potential market segments for effective commercialization of the selected banana products.

4. Determine the regulatory and institutional factors with potential to influence the commercialization of the selected products.

5. Recommend a business model for private sector investments and commercialization of the selected products.

6. Identify the key gender constraints, needs, and priorities and gender-specific opportunities that might arise from the development of the selected banana products.

7. Profile and determine potential research, capacity building, market, and value chain development partnerships for the successful commercialization of the selected products.

2.0 MATERIALS AND METHODS

To provide a comprehensive understanding of the market of the four products, an extensive preliminary literature review was first conducted to establish the market related knowledge gaps for each of the products. Based on the discovered gaps from literature review, tools were designed to collect data to address the knowledge gaps for each product. Tools were reviewed by the team at NARL before training of enumerators and data collection.

The study employed a mixed methods approach involving both qualitative and quantitative approaches. The qualitative approach used in depth face-to-face interviews with pre-selected key informants. Because the market for the four products has not been widely studied, a qualitative approach was employed to conduct in-depth investigations on such unexplored topics. Key Informant Interviews (KIIs) were conducted with targeted participants that had knowledge and experience of the selected products. Data collection was conducted in Kampala metropolitan area and Jinja city because they host most of the companies and individual entrepreneurs engaged in processing of the products.

Resistant Starch being a novel product, data was collected from NARL, the only place that has been able to extract resistant starch in Uganda. In total 44 KIIs were conducted for the four products and these targeted the processors of the product or processors of a direct substitute, traders, exporters, consumers, Pharmacists, chemists, laboratory technologists, and companies with potential to use RS (see appendix 1 for details of the KII conducted). Secondary quantitative data was obtained from the Uganda Bureau of Statistics (UBoS) and Uganda Revenue Authority (URA). The study also relied on secondary data from other countries already producing and marketing banana fibres (India, Philippines) and resistant starch (Australia). The secondary data supported estimations of the potential demand, supply, and the potential economic value of the different products.

2.1 Limitations and caution for interpretation of results

- Some of these products such as resistant starch are novel with no company or entrepreneur engaged in its production. It was therefore difficult to get key informants with knowledge about the product.
- Most of the companies and individual entrepreneurs could not reveal some of the information especially regarding the conversion rates and sales volumes.

Based on the above limitations, the study has documented all the assumptions used in estimation of figures reported in this report. These figures can change if new assumptions are made. Therefore, interpretation of the results should be based on assumptions made.

3.0 COMMERCIALIZATION OF BANANA FIBRES AND BANANA FIBRE PRODUCTS

3.1 Assumptions for estimating the potential supply and value of banana fibre in Uganda

Several assumptions (Box 1) based on expert opinion and secondary data were considered to estimate the demand, supply, and potential value of banana fibres and fibre products. Three banana fibre products were considered: Carpets, hair extensions, and paper bags.

Box 1: Assumptions for estimating banana fiber potential

1. Average weight of a pseudo stem equals 33 kg.
2. On average, 3 stems only can be harvested per mat per year.
3. With the current technology, only 0.005kg of fibre can be extracted per kg of stem.
4. Only 10% of the stems are available for fibre extraction.
5. Monetary values were computed at an exchange rate of USD=UGX 3,656 (March 2021).
6. Kayinja banana cultivars accounts for 8% of all the banana stems available.
7. All fibre from Kayinja banana cultivars to be used in production of hair extension.
8. Banana fibre carpet costs UGX 15,000/ square feet
9. The average weight of a square feet of a banana fibre carpet weighed 0.19kg
10. 1 Kg of banana fibre hair costs USD 1,000

This study estimated that more than 73 million tonnes of wastes are generated annually from pseudo-stems, peduncles, and corms in Uganda. If not utilized, these huge amounts of valuable untapped by-products are lost. However, on a positive note, banana fibre constitutes the biggest proportion of the by-products generatable from these wastes, especially from the pseudo-stems. For any private company to develop a commercial line of banana fibre products, the company would need a reliable supply of large quantities of banana pseudo-stems and/or banana fibres of different varieties. Table 1 shows potential quantities of fibre raw materials available in Uganda.

Table 1: Potential supply of banana pseudo-stems and fibres

Indicator	Value	Source
Current area under bananas (ha)	629,636	UBoS
Production (tonnes)	6,989,264	UBoS
Average mats per ha	988	NARO recommendation
Stems harvested (mat/year)	3	Expert opinion
Stems harvested (ha/year)	2,965	Authors' computation
Total stems harvested in Uganda per year	1,866,995,654	Authors' computation
Weight of a stem of banana (kg/)	33	Bioversity International
Weight per peduncle of banana (kg)	2	Bioversity International
Average weight per corm of banana (kg)	5	Bioversity International
Waste from stems (kg/year)	60,677,358,766	Authors' computation
Waste from peduncles (kg/year)	3,584,631,656	Authors' computation
Waste from corms (kg/year)	9,334,978,272	Authors' computation
Total waste generated (kg/year)	73,596,968,694	Authors' computation

Total waste generated (tonnes/year)	73,596,969	Authors' computation
Conversion rate of banana fibre based current extraction efficiency (kg of fibre/kg of stem)	0.0057	Extractor's experience
Fibre that can be got in Uganda based on current extraction efficiency (kg/year)	346,710,428	Authors' computation
Fibre that can be got in Uganda based on current extraction efficiency (tonnes/year)	346,710	Authors' computation

Source: Authors' computation.

Estimations in Table 1 indicate that a total of 61 million tonnes of banana pseudo-stems is generated annually in Uganda, with a potential of generating about 347,000 tons of fibre per annum using the current extraction efficiency (of about 0.01 kg of fibre per 1 kg of pseudo-stems). This is the potential quantity of raw materials available for banana fibre processing plants. However, it is practically impossible to use all the pseudo-stems generated in Uganda. A utilization percentage of only 10 percent of the available pseudo-stems, following the extent of use in India (Veerabathini, n.d)[1] was assumed. The 10% potential utilization would generate approximately 6.1 million tonnes of actual banana pseudo-stems that can used to extract banana fibres annually, equivalent to 34700 tons of fibre produced per annum. The 6.1 million tons is enough raw material for more than 3,325 processing plants, each with a daily capacity of 50,000kg[2] of banana. Based on this level of supply, by all means, the available raw materials are enough for the minimum requirements for commercial-level processing of banana fibres.

3.3 Potential supply of banana fibres based on current extraction efficiencies from other countries.

The results in table 2 show that if the fibre conversion rates are improved through a more efficient extraction process, drastic increase in available banana fibre can be achieved. More specifically, if the conversion rates are improved through better extraction efficiency to match 0.027 kg of fibre per kg of stem extracted in Philippines (Fibre2fashion, 2015), the potential supply of fibre increases more than fourfold from 346,710 tonnes per year to 1.64 million tonnes per year. Furthermore, much higher volumes of approximately 4.85 million tonnes can be achieved annually if the Indian conversion rates of 0.08 kg of fibre per kg of stem extracted are achieved (Preethi & Balakrishna,2013).

Table 2: Potential supply of banana fibres based on different extraction

Indicator	**Value**	**Source**
Conversion rate of banana fibre based on Philippines' extraction efficiency (kg of fibre/stem)	0.027	Philippines' extraction efficiency
Total potential fibre in Uganda from all cultivars based on Philippines' extraction efficiency (tonnes/year)	1,638,289	Authors' computation

[1] Accessible HERE

[2] Processing capacity is considered at 8hrs per day.

Conversion rate of banana fibre based on India's extraction efficiency (kg of fibre/stem)	0.08	India's extraction efficiency
Total potential fibre in Uganda from all cultivars based on Indias' extraction efficiency (tonnes/year)	4,854,189	Authors' computation

Source: Authors' computation.

3.4 Potential value of the banana fibres in Uganda

There are two pathways through which processed banana fibres can generate revenue. The first is through the sale of processed banana fibres to other processing plants, and the second is the sale of banana fibre products such as carpets, hair extensions and paper bags.

Using a 10% utilization of the available banana stems, the potential values from each pathway are represented in Tables 3 and Table 4. The values are disaggregated for local and international market, while controlling for the different extraction efficiencies. As presented in Table 3, with the current extraction efficiency, the market value of banana fibres is USD 0.28 billion at local and USD0.47 billion at international markets. Achieving extraction efficiency equivalent to that of India will generate additional USD 3.66 billion for the local and USD 6.09 billion for international markets.

Table 3: Potential value of banana fibres from selling processed fibres

	Market value (USD Billion/year) at different extraction efficiency		
	Uganda	Philippines	India
Local market	0.28	1.33	3.94
International market	0.47	2.21	6.56

Source: Authors' computation.

Note: 1 USD= UGX 3,656 (March 2021).

To estimate the potential value for the second pathway of selling banana products, instead of banana fibres, the available banana fibres were apportioned to the three products (carpets, hair, and paper bags). The total volume of banana fibre that was allocated to each product was calculated based on the import volumes of the direct substitutes obtained from Uganda Revenue Authority (URA) as shown in Figure 1. Paper bags were assigned the biggest volumes of fibre because they accounted for the largest average volume of imports (7.5million tonnes), followed by carpets (3.7 million tonnes), and then hair extensions (0.6 million tonnes) between 2017 through 2020.

Figure 1: Percentage distribution of banana fibre among the three products based on import volumes

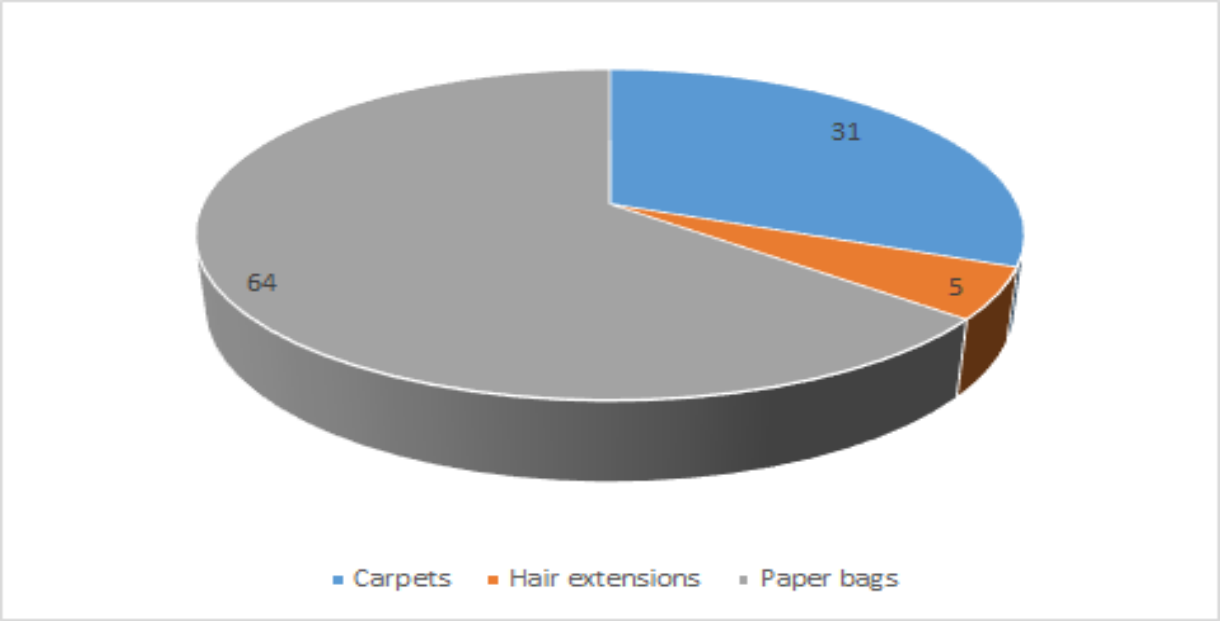


Table 4 shows the value of banana fibres when processed into carpets, hair extensions and paper bags, considering the different extraction efficiencies. The quantities of fibre assigned to each product (out of the 10% extractable fibre) was calculated based on the import volumes of the direct substitutes as proxies for demand of each product (as indicated in Figure 1). At current extraction efficiency, carpets generate the highest value (USD0.22 billion), followed by hair extensions (USD0.15 billion), and lastly paper bags (USD0.08 billion).

Table 4: Value of banana fibre products (USD Billion/year) at different extraction efficiencies

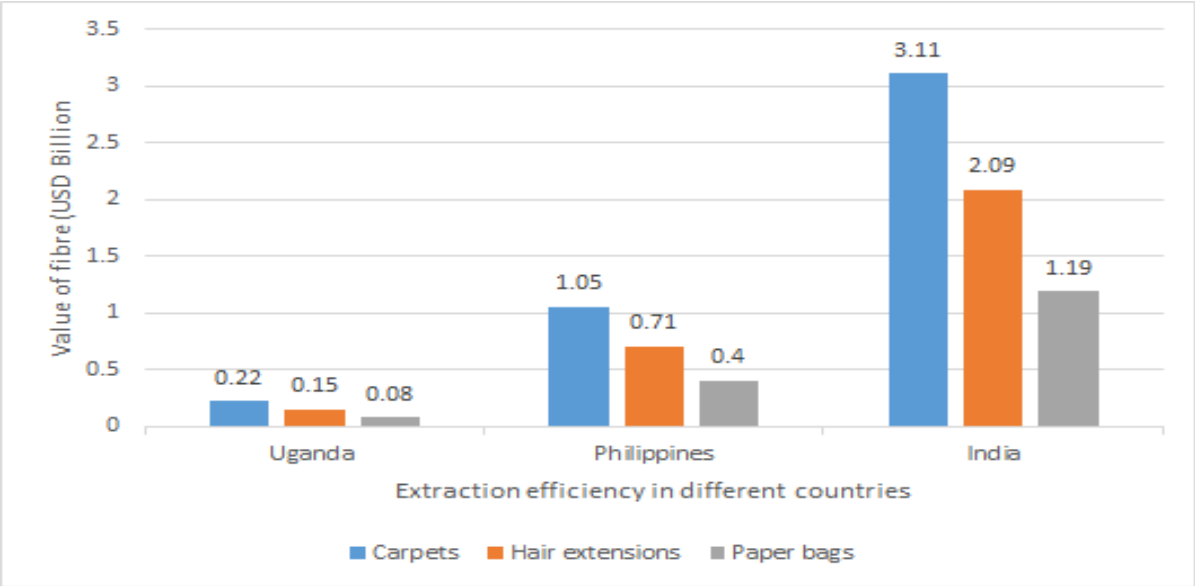
Fibre product	Market value (USD Billion/year) at different extraction efficiency		
	Uganda	Philippines	India
Carpets[3]	0.22	1.05	3.11
Hair extensions[4]	0.15	0.71	2.09
Paper bags[5]	0.08	0.40	1.19
Total	**0.45**	**2.16**	**6.39**

Source: Authors' computation

If Uganda achieves the extraction efficiency similar to that of India, it will increase the annual value of carpets, hair extensions and paper bags by USD2.88 billion, USD1.94 billion and USD 1.10 billion, respectively.

[3] See detailed estimations in Annex 2.
[4] See detailed estimations in Annex 3.
[5] See detailed estimations in Annex 4.

Figure 2: Market value of different products based on extraction efficiency



The graphical presentation (Figure 2) of the market value of the different products at the different extraction efficiencies supports the investment in a more efficient extraction technology. That is, a considerable increase in value can be achieved even using the same volumes of pseudo stems when matched with the conversion rates of Philippines or India. On the other hand, a comparison of the two pathways (i.e., sell of processed fibres OR sell of fibre products) indicates that more value is generated by selling processed fibres at international market (USD0.47 billion) than selling fibre products (USD0.45 billion). However, less value will be generated if the processed fibre is sold at local market instead of selling fibre products.

3.5 Potential value of banana fibre based on higher efficiency levels

The local price of a kilo of banana fibre in Uganda (UGX30,000/kg) is approximately three times higher than the local price of the same quantity in India (UGX10,429/kg). This price difference could be attributed to the low extraction efficiency in Uganda. Table 5 shows that, considering the fibre prices in India, the values of the banana fibre based on extraction efficiencies of Philippines is USD0.46 billion and India is USD1.37 billion per year, which is higher than the local value of USD0.28 billion per year based on Ugandan price and extraction efficiency. This suggests that improvement in extraction efficiency can lead to a reduction in unit price of fibre, with an increase in the overall value of the available fibre.

Table 5: Potential value of banana fibre based on Indian prices

	Market value (USD Billion/year) based on Indian fibre prices at different extraction efficiency	
	Philippines	India
Local market	0.46	1.37

Source: Authors' computation

Note: 1kg of banana fibre costs on average 212 Indian Rupees equivalent to UGX10,429

3.6 Potential demand for the banana fibre products

At the current extraction efficiency, the supply of all the three banana fibre products will be enough to substitute the imported volumes of close substitutes, and provide a surplus that can be exported. More surplus will be generated from paper bags (13,912 tonnes), followed by carpets (10,480 tonnes) and the least surplus from hair extensions (138 tonnes) per annum. The surplus volumes from all the three products if exported will generate USD414 million[6] with carpets contributing USD220.9 million, hair USD137.9 million and paper bags USD55.3 million per year.

Table 6: Potential demand[7] and supply (tonnes) of close substitutes of banana fibre products

Product	Volumes of imported substitutes* (tonnes)	Potential supply (tonnes)	Surplus (tonnes)	Value of surplus (USD million)
Paper bags	7,459	21,371	13,912	55.3
Hair extensions**	20	149	129	128.6
Carpets***	46	10,526	10,480	220.9

Source: Authors' computation

Note: *Estimated based on URA average import volumes from 2017 to 2020.

**Based on URA average import volumes of human hair-a close substitute to banana fibre hair based on price.

***Based on URA average import volumes of woollen carpets-a close substitute to banana fibre carpets based on price.

However, it is practically impossible for the three banana fibre products to completely substitute their direct substitutes. Therefore, assuming a market share of 20% to reflect the potential demand, the potential market value of the three products would be USD5.93, 3.99 and 0.2 million for paper bags, hair extensions and carpets, respectively (Table 7). The annual surplus amounting to USD145 million for hair extensions can easily be absorbed into the global market that stands at USD5 billion (Report Linker, 2021). Similarly, the surplus carpets valued at USD222 million accounts for only 0.02% of the global market, standing at USD93.6 billion (market research future (2021). This suggests that the biggest volumes of the banana fibre products will be targeting the global market. On the other hand, if the fibre used for making paper bags would be used to make corrugated packaging paper, a potential demand at 20% market share would stand at 353 tonnes valued USD0.28 million, which would be much lower than the USD5.93 million for the paper bags.

[6] The value is based on current prices of the three products in Uganda.

[7] Potential demand is based on URA import volumes of close substitutes.

However, corrugated packaging paper would be easier to market compared to paper bags that are mostly targeting a niche market.

Table 7: Potential demand and supply of the different banana fibre products at 20% market share

Product	Volumes of imported substitutes* (tonnes)	Potential demand at 20% market share (tonnes)	Value of potential demand 20% market share (USD million)	Potential supply (tonnes)	Surplus (tonnes)	Value of surplus (USD million)
Paper bags	7,459	1492	5.93	21,371	19879	79.0
Hair extensions	20	4	3.99	149	145	144.6
Carpets	46	9.2	0.20	10,526	10,517	221.7
If fibre used for paper bag is instead used to make corrugated packaging paper						
Packaging paper	1,766	353	0.28	21,371	21,018	60.3

Source: Authors' computation.
Note: Potential demand is estimated based on the assumption that banana fibre products can attain 20% market share.

3.6.1. Current demand and supply for hair extensions.

Globally, the hair extension market is currently valued at USD5.8 billion and is expected to grow at a compound annual growth rate (CAGR) of 13% reaching a value of USD13.3 billion by 2026. This is attributed to the growth in per capita disposable incomes that have led to increased discretionary spending (Arizton, 2021). Additionally, the retail market for human hair products is relatively inelastic with the demand for wigs and extensions made of high-quality human hair remaining relatively high (Research and Markets, 2021). Locally, the results in Table 6 show that the potential supply of hair extensions (149 tonnes) outweighs the local demand (20 tonnes), leaving a surplus worth USD144.6 million (or 0.03% of the global market value) that can be exported. Currently, however, findings from the Key informant interviews revealed that the demand for hair extensions made from banana fibres outweighs the level of supply. This has mainly been attributed to the limited processing technologies presently available. For instance, a processor of banana-based hair noted that, *"we can't meet the demand for hair extension mainly due to the manual nature of the work. If someone asked us for 100kg of hair, it would take ages or would even be impossible for us to fulfil that order".* Another processor added that*, "the interest and the market are there, but the capacity to produce is the problem."* (Processors of banana-based hair).

The low level of supply in relation to demand could also be due to the limited number of individuals/companies that have ventured into this industry. One processor stressed that,
"I would say that if I betted my bill of health, you could hardly find more than three people or companies making hair from banana fibres in Uganda." (Processor of hair)

3.6.2. Current demand and supply for banana fibre carpets.

According to a report by the Market Research Future (2021), the Global Carpet & Rugs market size is projected to reach USD93.6 billion, recording a CAGR of 4.75% by the end of 2024. This increasing global demand for carpets and rags has been attributed to the rapid urbanisation in emerging economies of Asia-Pacific and consumer inclination towards the interior decorations coupled with the rising per capita disposable income (Market Research Future, 2021). Currently, the potential local demand for high value fibre carpets based on import volumes stands at 46 tonnes, despite the potential supply of 10,526 tonnes. Interestingly, the volumes of banana fibre carpets currently supplied don't satisfy the current demand. This is mainly due to the manual nature of the production process. One processor of carpets noted that they lack the capacity to fulfil all the orders that come their way. He stated that, *"maybe we are meeting about 60% to 65% of the total demand*. *There are people who come here and say I have a market in the USA. I want to pick 100 rugs every after 2 months. We tell them that we cannot manage. We have had about 2 or 3 of such people." (Processor of textile).* He further added, "*we have orders that cannot allow us to make carpets for stocking. You would have found so much piled here. What you see here are actually orders. Orders are many but it is only the capacity to make that we are lacking*." He added that, "*we are not meeting the demand at all because like during the period between August and December, we dropped so many orders because we could not manage. We have a lot of orders but we don't have the weavers (skilled labourers), which is the biggest problem."*

3.6.3. Current demand and supply for paper bags.

According to a report by Future Market Insights (2020), the global paper bags market is expected to grow at a CAGR of 4.1% from the year 2020 to 2030. But based on URA data, the potential demand for paper bags in Uganda is equivalent to 7,500 tonnes per annum yet the potential supply when utilizing 10% of the pseudo stems is approximately 21,000 tonnes leaving a surplus of 13,500 tonnes. However, one processor of paper bags noted that, *"for us we make paper bags depending on orders"*. This implies that the paper bags from banana fibres are currently targeting a small market and this could partly be attributed to the limited awareness about the availability of paper bags made from banana fibres. But on the positive side, the demand for paper bags only keeps increasing. One of the processors reported that*, "it is increasing because at the start we had few customers and I remember asking my husband to concentrate on other things and leave out paper bags but he insisted it was his project from the university, so he kept on doing marketing and by the time he died we were supplying so many people."*

3.7 Local and imported products that compete with the banana fibre products

This section presents findings on the level of competition between the three banana fibre products and their substitutes. From the findings, it is clear that the banana fibre products compete favourably with their known substitute and in most cases even fetch higher prices.

3.7.1. Local and imported products that compete with banana fibre hair

Hair extensions made from banana fibres are high value products cost about USD1000/Kg and the closest substitute is the equally expensive human hair normally imported from Asia and south America. Processors of the hair extension reported that the competitiveness of the banana fibre hair on the market has greatly been aided by the declining demand of synthetic hair. One processor noted that, *"We have been helped by the outcry for climate change, this hair is biodegradable. Another thing is that it is healthy and doesn't cause any allergies because for other types some people keep scratching themselves after plaiting due to the allergies. We are competing with synthetic plastic much as it has cheap prices, it has that disadvantage. So, our clients go in for something natural that they can reuse but again it also has that advantage of being healthy environmentally". (Processor of hair)*

3.7.2. Local and imported products that compete with banana fibre carpets

The carpets from banana fibres are competing very favourably with the other substitutes because they are a unique product and target that kind of consumers who want to stand out. On average, a square foot of the banana fibre carpet cost UGX15,000/metre compared to UGX13,000/square foot for the closest substitute (woollen carpet). However, despite going for higher prices, fibre carpets compete favourably because, *"There people who want new things, they want a unique thing and banana fibre offers them a very good opportunity, an alternative for a unique thing" (processor of carpets).* Additionally, some buyers of these carpets especially the expatriates are attracted by the story behind the carpets as it was highlighted below,

"I have come to realize that they (expatriates) are not interested in Chinese products and so they feel bad when they see those carpets out there. So, anything that is indigenous, made by hand and has a storyline for example knowing that this is made from stems that would have been wasted but the farmer earned money from them. So, they feel they are participating in a good cause by buying this product. "(Processor of textile).

3.7.3. Local and imported products that compete with banana fibre paper bags.

Paper bags made using banana fibres out compete other paper bags due to their uniqueness and durability. One processor noted that, *"because of the banana fibre, the papers come out so hard that they can't easily be torn, fibre acts as a binding factor in paper so that even if you carried food in the bag, it can't just fall out even if you are to travel over a long distance. There is also*

another chemical called Resin that we put in which helps a paper resist water for a longer period compared to other paper bags. "He added that, "these paper bags can be reused in shopping because of their uniqueness and durability". Another one added that, "you may brand them (different paper bags) the same way but the quality of the paper differs because the handmade paper can carry heavy stuff, yet the other ones can't". Additionally, paper bags made using banana fibres also sell for a higher price compared to other locally made paper bags. One respondent noted that, *"Because we put a lot of things in our paper bags, the cost is a bit higher. Then the quality, the handmade paper is stronger and the appearance is better"*

3.8 Marketing channels for the banana fiber products

All the processors of the banana fiber products reported social media and referrals as the major marketing channels used. One processor noted that, *"We advertise through internet and even the customers inform other people about the products especially when one gets a product that fits in their desires, they recommend others to buy. So, the products' quality also markets them. Then also on WhatsApp and Facebook, we have groups and pages for the company and its products" (processor of paper bags).*

3.9 Potential market segments for effective commercialization of the banana fibre products

It was clear from the findings that most processors of banana fibre products target the foreigners or local consumers in the middle- or high-income class. This kind of clients place a high value on being unique and can afford to pay a premium for unique products.

3.9.1 Market segments for hair extensions.

Globally, North America dominated the market for hair wigs and extensions especially among the African and Caucasian descent population with consumers in the age group of 35 to 44 years accounting for the largest market share (Report Linker, 2021). In Uganda, hair extensions made from banana fibres are currently high value products that can only be afforded by women in the middle- and high-income classes. However, findings from the KII revealed that processors of banana fibre hair are currently targeting markets in Europe. one processor of hair extensions revealed that, *"Right now the biggest number of our clients who appreciate this type of fiber is in Australia and these are the white people" (Processor of hair).* This could be attributed lack of awareness about the availability of banana fibre hair extensions by the local population.

3.9.2 Market segments for banana fibre carpets

Unlike hair extensions that are currently sold only on the export market, manufacturers of carpets reported having local demand for their products in the high-end hotels and from individuals in the middle- and high-income class, *"Our main customers are the hotels, then the expatriate community and also I can say middle- and upper-class categories of people. But there are also various individual home owners and interior designers as well who come and buy our rugs." (Processor of fabric).*

Regarding gender and age groups of the consumers of banana fibre products, the findings show that most of the banana fibre product are bought by women and mostly those in the Middle Ages. One processor of textiles noted that, *"I think we have received more women than men who are our clients maybe about 80% of our clients are women, we don't see manyyoung people coming for our products, and we see mostly middle-aged people. There are few who are in their 30s. The young ones who come are normally traders but the other consumers come to buy for their personal use."*

3.9.3 Market segments for paper bags

From the KII, it came out clearly that the paper bags made from banana fibres are **mainly** traded locally to supermarkets, individuals with functions and to manufacturers of products that require unique packaging. They noted that *"you see, we sell to common people, everyone can buy from us we don't have a specific group of people because as I told you supermarkets, hotels and restaurants and boutiques are all common people's businesses"*
However, most buyers of these paper bags use them mainly as gift bags. One respondent noted that, *"Our customers for the paper bags are people who need gift bags for functions, supermarkets that sell gift bags and also the ordinary people who want to gift their loved ones in a unique way."*

3.10 Regulatory and institutional factors with potential to influence the commercialization of the banana fibre products

Based on the KIIs, currently there are no institutional or regulatory factors with potential to influence the commercialization of the banana fibre products. However, this is likely to change in the near future due to the increasing interest in banana fibre both locally and internationally. Some of them noted that,
"I think they are not even aware that we are making hair from banana fibres in Uganda. From our small research, this is a cottage like kind of business and UNBS has no standards of regulating this industry and till they do that, it is the buyer who will keep regulating our quality." (Processor of hair)

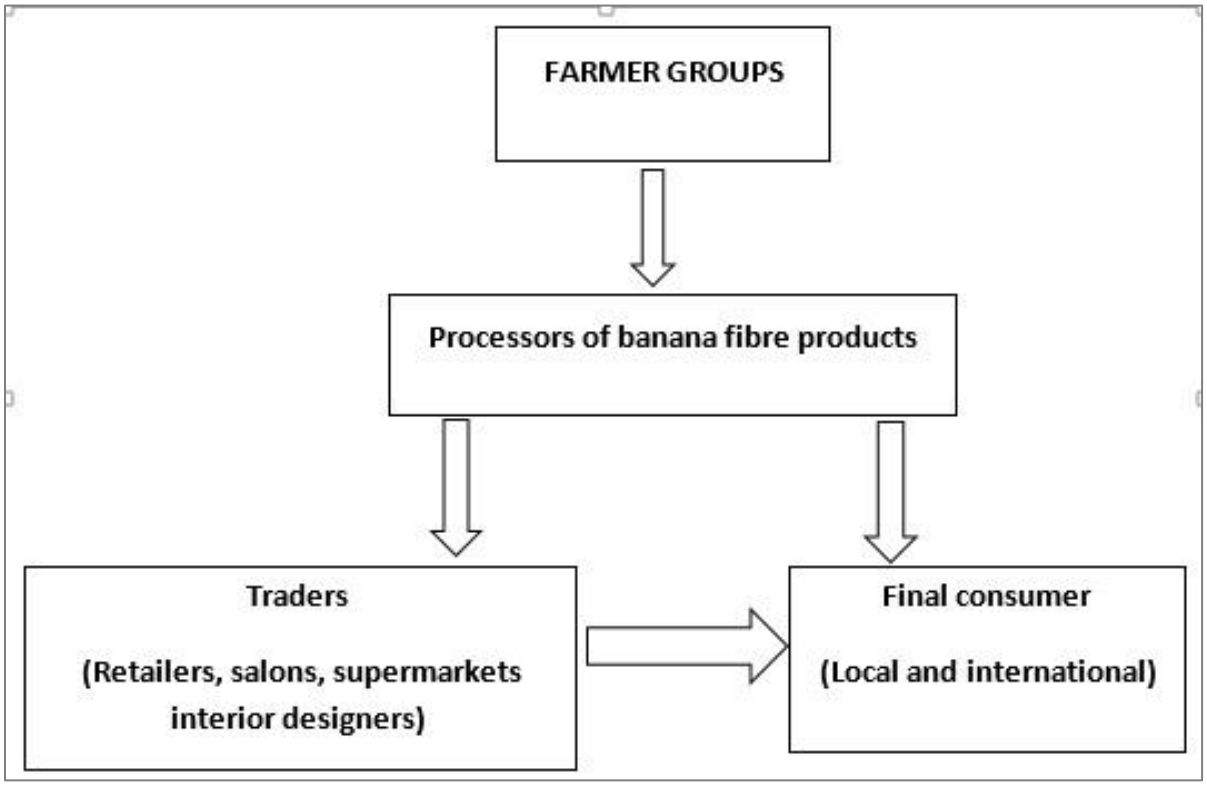
"These are just innovation commercialization labs because the government is maybe not even aware that there are banana fibres being extracted and being transformed into these different products. I have had a few government officials coming here but they only come for their own private interests. They don't come to work out policies or regulations" (processor of textile).

However, the rapidly growing interest in the banana fibre extraction is expected to attract some policies and regulations as one respondent noted, *"*But I feel it is just the beginning because people are now picking interest in banana fibre and I think very soon it will begin to attract some procedures."

3.11 Recommended business model for private sector investments and commercialization of the banana fibre products

This business model would involve formation of farmer groups that would be empowered to acquire banana fibre extractors so that they can extract fibre which they sell directly to the processors of fibre products. This will help reduce on the transportation costs normally incurred by processors when dealing with pseudo stem but will at the same time help maintain soil fertility through the reusage of the non-fibrous biomass as manure. And to reduce the role of middlemen, the processor should either sell the products directly to theconsumer or to retailers who can sell directly to the consumers. This will ensure that none of the actors is cheated along the chain.

Figure 3: Recommended model for effective commercialization of banana fibre products



This model was supported by the majority of the processors interviewed. For instance, all the processors noted that transportation of pseudo stems from the plantation to the fibre extraction point is costly and generates enormous wastes that would have otherwise remained in the plantation as manure. One processor even recommended that fibre should be extracted on farm such that the farmer earns from selling the fibre but at the same time retains the other non-fibrous waste as manure. He said that, "*the first option we have thought of is having mobile banana fibre extraction. We would need an extractor that is mounted on a truck such that if a farmer is harvesting, we go and park at the plantation and extract the fibre using the diesel-powered extractor. It would imply that you would only pick the fibre and leave the rest in the garden as manure." (Processor of textile)*. Moreover, this is an idea already in the pipeline for

some of these processors.one of them noted that, *"This week we are moving to kiboga and we have identified a place, we want to start extracting from Kiboga district and this is because we are targeting the Kayinja type which was ordered for by some clients in Europe." (Processor of textile)*.

Additionally, this will create more jobs for the farmers along the banana fibre value overtime. For instance, one processor suggested that, *"Our intention is that we start with extraction and if the extraction is giving us enough and there is excess fibre, we can now train the farmers on how to add value on the excess fibre by maybe twisting so that I don't have women twisting fibre from here and at that level, if I see that the supply of ropes is high, we train the farmers how to make circular rugs so that we don't make circular rugs from here but just put final touches from here."*

3.12 Gender constraints, needs, and priorities and gender-specific opportunities in the development of banana fibre products

From the discussions, it is clear that some activities during product development are gender sensitive. For instance, aggregation and extraction of fibers are mainly done by young men because they necessitate using great physical strength that women and the elderly men might not have. The processors noted that,

"Picking them from the farmers is done by the men. Now like for a lady, you cannot easily cut this stem and carry it yourself. You cannot because they are very heavy." (Processor of hair)

However, women can be in position to do these activities if they were encouraged to work in groups as was noted by one processor, *"there are active women but I think they can only be in position to do it alongside men. We have some women who are naturally strong and can do some of the work but these can only get to work in pairs or like 3 of them but no in singles. But a man can go to someone's plantation and locate all stems read for harvest and cut and carry them which is no possible for a woman".*

Another processor emphasized the need for attitude change and training if women are to be involved in some tasks predominantly done by men. She said,

"Number one is attitude change. For them (women) to understand that what a man can do a woman can do. The second, we would need to train them because this is not rocket science. The woman can be trained the same way a man was trained if she is to do the same job. So, the involvement would be clear by saying we need more women to be involved in this area and get them on board."

On the other hand, some activities such as knitting of fabric, brushing of hair and gluing of paper bags are mainly done by women mainly because these don't require physical strength and most men have limited interest in them because they require a lot of concentration. For instance, some processors noted that,

"A woman can easily sit down and concentrate on a given activity. For men, concentration for prolonged periods is hard and it is what pushes them out of these tasks." (Processor of hair)

3.13 Potential research, capacity building, market, and value chain development partnerships for successful commercialization of banana fibre products

For some products like textiles and hair, there is a preference for use of fibres extracted from the kayinja banana variety because of its strength properties and appearance as one processor noted,

"This one (kayinja) is stronger in terms of fibre strength and it also has a more shinny appearance when the fibre comes out. So, it is more appealing to the eye. Even when extracting, you get more fibre from this (kayinja). That one generates a lot of wastes because the fibre is not strong. Just like you can see here at the extraction point, there are a lot of fibres from that variety in the wastes. And this is one of the challenges that we have been discussing with NARO because our machine here may waste up to 30% which is quite a lot so we are telling them to help improve on this equipment through this research and we are already talking to the engineering department to see what they can do." (Processor of fabric)

However, this variety is rare because it is highly susceptible to banana bacteria wilt. This calls for more research aimed at increasing the resistance of kayinja to banana bacteria wilt and this could be done partly through the provision of clean planting material. One respondent noted that,

"In fort portal, most of us used to have banana plantations that had the kayinja variety because people used to make waragi (local brew) but it got infected and many were wiped out. Even the gentleman in Mubende with a huge plantation of kayinja keeps clearing parts of his plantation because they get infected with bacterial wilt. So, there is a need to give the farmers clean planting materials and this is something NARO can do." (Processor of hair)

Transportation of pseudo stem for fibre extraction was reported to be a costly venture and most processors suggested that it would be cheaper if the fibres were extracted on farm such that only the light fibre is transported with the residues remaining on farm as manure. One processor suggested that, *"There is need to train and empower farmer groups to extract fibre from the stems. That way I can jump into a taxi and go pick the fibres instead of looking for a lorry to put the pseudo stems".*

Additionally, the processors of banana fibre product were in agreement that the current extraction technology is wasteful and uses a lot of electricity and thus requires urgent improvements. Some of them noted that,

"Between 20-30% of the fibre is extracted with the rest being lost during extraction. Have you been in position to see the extraction process, do you see how much fibre is extracted, even in what comes out as waste, you can clearly see strands of fibre." (Processor of hair)

While another recommended that, "you see this machine has one motor and my thinking is that this can be improved such that we have about four blades being operated using only one motor

because we feel there is a lot of power wasted here. Even when you bring two people to work on the same machine with one feeding here and the other feeding there, they can work well and the motor remains stable. So, we feel that this extraction process can be improved to make it cheaper. So, you can have one motor and about three extractors attached to it and then you use the same power to produce more fibres".

Furthermore, the manual nature of producing most of these fibre products leads to lengthy production periods. For instance, processors of hair reported that they need about 3 months before they can get to the final product and this can only be improved through designing more efficient production technologies. One processor noted that,
"Yes, the demand (for hair) is there but production is a challenge. They can ask for 50kg of hair say in a month, there it would be like someone wants to fail you. So sometimes the timelines that customers give are not feasible. Possibly that client has received some abrupt order but again she will not understand the process we go through to get to the finished product. So, if you say that instead of one month, let's make it 3 months, they will put you under extreme pressure. That is why I think we need to device technologies which can make the production process faster."

Based on the available technologies, banana fibres can only be processed up to limited levels and this dictates the types of products that can be produced. For instance, those making textile cannot make wearable fabric because of the rough nature of fibre which restricts them to carpets and table mats. One processor noted that *"I feel a lot of limitation because I cannot make a fabric for wearing from banana fibre because I have no technology and I feel that is one area where we need support in terms of research so that we can be in position to access that level of material and diversify into other products with softer fabrics."*

On the other hand, some of the processors were of the view that wastes from the extraction process have the potential to generate more useful products. For instance, one processor noted that,
"If we start with this sap that is generated, when you see where it moves, you can see that it is fermenting. I think that sap can be used to produce something. I have heard people who say that it can probably make a bio fertilizer that can be sprayed. There are people who say it can be used for pharmaceutical use for medicines. Locally I have been told that it can be used when someone has been bitten by a snake. So definitely if a chemical or material scientist can handle this, I am sure that sap can be a good area of research based on the properties that it has. And now this other waste, I think it can be improved into animal feeds, if the cows eat the raw stems, then this one has just been extracted, all we remove is the fiber so the rest of the biomass can be formulated maybe dried, crushed and mixed with salt or magadi which can make feeds for animals. It can also make materials for making paper because it has this fibrous material and probably other things that we presently don't know." (Processor of fabrics)

3.14 Conclusions and recommendations for banana fibres and banana fibre products

The market research study was conducted for three products (carpets, paper bags and hair extensions) from the banana fibres extracted from pseudo stems with the aim of exploring the opportunities for sustainable commercialization. The study used both qualitative data that was collected through key informant interviews with processors and quantitative data from Uganda Revenue Authority (URA) and Uganda Bureau of Statistics (UBoS).

The findings from the study show that about 61 million tonnes of banana pseudo-stems with a potential of generating 37,000 tonnes of fibres are produced annually in Uganda at the current extraction efficiency of about 0.01 kg of fibre per 1 kg of pseudo-stems. However, it is practically impossible to use all the pseudo-stems. Assuming a utilization percentage of only 10 percent, about 34,700 tons of fibre can be produced per annum, with a potential to increase to between 1.6 million tonnes and 4.6 million tonnes if the extraction efficiencies of Philippines and India are achieved. Furthermore, at the current extraction efficiency, the market value of banana fibres is USD 0.28 billion and USD 0.47 billion at local and international markets, respectively. However, achieving extraction efficiency equivalent to that of India will generate additional USD 3.65 billion and USD 6.09 billion at local and international markets, respectively. Findings also show that the banana fibre industry can make more money if they were to sell processed products such as carpets, hair extensions and paper bags than when they trade in actual fibre. Additionally, higher value can be achieved if the fibre is processed into higher value products such as wearable textile and packaging boxes.

Findings further show that the level of supply of the three banana fibre products is currently low despite the availability of pseudo stems. This could be attributed to the poor processing technologies currently employed. On the other hand, the demand for the three fibre products is projected to increase due to increasing awareness and interest in banana fibre.

Regarding competitiveness, all the three banana fibre products were found to command a higher price than their direct substitutes and this was mainly attributed to their durability and unique appearance that make the consumers to stand out. The competitiveness of these products has also been aided by the massive promotion of environmental conservation.

The three banana fibre products are mainly marketed through social media platforms such as Facebook, WhatsApp, and company websites. With exception of the paper bags, processors of hair extensions and carpets reported that they mainly target the foreign market (expatriates) and local consumers in the middle- and high-income classes who can afford to pay a premium for the unique products.

Three recommendations can be derived from the study findings. First, given the high transportation costs of pseudo stems, as reported by all processors interviewed, it is recommended that farmer groups should be empowered to acquire the knowledge and extraction equipment such that extraction is done on farm. This will create additional benefits to the farmers in terms of income generation from fibre sales and retention of non-fibrous biomass

as manure, which reduces time and the transportation costs currently incurred by the processors. Second, all processors agreed that the current extraction technology is inefficient and wasteful; thus, limiting the volume of extractable fibres. This calls for investment in more efficient extraction technology. This is confirmed by the study findings which revealed that the value of fibre from the same volume of pseudo-stems increased massively when simulated based on the extraction efficiencies of Philippines and India. Third, there are some wastes generated with untapped potential, creating a need for more research to unmask this potential. For instance, one processor suggested that the sap generated during extraction has medicinal values and that the other biomass can potentially be transformed into animal feeds.

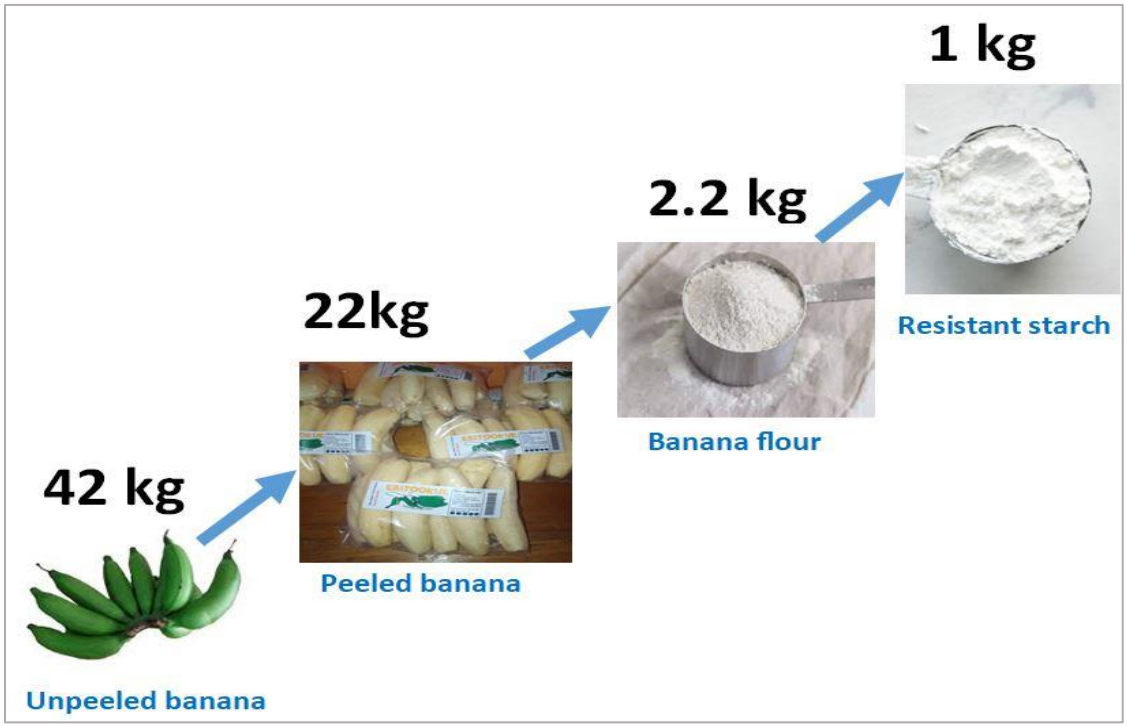
4.0 COMMERCIALIZATION OF GREEN BANANA RESISTANT STARCH

4.1 Viability of producing Resistant Starch in Uganda at commercial scale

Before commercial production of RS and its products, it is important to first establish whether the available banana cultivars in Uganda contain economic levels of RS to sustain commercial production. Results of key informant interviews at NARL indicated that almost all common banana cultivars in Uganda have economic levels of resistant starch. For instance, Kayinja, a beer banana cultivar, has the highest RS conversion (80%) from banana flour, producing the highest proportion of RS among the cultivars so far tested. In case of cooking bananas, Nfuuka has the highest RS conversion (60%), followed by Mpologoma (59%), while Kibuzi has the lowest RS conversion (30%). The RS extractor expert at NARL estimated the average conversion rate of RS from banana flour for cooking bananas to be 45%. With these levels of RS from the common banana cultivars and their mass production in the country, Uganda may be the most suited country in the world to produce and commercialize RS and its products.

Using the current RS extraction technology at NARL, 10 kg of peeled cooking bananas (*pulp*) produces 1 kg of banana starch. The 1 kg of banana starch can in turn produce 450g of RS. Figure 3 illustrates how much quantities of raw matooke required to produce 1 kg of resistant starch. Given the conversion rates in Figure 4, the current production of bananas in Uganda can assuredly support commercial production of resistant starch.

Figure 4: Quantities of cooking banana required to produce 1 kg of resistant starch



4.2 Potential supply and value of Resistant Starch in Uganda

To establish the potential supply and value of supply of RS in Uganda, assumptions in Box 2 below were used.

Box 2: **Assumptions for estimating resistant starch potential**

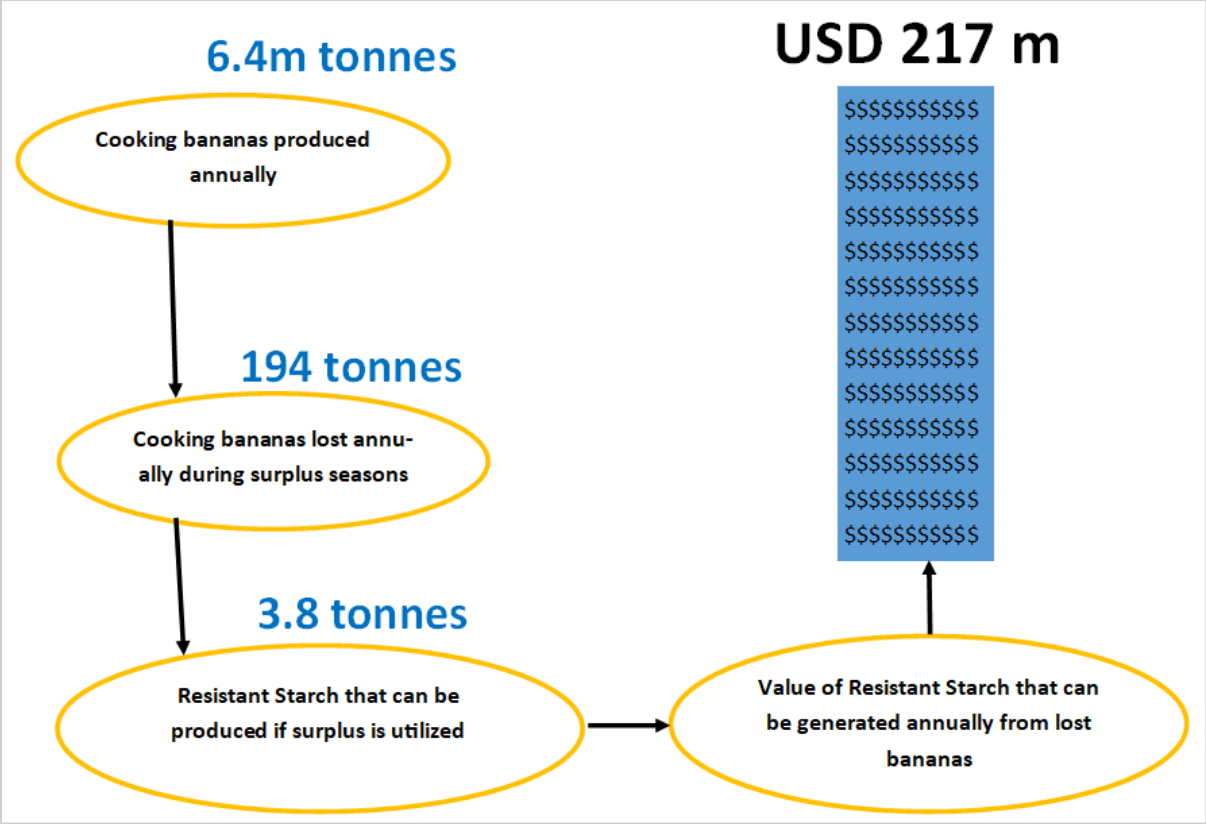
- Resistant starch will be made from cooking bananas. We therefore use that production of matooke from UBOS statistics standing at 6.5m tonnes/year
- In Uganda, 70% of cooking bananas are consumed at farm and 30% marketed.
- 10% of the marketed bananas is lost due to excess supply and this is the percentage to be used to produce resistant starch.
- 5 out of the 6-common traded matooke cultivars (Nakitembe, Mbwazirume, Kibuzi, Musakala, Mpologoma and Musakala) have good levels of resistant starch. Its only Kibuzi with low levels of RS. The 5/6 cultivars make a percentage of 83% of cooking bananas having economic levels of resistant starch.
- When 10kg of bananas are peeled, they produce 5.2kg of peeled bananas called pulp. It is the pulp that is converted into banana starch and then resistant starch is extracted from the banana starch.
- 10 kgs of fresh pulp produce 1kg of banana starch
- 1kg of banana starch produces 450g of resistant starch. This is the average for cooking bananas.
- We used two prices from companies that are already selling RS products to estimate the supply value of RS from Uganda. The prices are USD 57/kg and USD 36/kg of RS.

Source: Authors' elaboration

Based on the key figures and assumptions in Box 2, Uganda loses about 194 tonnes of cooking bananas annually (as shown in Figure 5) due to excess supply during surplus seasons. This quantity lost can be used to produce 3.8 tonnes of resistant starch worth USD 217 million[8].

[8] The USD 217 million is estimated using the price of USD 57/kg of resistant starch product sold by Natural Evolution Foods in Australia.

Figure 5: Potential economic value of RS by utilizing the 10% of bananas lost during surplus season



This USD 217 million value of RS that can be produced in Uganda is estimated based on the price of an already marketed RS product which contains only 38% of resistant starch. Results from KIIs indicated that NARL can produce an RS product that contains more than 60% resistant starch. This suggests that Uganda will be able to market RS products with the highest proportion of RS on the world market. Such products are more likely to fetch a premium price and have a potential to generate more value than currently estimated. Details of the computations of the potential supply volume and value of RS that can be produced in Uganda annually are shown in Table 8.

Table 8: Potential supply and potential value of RS in Uganda

Indicator	Number	Source
Total cooking banana produced in Uganda (tonnes/year)	6,494,056	UBOS
Quantity of bananas marketed (tonnes/year)	1,948,217	Nalunga et al. 2015
Proportion of surplus quantity of bananas (%)	0.1	Nalunga et al. 2015
Quantity of surplus bananas to be used to produce resistant starch (tonnes/year)	194,822	Authors' computation
Proportion of marketed bananas with economic levels (at least 40% of resistant starch extractable from banana starch)	0.83	Akankwasa et al., 2020

Quantity of bananas with economic levels of resistant starch (tonnes/year)	161,702	Authors' computation
Proportion of peeled bananas (***pulp***) from unpeeled bananas	0.52	Actual measurement
Pulp available for resistant starch (tonnes/year)	84,085	Authors' computation
Proportion of banana starch that can be produced from banana pulp	0.10	NARL laboratory
Quantity of banana starch that can be produced (tonnes/year)	8,409	Authors' computation
Proportion of resistant starch that can be produced from banana starch	0.45	NARL laboratory
Quantity of resistant starch that can be produced (tonnes/year)	3,784	Authors' computation
UGX to USD rate	3,656	BoU as of 08/April/2021
Price of resistant starch based on *Natural Evolution Foods* (USD/kg)	57	Natural Evolution Foods
Price of resistant starch based on *The Source Bulk Foods* (USD/kg)	36	The Source Bulk Foods, 2021
Value of resistant starch based on the price of *Natural Evolution Foods* (USD/year)	217,097,064	Authors' computation
Value of resistant starch based on the price of *The Source Bulk Foods* (USD/year)	135,461,000	Authors' computation

4.3 Potential market for Resistant Starch in Uganda

Several studies (Malcomson et al., 2015; Hylla et al., 1998; Maki et al., 2012; Birt et al., 2013; Sullivan, 2020) report the health benefits of RS in prevention of diseases such as colon cancer, diabetes and heart diseases. Use of RS in management of diabetes can significantly contribute to reducing the public health burden of those diseases. In Africa alone, USD9.5 billion was spent on healthcare for people with diabetes in 2019 (IDF, 2019). Yet trends are projecting significant increases in the disease prevalence. For example, by 2019, 19 million adults (20-79) in Africa were living with diabetes and the numbers were estimated to increase to 47 million by 2045. Furthermore, 45 million adults (20-79 years) in Africa had impaired glucose tolerance which places them at high risk of developing type 2 diabetes. This figure was estimated to reach 110 million by 2045 (IDF, 2019). This represents a growing potential market for RS.

In Uganda, 296,200 adults are diabetic representing a prevalence of 1.6% (IDF, 2020). However, this figure is more likely an underestimate as Wasswa (2008) asserts that the number of people not aware that they are diabetic are be equal to the actual diabetic patients. These figures represent potential users of RS and were used to estimate the potential market for RS.

The potential market of RS in Uganda is estimated at 3.3 tonnes/year and valued at USD68.2 million (Table 9). With a potential supply of 3,784 tonnes/year of RS, there will be a surplus of 2,595 tonnes/year, valued at USD149 million/year (Table 9). This surplus can potentially be exported to generate foreign exchange for the country and also contribute to import substitution.

Table 9: Potential demand, market, supply, and surplus of Resistant Starch in Uganda

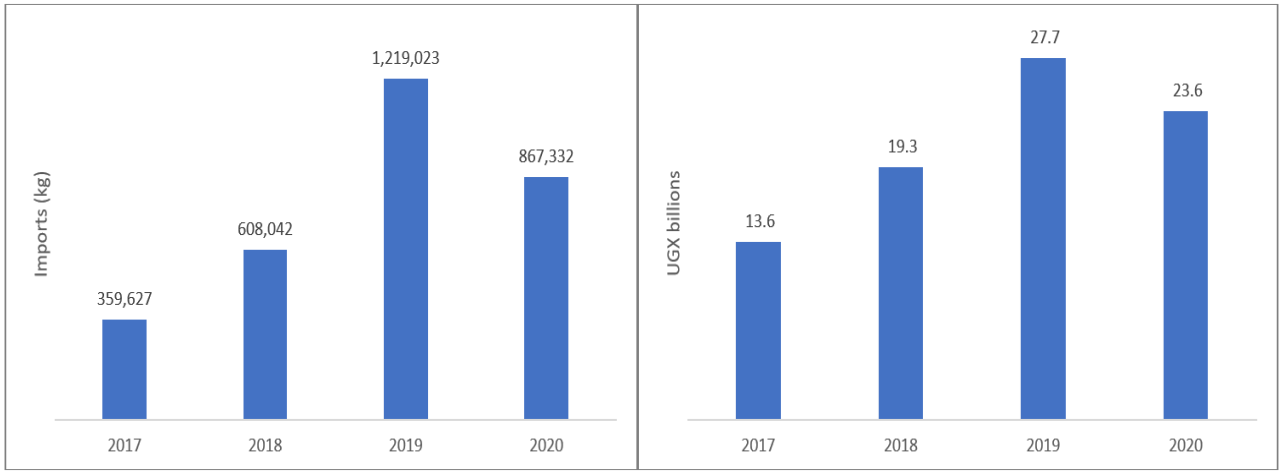
Indicator	**Value**	**Source**
Number of diabetic people in Uganda	296,200	IDF, 2020
Proportion of diabetic people with potential to buy RS supplement	0.55	Friecca and First pharmacy
Number of diabetic people with potential to buy RS products	162,910	Authors' computation
Recommended intake (kg/day)	0.02	The Source Bulk Foods, 2021
Potential demand in Uganda (tonnes/day)	3.3	Authors' computation
Potential demand in Uganda (tonnes/year)	1,189	Authors' computation
Value of potential demand based on price of Natural Evolution Foods (USD million/year)	68.2	Authors' computation
Value of potential demand based on price of the Source Bulk Foods (USD million/year)	43	Authors' computation
Proportion of the market that can be captured by a new RS product	0.07	McCoy et al., 2019
Potential local demand based on new market that can be captured (tonnes/year)	85.6	Authors' computation
Potential local demand value based on the market that can be captured by a new RS product, based on price of Natural Evolution Foods (USD Million/year)	4.9	Authors' computation
Potential local demand value based on the market that can be captured by a new RS product, based on price of the Source Bulk Foods (USD Million/year)	3.1	
Potential supply (tonnes/year)	3,784	Authors' computation
Potential surplus as a result of only capturing 7.2% of the market (tonnes/year)	2,595	Authors' computation
Price of resistant starch (USD/kg). The product marketed by Natural Evolution Foods and has only 38% resistant starch	57	Natural Evolution Foods
Price of resistant starch (USD/kg). The product marketed by The Source Bulk Foods and has only 38% resistant starch	36	The Source Bulk Foods, 2021
Value of potential surplus based on Natural evolution foods price (USD million/year)	149	Authors' computation

Value of potential surplus based of The Source Bulk Foods price (USD million/year)	93	Authors' computation

4.4 Local and imported products with a potential to compete with resistant starch

There are already several local and imported dietary supplements marketed with claims to manage diabetes, high glucose levels, colon cancer and high blood cholesterol. All these products are potential competitors of RS. The study was not able to present the specific names of the dominant dietary supplements because a wide range of them is available on the market. The study however presents imported volumes and values of these dietary supplements as shown in Figure 6. Overall, import quantity and value of dietary supplements have consistently increased since 2017. These quantities represent both the local competition RS will face, and a growing local market for dietary supplements which commercialization of RS can tap into.

Figure 6: Quantity (kg) and value (UGX billion) of imports of dietary supplements in Uganda



Source: Uganda Revenue Authority Customs data

4.5 Marketing channels for resistant starch

As indicated earlier, there is no RS on the Ugandan market. The marketing channels presented in this section are channels currently used in other countries that are already marketing RS products. The chain starts with manufacturers that process and sell RS through their physical and online stores. The manufacturers also sell their products to online stores such as Amazon and eBay as well as dietary and pharmaceutical shops (Figure 7).

Figure 7: Marketing channels of Resistant Starch currently used in countries where the product is available

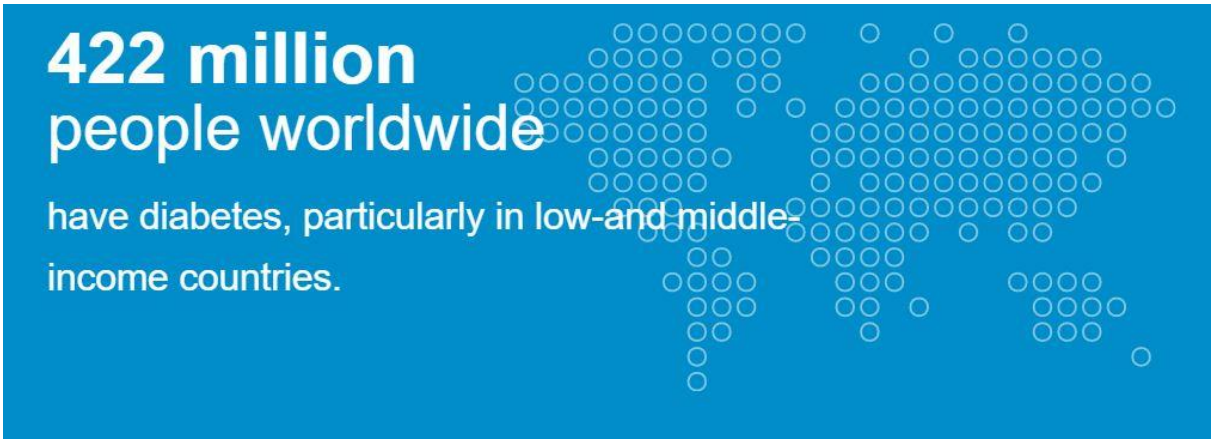


4.6 Potential market segments for effective commercialization of resistant starch

4.6.1 Diabetic people

Some risk factors to diabetes such as decreased insulin sensitivity and obesity can be reversed through lifestyle modifications. One such lifestyle change is the replacement of ordinary starch in foods with resistant starch, owing to its low glycaemic index. The diabetic people as shown in Figure 8, therefore, become one of the most important market segments for RS.

Figure 8: Number of diabetic people in the world represent one of the potential market segments for commercialization



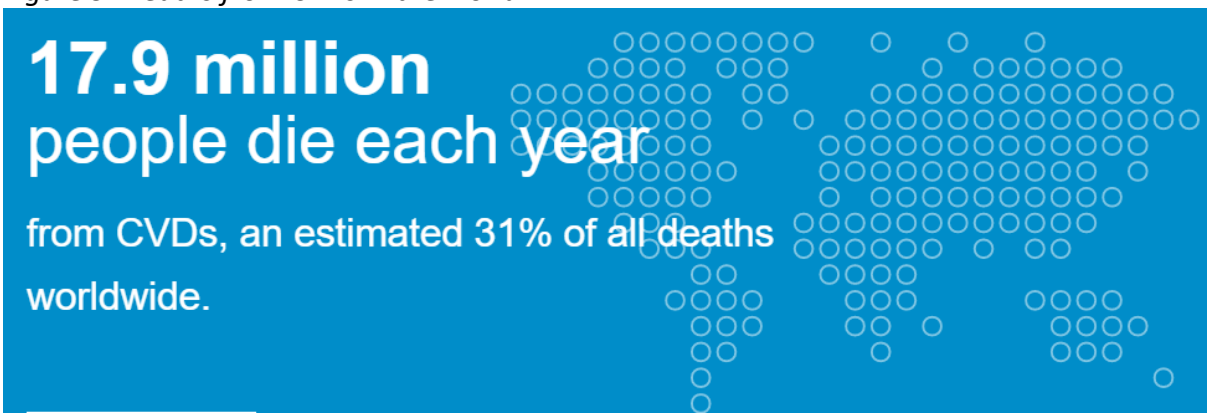
4.6.2 People with colorectal cancer

Epidemiological and experimental evidence suggests that non-digestible carbohydrates including resistant starch are protective against colorectal cancer (Malcomson et al., 2015). Colorectal cancer is the third most commonly occurring cancer in men and the second most commonly occurring cancer in women. With over 1.8 million new cases discovered for example in 2018 (World Cancer Research Fund, 2020), there is a growing potential market for RS in this segment.

4.6.3 People with cardiovascular diseases

Use of RS can contribute to reducing these risk factors and prevent a large number of heart attacks and strokes. Cardiovascular diseases (CVDs) are the number 1 cause of death globally, taking an estimated 17.9 million lives each year (WHO, 2020). Physiological factors, hypertension, high blood cholesterol and high blood sugar or glucose are some of the key risk factors for CVD.

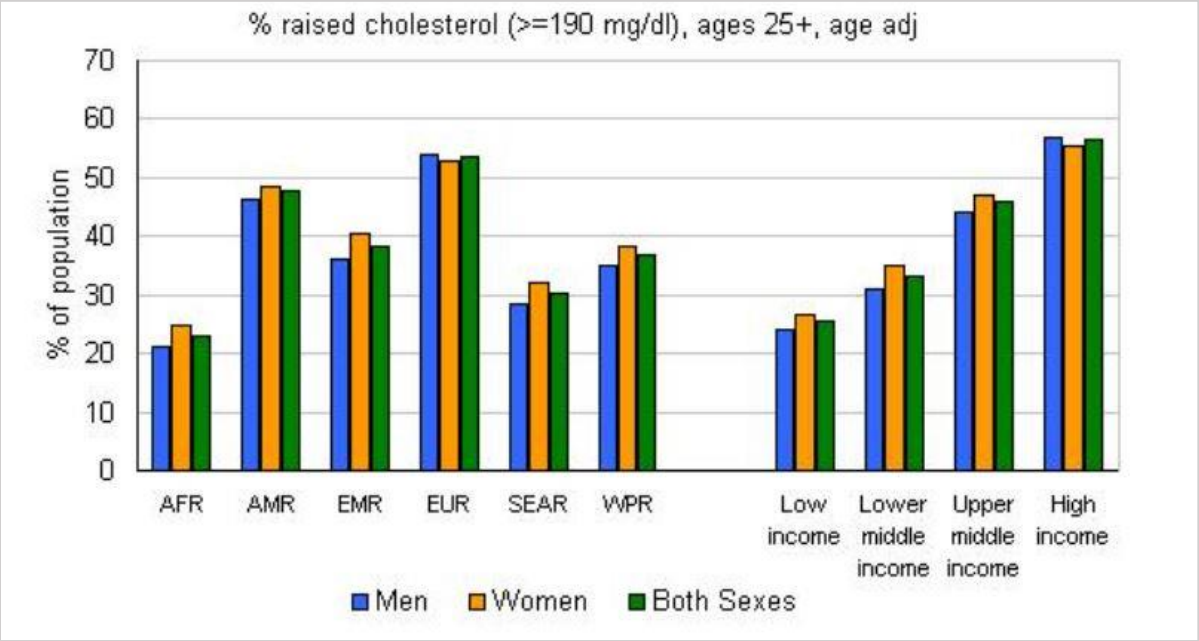
Figure 9: Deaths from CVDs in the world



4.6.4 People with raised cholesterol

Resistant starch has been shown to lower cholesterol (Yuan et al., 2018) which makes people with raised cholesterol as a potential market for RS. Raised cholesterol increases the risks of heart disease and stroke. Globally, a third of ischaemic heart disease is attributable to high cholesterol. Overall, raised cholesterol is estimated to cause 2.6 million deaths (WHO, 2020). This market segment differs across regions as indicate by data from WHO in Figure 11. The prevalence of elevated total cholesterol is highest in Europe, followed by Americas. African region and South East Asian region showed the lowest percentages. These results suggest that the biggest market for RS may be in Europe and US.

Figure 10: Proportion of people with raised cholesterol represent one of the segments for commercialization of RS



***Source**: WHO, 2020*

4.7 Regulatory factors with potential to influence the commercialization of resistant starch

Resistant starch being a dietary supplement, it is regulated by the National Drug Authority (NDA) and Uganda National Bureau of Standards (UNBS). Key guidance documents include the National Drug Policy and Authority Act, the Food and Drugs Act, Vitamin and mineral food supplements — Requirements by UNBS.

Because of the potential of RS for export, international regulations should also be considered. Some of the key considerations for international regulations can be picked from the Food and Drug Administration (FDA) of the US. These include the following;

- Regulations state that companies are responsible for having evidence that their dietary supplements are safe and for ensuring that product labels are truthful and not misleading.
- Manufacturers are required to produce dietary supplements in a quality manner, ensure that they don't contain contaminants or impurities, and label them accurately.
- The FDA can take action against adulterated or misbranded dietary supplements only after the product is on the market. In contrast, companies must show the FDA evidence that their prescription and over-the-counter drugs are safe and effective before the drugs are marketed.
- Once a dietary supplement is on the market, the FDA tracks side effects reported by consumers, supplement companies, and others. You can report any safety concerns you may have about a dietary supplement through the U.S. Health and Human Services Safety Reporting Portal.

- If the FDA finds a product to be unsafe, it can take legal action against the manufacturer or distributor and may issue a warning or require that the product be removed from the marketplace.

4.8 Recommended business model for private sector investments and commercialization of Resistant Starch

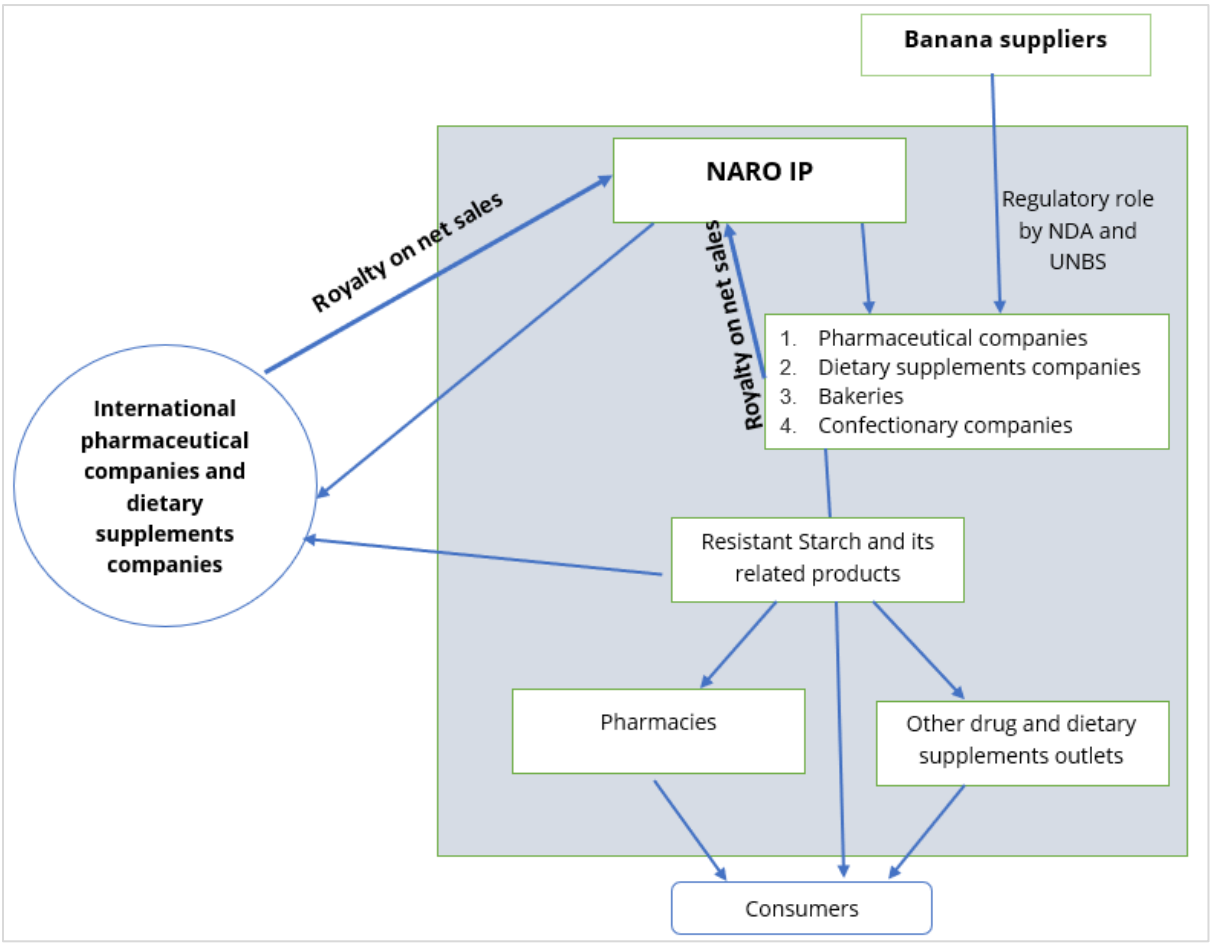
Figure 8 shows the proposed business model for commercialization of RS. Based on lessons learnt from the case study of University of Nairobi in commercialization of BIOFIX (FTF, 2017)[9], it is suggested that NARO should not pursue inhouse production and commercialization of RS. This path may not be sustainable because of the limited distribution network meaning customers will access RS from NARO centres, which may limit market penetration.

It is suggested that for successful commercialization, NARO should licence the technology to private sector firms such as pharmaceuticals, bakeries, etc., both local and international. An agreement can be reached that gives rights to the firms to produce and market RS and RS products. In turn, these companies will pay NARO a royalty on net sales and NARO may provide the technical support that maybe required in the process.

Banana suppliers would then supply the private companies required bananas of the right maturity index. Private companies can produce RS and RS products which will be sold to Pharmacies and other drug /food supplement outlets or directly to consumers. RS being a dietary supplement, the manufacturing and distribution processes will have to be regulated by the National Drug Authority and Uganda National Bureau of Standards.

[9] FTF, 2017. Feed the Future Partnering for Innovation. Success Factors for Commercializing Agricultural Research. Lessons from Feed the Future Partnering for Innovation.

Figure 11: Recommended model for commercialization of Resistant Starch



4.9 Potential research, capacity building, market, and value chain development partnerships for successful commercialization of resistant starch

Resistant starch has a large potential to be incorporated into food processing in order to convey a wide range of health benefits. Studies of resistant starch on disease processes, including colon cancer, diabetes, and obesity, show promise, and intriguing hypotheses have been developed. However, there is a need for considerable research to identify the potential effectiveness of RS in the prevention and control of human diseases and to identify mechanisms underpinning their actions.

With a wider range of possible applications of RS, more research is still needed to better understand whether and how it can be effectively used in pharmaceutical, bakery and confectionary industries. In pharmaceutical industries, research is needed to provide evidence on effective doses and modes of consumption for better health benefits from RS. Potential areas of research in bakery industry include whether and how RS can substitute wheat flour in making bakery and confectionary products. As NARL develops the RS products, more market studies focusing on willingness to pay and how much consumers will be willing to pay for RS will be required to inform marketing strategies.

4.10 Conclusions and recommendations for resistant starch

Uganda is one of the leading producers of bananas and plantains in the world. However, during surplus supply, Uganda losses about 194 tonnes/year which can be used economically through processing it into high value-added banana products such as Resistant Starch (RS).

Resistant starch is a natural fibre that is not broken down or absorbed, rather converted by intestinal bacteria short chain fatty acids which benefits the body in many ways such as: lowering blood cholesterol and fats and restricting the production of new fat cells, keeping appetite stable, improving insulin sensitivity and digestion, assisting in rehydration process of body and improving immunity. RS is also helpful in preventing diseases like colon cancer, diabetes and heart disease and boost immune system.

The quantity of bananas lost during excess supply can be used to produce 3.8 tonnes of resistant starch worth USD 217 million/year. Results further estimate the potential demand of RS in Uganda at 3.3 tonnes/year, valued at USD 68.2 million. With a potential supply of 3,784 tonnes/year of RS, there will be a surplus of 2,595 tonnes/year, valued at USD 149 million. This surplus can potentially be exported to generate foreign exchange for the country and also contribute to import substitution.

With the potential for application in a wide range of industries such as bakeries, confectionaries, pharmaceuticals, together with a broader and increasing market segments e.g., diabetic people, people with cardiovascular diseases, people with colon cancer, and raised cholesterol, commercialization of RS has a potential to generate foreign exchange earnings for Uganda and also greatly contribute to import substitution.

5.0 COMMERCIALIZATION OF FRESH PEELED AND PRESERVED COOKING BANANAS

5.1 Assumption for estimating potential value of peeled and preserved cooking bananas

We used the quantitative methods to estimate the potential supply and demand of peeled banana using the nanotechnology. To calculate the marketed volume of matooke in Uganda (Table 10), we considered the 30% of the total production that is marketed (Akankwasa et al., 2013) which we further reduced by 7.2% that is totally lost due to post-harvest loses (Kikulwe et al., 20180)

Table 10: Current production and volumes of marketed matooke in Uganda

Parameters used	**Value**	**Source**
Total cooking banana produced in Uganda (tons/year)	6,494,056	FAOSTAT
Quantity of bananas marketed (tons/year)	1,948,217	Akankwasa et al., 2013
Quantity of bananas available after PHL (tons/year)	1,807,945	Kikulwe et al., 2018

Estimations in Table 1 indicate that a total of 6.5 million tons of cooking bananas are produced annually, but only 30% (1.95million tons) of the bananas are traded. Kikulwe et al. (2018) found that about 7.2% of the traded bananas are totally lost due to post-harvest loses implying that only 1.81million tons of bananas are consumed by the final consumers.

We estimated the potential demand for nanotechnology peeled banana following Rogers (2003). Rogers (2003) separated consumers into five segments based on their receptiveness to new ideas (Figure 1). Innovators who make up 2.5% are the first to adopt an innovation followed by the early adopters who account for 13.5% of the market. The innovators and early adopters (accounting to 16%) were used for estimating the potential consumers of the nanotechnology peeled banana in this study.

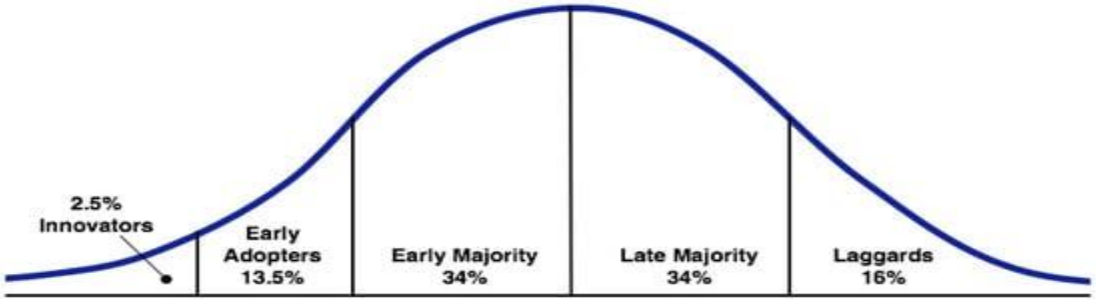


Figure 1: Consumer adoption of new innovations

5.2 Current supply, demand, and value of fresh unpreserved peeled matooke in Uganda.

Approximately, 70% of the marketed bananas are consumed in the major districts of Kampala, Wakiso, Mukono and Jinja, translating into approximately 1.3 million metric tons of bananas marketed/supplied in these districts. Results from KIIs with retailers in the districts of four districts revealed that approximately 20% (151867 tons) of the traded banana valued at USD 51 million are peeled by the retailers at the time of purchase. However, given the current population (6.1million) in the four major consuming districts of peeled bananas and the per capita consumption of 172kg, the potential demand for peeled banana in Uganda stands at 212,563 tons(table 11), implying that there is an unexploited demand of approximately 101,160 tons per year for any form of peeled bananas.

Table 11: Current demand and supply of fresh peeled and unpreserved matooke in Uganda

Indicator	**Value**	**Source**
Quantity of supply to districts (Kampala, Wakiso, Mukono and Jinja) with consumers of peeled matooke (tons/year)	1,265,562	Authors' computation
Current supply of peeled matooke (tons/year)[10]	151,867	Authors' computation
Current demand for peeled matooke (tons/year)	151,867	Authors' computation
Potential demand for peeled matooke (tons/year)[11]	212,563	Authors' computation
Unexploited local demand for peeled matooke (tons/year)	60,696	Authors' computation
Price of peeled (UGX/ton)	1,200,000	Bioversity International
Value of currently marketed peeled matooke (USD/year)	51,006,583	Authors' computation

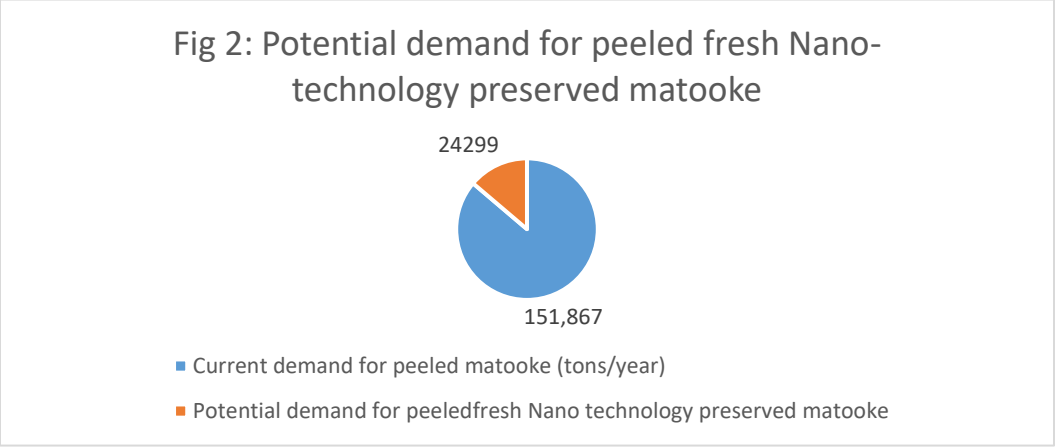
Note: 1USD=UGX3573

[10] Current supply =1,265,562*0.2(proportion of banana sold peeled)*0.6 (weight that remains after peeling)

[11] Potential demand= 172 (per capita consumption)*0.34 (proportion of consumers willing to buy peeled bananas)*6,058,000(population in the four districts)

5.3 Potential local demand for fresh Nano-preserved peeled bananas

If 16% of the consumers (adapted from Roger, 2003) would account for the potential market share of Nanotechnology preserved fresh peeled bananas, the potential demand would stand at 24,299 tons/per year (16% of the current demand for peeled matooke (see table 2) with a potential value of USD 10.2M[12] per year as shown in Figure 2.

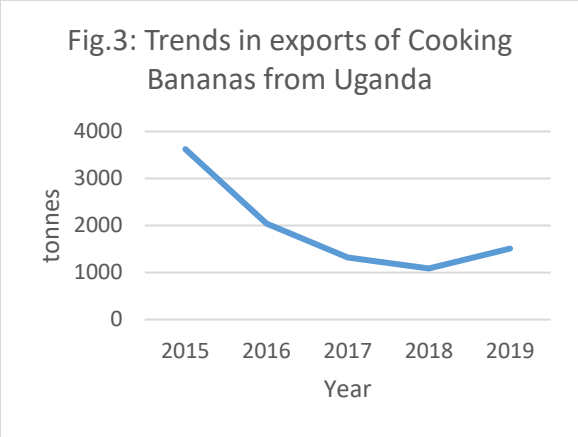


5.4 Exports of cooking bananas in Uganda

The results in figure 3 reveal a sharp decline in cooking banana exports between 2015 and 2018 and a gradual increase between 2018 and 2019 averaging at 1918 tons per annum during the selected period. This finding clearly shows that only a small proportion (0.1%) of the marketed cooking bananas is exported highlighting the fruit's relative importance in the local markets. These low volumes of exports can be attributed to a small target market of mainly Ugandans in the diaspora. One export said,

> *"Most of the people consuming matooke are African in Diaspora irrespective of where they come from and a few whites who have been to Uganda at tourists. But definitely about 70-85% is consumed by Ugandans."*

[12] Potential value =24,299(potential demand)*1500000 (price per ton in UGX)/3573(dollar exchange rate)





Source: FAOSTAT, 2021



Packed peeled bananas ready for sale in Europe (Photo credit, Google)

However, on a positive note, the value per ton of the bananas exported increased gradually from USD189 in 2015 to USD1572 in 2019 (see figure 4) implying that there is increasing value in banana exports despite the low volumes exported. Moreover, exporting peeled and preserved cooking bananas has an added advantage of reducing the cost of doing business for the exporter in that it can potentially reduce the handling and freight cost by approximately 40% (Table 12)

Table 12: Freight and Handling costs for banana exports

Indicator	**Value**	**Source**
Enhass handling services (USD/ton)	40	Exporter
Cold storage (USD/ton)	57	Exporter
Flight costs (USD/ton)	2,000	Exporter
Total export costs (USD/ton)	2,097	Exporter

Potential cost reduction if peeled matooke is exported instead of unpeeled (USD/ton)	**839**	Authors' computation

Note: The banana peel contributes approximately 40% of the weight of the green banana.

More specifically, all the handling and freight costs for the bananas are weight-based yet the banana peel accounts for about 40% of the weight of the green bananas. This implies that the exporter can export a smaller volume of matooke of higher value at a lower cost and still meet the food (matooke) needs of his clients by simply eliminating the unwanted banana peel.

5.5 Potential export demand for peeled bananas

Considering export volumes of cooking bananas averaging approximately 1900 tons (FAOSTAT, 2021) and assuming a market share of 16% for the peeled matooke based on consumer openness to new innovations (Rogers, 2003). The potential demand for exported peeled and preserved bananas was computed at approximately 307 tons per year valued at around USD 1million (table 13) and these values will likely go higher with increasing exports of cooking bananas and increased product awareness.

Table 13: Potential demand and value of peeled and preserved matooke for export

Indicator	**Value**	**Source**
Average exports of cooking bananas (Tons/year)	1918	FAOSTAT,2021
Potential exports of peeled and preserved bananas at 16% market share (Tons/year)	307	Authors' computation
Average price of exported green bananas (USD/Ton)	2,097	Exporter
Potential price of peeled matooke taking a 25% increase in price to cater for preservation and packaging costs (USD/Ton)	2726[13]	NARO expert opinion
Potential value of peeled and preserved matooke for export (USD/year)	**836,913**	Authors' computation

The exporters suggested that this would be a product better suited for the formal banana markets where it can command premium prices because of its unique attributes. One exporter mentioned,

[13] Increased the price by 30% to account for the cost of processing and packaging

"This will be an upgraded product and as you market it, you should be in position to give its special attributes, like ready peeled, easy to cook and because of those added advantages, the higher price will be justified."

The majority of the exporters viewed Nano-preserved fresh peeled matooke as a product better suited for the formal markets and not the informal market that they are currently supplying the green bananas. One *exporter noted that,*

"We see that this is already a supermarket product and not for retail. So, for us to succeed in marketing it, we shall have to lay modalities for marketing it in the formal markets starting with certification. There are market standards that give the exporter a premium and these are the same standards that allow the exporter to export directly to these formal markets."

A consumer study by Kikulwe et al. (2021) reported that 34% of randomly selected urban consumers were willing to purchase peeled matooke compared to 66% of the consumers who preferred the unpeeled matooke. However, for the peeled matooke currently on the market, peeling is done mostly in the presence of the consumer. This can be attributed to lack of trust between retailers and the consumers of peeled matooke. Some consumers noted that,

"In most instances, a retailer will choose to peel and pack bananas that are looking bad because they have over stayed and you can't easily tell the variety when already peeled, so I normally choose the unpeeled bananas and the retailer then peels in my presence."

One retailer had this to say regarding trade in peeled matooke*,*

"The challenge is that the peeling culture of Ugandans stops some of them from purchasing the bananas peeled matooke. They would rather peel the matooke themselves because in every home, there is someone who knows how to peel,"

Consumers of matooke also noted that the poor hygiene in most of the Ugandan markets makes it hard for them to embrace buying already peeled matooke and it is one of the reasons most buyers prefer buying the unpeeled type.



Matooke being traded in the local market (Photo credit: Google)

One consumer noted that,

> *"I can never buy peeled matooke because the markets are always dirty moreover, you never see any signs that the retailer washes their hands before peeling."*

Kikulwe et al. (2021) further suggested that promoters of the peeled banana products should prioritize pricing to avoid the product becoming uncompetitive, compared to the alternative of unpeeled bananas.

5.6 Marketing channels for the fresh and preserved peeled matooke

Considering that this is a product that would require a certain degree of Hygiene standards, this product would be well suited to the supermarkets where such levels of hygiene can be maintained. For instance, one consumer of peeled matooke noted that,

> *"Whenever I go to the market, I only take the peeled matooke if the peeling is done in my presence because with our dirty markets, the longer the peeled matooke stays in the market, the more it gets contaminated".*

Another consumer had this to say,

"In my view, already peeled matooke would be better marketed in places like the supermarkets and some built up markets like Bugolobi because in such places, efforts can easily be made to maintain good hygiene standards".

Additionally, some retailers suggested that this product can easily be marketed using social media and other online marketing channels such as Jumia because it is a product that appeals to the people of high class who frequent such platforms. One respondent said,

"There will be a need for massive advertisement campaigns because this product will call for attitude change. We could even interest online marketing channels like JUMIA because the youngest population of buyers and corporates have embraced JUMIA."

Branding of the fresh peeled and preserved bananas should be considered highly if the nanotechnology preserved bananas are to become competitive both on the local and export markets. They suggested that promoters of this product should borrow ideas from other similar branded products on the market to come up with the most appropriate branding. One consumer noted that,

"Maybe the buyer of this peeled matooke wants to get the feel like they bought it from a supermarket. Supposing the branding is good, a customer will feel good about it, even women would stand in their kitchens, take pictures, and post them all over social media because they have an impression that it is superior quality matooke. This will ultimately bring more buyers on board."



Branding for vacuum sealed preserved matooke (Photo credit: Google)

Similarly, several respondents suggested the transmission of information about the new product using public address systems stationed outside the points of sell. This can be supplemented by sales persons stationed in the supermarkets who would be tasked with giving potential clients all the needed information about the product. According to Kikulwe et al. (2021), promotion campaigns are needed with messages carrying some of the enticing attributes such as excellent taste, soft texture, and packaging, together with the labels, which was a feature preferred by consumers of both peeled and unpeeled matooke

5.7 Potential market segments for effective commercialization of the fresh and preserved peeled matooke

According to Kikulwe et al., 2021, potential buyers of peeled matooke were reported to be a young group of consumers, more educated and mostly males considering that it is a common practice in Uganda that men like trying out a variety of food products, while women tend to be slightly conservative and stick to predefined food products.





Additionally, consumers of peeled bananas belonged to households with fewer members. More so, these consumers throw away banana peels as waste. The already peeled matooke also appeals more to the university students and the corporate class of people who do not want to invest a lot of time in peeling but instead prefer a product that does not require a lot of preparation time. One respondent said that,

> *"Such a product (peeled matooke) if well packaged and of high quality would appeal most to the rich people who value convenience and are willing to pay a premium price for it, they would just order it directly from Jumia and drop it in the saucepan, no need for peeling".*

> *"Back then we used not to peel matooke but started slowly for Makerere students who could pay us for the banana fingers on a monthly basis."*

5.7 Regulatory and institutional factors with potential to influence the commercialization of the fresh and preserved peeled matooke

According to Bajpai et al. (2018), despite the enormous potential nanotechnology, there are emerging concerns regarding its considering that the accumulation of Nano Structured Materials in human bodies and in the environment can cause several health and safety hazards. Therefore, safety and health concerns as well as regulatory policies must be considered while manufacturing, processing, intelligently and actively packaging, and consuming Nano-processed food products. However, several studies have demonstrated that nanotechnology offers a cheap alternative to fruit preservation and that no side effects have been reported (Sridhar et al., 2021; Agriopoulou et al., 2020; Cerqueira and Pastrana. 2019). Cerqueira and Pastrana (2019) note that

researchers, industries, and governments need to build public confidence by clearly explaining the advantages of using nano-technology and demystify any wrong information about it.

5.8 Recommended business model for private sector investments and commercialization of the fresh and preserved peeled matooke

Fresh, peeled and nanotechnology preserved matooke would require high levels of hygiene that cannot easily be achieved in our local markets or at the farmer level. As one trader put it,

> *"You cannot prepare food from everywhere; you need a place with right hygiene standards. We would have to have facility where the technology should be stationed so that whoever needs it can just order and this will help us not to compromise the quality because remember as they peel"*

Therefore, in our business model, we propose farmers to sell bananas to either wholesalers or brokers, who would in turn sell them to the processor with IP acquired from National Agricultural Research Laboratories (NARL). The processor would then sell to local supermarkets which would sell to local consumers either directly or through online Apps like Jumia. The processor would also supply to exporters targeting buyers in the diaspora.

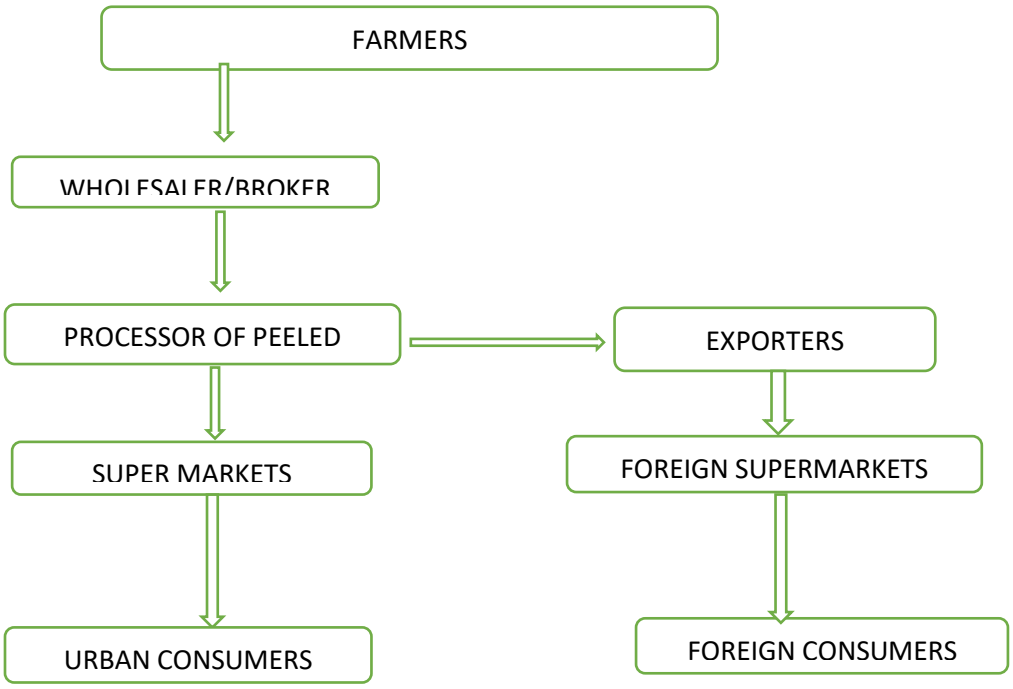


Figure 5: Recommended business model for fresh preserved peeled matooke

5.9 Gender constraints, needs, and priorities and gender-specific opportunities in the development of fresh and preserved peeled matooke

There exist some gender specific opportunities for marketing peeled matooke. For instance, most of the traders interviewed reported that only few men can peel matooke because culturally, matooke preparation is a task reserved for women. The bulky nature of the product will most favour the men who can easily carry heavy loads, but women can also be involved during packaging because they are known to pay attention to detail.

5.10 Potential research, capacity building, market, and value chain development partnerships for successful commercialization of fresh and preserved peeled matooke

Lastly, further studies need to be conducted to compare the unit cost of producing peeled banana products with the value consumers are willing to pay for them. Additionally, there is need for more research centred on incorporating the protective Nano coating in the acceptable packaging materials especially for the export markets.

5.11 Conclusions and recommendations

The finding from the market study show that Nano technology has great potential in reducing post-harvest losses by increasing the shelf life of fresh perishable fruits like bananas. However, based on the study findings, the demand for fresh peeled and preserved matooke in Uganda is low mainly because local consumers can easily access fresh matooke from the numerous markets. The demand for peeled matooke is mostly in the urban centers due to the high costs of garbage management and moreover it is mostly among the middle class and university students who account for only a small proportion of the urban population. Additionally, many of the consumers of peeled matooke prefer that the retailers peel the bananas in their presence since that is the best way to be certain of the variety and quality of the bananas.

On the export side, the level of export of cooking bananas from Uganda have remained low overtime and this has mainly been attributed to the small targeted market among the Ugandans in diaspora. The potential local demand for fresh peeled nanotechnology preserved cooking banana at 16% market share stands at 24,299 tons per annum valued at USD 10.2M million. The potential value of exports for fresh peeled and preserved banana is approximately USD

0.84million and has a potential to increase with increasing banana exports. On a positive note, the unit value of banana exports has increased over time which can act as an incentive for increased banana exports from Uganda.

Regarding marketing channels, the actors interviewed suggested that due to the hygiene standards and the consumer segment for peeled matooke, this product would be better suited for the supermarkets and other online marketing channels like Jumia. The exporters also suggested that the product would be most suited for the formal marketing channels where it would command premium prices unlike the green bananas that are traded in the informal marketing channels.

Based on the study results, the potential demand for peeled bananas locally stands at 40,498 tons per year valued at USD 17 million while the potential demand of peeled bananas for export stands at 307 tons/annum valued at USD1million. To achieve this potential, first, massive investment in awareness campaigns is needed to foster attitude change and build consumer confidence in ready peeled bananas. Second, strong attention needs to be given to the type of branding and packaging to make the product more appealing to the targeted consumers. Finally, more studies need to be conducted to compare the unit cost of producing peeled banana products with the value consumers are willing to pay for them. Moreover, there is need for more research centered on incorporating the protective Nano coating in the acceptable packaging materials especially for the export markets.

6.0 COMMERCIALIZATION OF ETHANOL FROM BANANA CORMS

6.1 Local and imported products that compete with ethanol

Ethanol is a member of the alcohol family with the chemical formula C_2H_5OH. Because of its unique chemical and physical properties that cannot be exhibited by another chemical, ethanol does not have direct competitors. Further, ethanol has the same chemical formula regardless of whether it is produced from starch or sugar-based feedstocks, sugar cane, or from cellulosic feedstocks, as long as the production process is the same.

However, ethanol differs in grades due to different levels of purification. The 95% and above ethanol is the highest concentration of ethanol that can be got by distillation; the 99% and above ethanol is produced by using additives that disrupt the azeotrope composition and allow further distillation and, denatured ethanol contains additives (such as methanol and isopropanol) that render it unsafe to drink.

6.2 Potential supply of ethanol from banana corms in Uganda

Table 14 shows estimates of potential supply and value of supply of ethanol that can be generated in Uganda, disaggregated by different production efficiencies (NARO vs. Kakira Sugar Works (KSW) efficiency). We used equation 1 to estimate the quantity of ethanol (96.4%), that can be generated using the two production efficiencies.

$$Ethanol\ (96.4\%) = \frac{SC * CF * FE * DE * TY}{0.964} \ldots\ldots\ldots\

Table 15: Potential supply and value of ethanol from banana corms in Uganda

Indicator	NARO proof of concept efficiency	Kakira efficiency
Total available biomass from corms (tonnes/year)	9,334,978	9,334,978
Total usable biomass from corms (tonnes/year)	4,667,489	4,667,489
Conversion rate of ENA from corm (ltrs/tonne)	34	243
Quantity of ENA that can be generated from all usable corm biomass (ltrs/year)	158,227,882	1,134,199,860
ENA quantity using 27% of usable corms	42,721,528	306,233,962
UGX to USD rate	3,573	3,573
Price of ENA on the market (UGX/ltr)	6400	6400
Total value of ENA that can be generated from all usable corms (USD/year)	281,294,012	2,016,355,307
Total value of ENA that can be generated from 27% of usable corms (USD/year)	75,949,383	306,233,962

However, not all usable banana corms in Uganda can be extracted and used to make ethanol. This is because not all farmers will accept extraction of banana corms from their farms. We used only 27%[14] of all usable banana corms to estimate the actual quantity and value of ethanol that can be generated from banana corms in Uganda. The 27% assumes that farmers who have adopted removal of corms in their banana fields will also adopt corm removal for ethanol production.

Using the adoption rate of 27% for corm removal, the actual ENA that can be generated from banana corms in Uganda is 43 million litres, worth USD 76 million. If production efficiencies are improved to reach that of KSW, the quantity of ethanol that can be generated at 27% adoption rate will increase to 306 million litres, worth USD 544 million.

6.3 Potential demand for ENA in Uganda

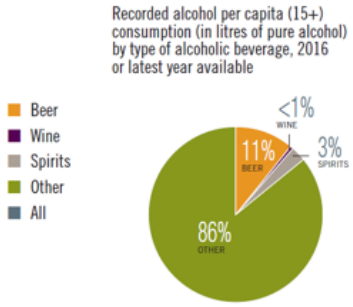
The main use type for ethanol in Uganda is making alcoholic beverages and alcohol-based hand sanitizers. The current per capita alcohol consumption in Uganda stands at 9.5 liters (WHO, 2020). With the current population of 22.8 million Ugandans of 15 years and above (UBOS, 2020), the current per capita alcohol consumption in Uganda stands at 217 million liters.

[14] Bioversity International, 2019 indicated that 27% of banana farms adopted corm removal in their banana fields.

Figure 12: Per capita consumption of alcohol among 15+ years Ugandans and the type of alcohol

Alcohol per capita (15+) consumption (in litres of pure alcohol)

	2010*		2016*	
Recorded	11.3		7.6	
Unrecorded	2.0		1.8	
Total**	**13.2**		**9.5**	
Total males / females	21.9	4.7	16.1	3.0
WHO African Region	6.3		6.3	



Source: WHO, 2020

However, only 3% of all alcohol consumed is spirits (Figure 2), which use ethanol as the main component. This puts the annual local demand for ethanol for alcoholic beverages at 2.6 million liters, worth USD 4.6 million.

Since the outbreak of COVID-19, the demand for alcohol-based hand sanitizers has increased exponentially. However, this is not the case especially in rural areas where hand washing with soap is the most applied hygiene measure. To estimate the local demand for ethanol for alcohol-based hand sanitizers, we used the assumptions in Table 16.

Table 16: Assumptions used to estimate local demand for ENA for alcohol-based hand sanitizers in Uganda

S/N	Assumption
1	Hand sanitizers are mostly used by the population in Kampala and Wakiso
2	The population of Kampala and Wakiso is 4,595,800 (UBOS, 2020)
3	Estimated daily usage quantity of hand sanitizers is 3ml. This is the recommended for effective killing of germs
4	The sanitizer has at least 60% ethanol content
5	At least 16% of the population in Kampala and Wakiso sanitize at least once a day with 3ml. The 16% is the combination of innovators and early adopters for any new idea in the diffusion curve

Based on assumptions in Table 16, the annual local demand for ethanol for hand sanitizer is estimated at 4.8 million liters, worth USD 8.7 million per year. Combining the local demand for ethanol for alcoholic beverages and alcohol-based hand sanitizers gives a total local demand for ethanol of 7.4 million liters, worth USD 13.3 million.

As it can be seen in Table 17, the potential supply of ethanol outweighs its potential demand. This suggests that there will be a surplus of ethanol that will need to be exported. Considerig the current efficiencies at NARO, the surplus ethanol is 35.3 million litres and it can generate USD 63 million if exported. However, considering production efficiency at Kakira, the surplus is 298.8 million litres and they can generate USD 535 million if exported (Table 17).

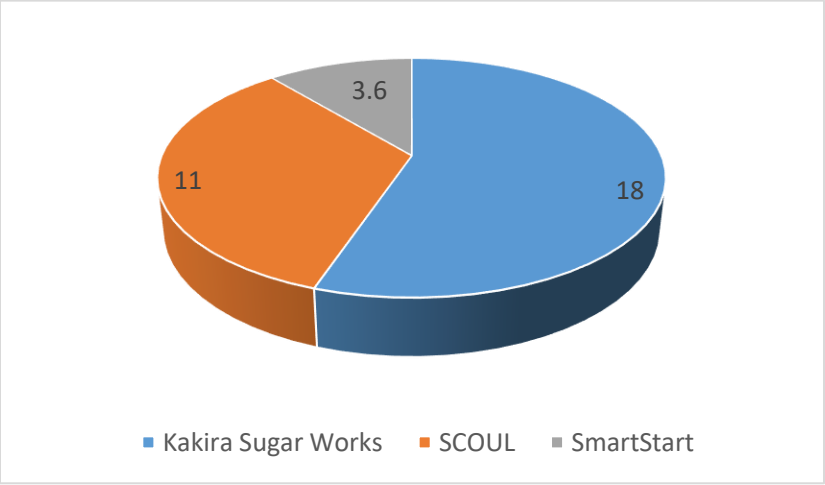
Table 17: Current demand of ethanol, surplus of ethanol and value of surplus if exported

Parameter	NARO proof of concept efficiency	Kakira efficiency
Ethanol that can be generated using 27% of usable corms (L/year)	42,721,528	306,233,962
Current local demand for ethanol (L/year) for spirits	2,598,391	2,598,391
Current local demand for ethanol (L/year) for sanitizer	4,831,105	4,831,105
Total current local demand for ethanol (spirits & Sanitizers) (L/year)	7,429,496	7,429,496
Value of current local demand of ethanol (USD/year) for sanitizers	8,653,533	8,653,533
Value of current local demand of ethanol (USD/year) for spirits	4,619,361	4,619,361
Total value of current local demand for ethanol (spirits & Sanitizers) (USD/year)	13,272,894	13,272,894
Total surplus ethanol (L/year)	35,292,033	298,804,467
Value of export if the ethanol surplus is exported (USD/year)	63,215,507	535,222,107

6.3 Current structure and marketing channels for ethanol in Uganda

Due to high initial investment costs, the ethanol industry exhibits an oligopoly structure. There are only three known large-scale producers of ethanol in Uganda. The largest producer (KSW) controls 55% of the market share, followed by SCOUL that controls 34% and lastly Smart Start Industries East Africa Ltd which controls 11% of the market share. The ethanol industry in Uganda may not have sufficient competition among the three industry participants. There may also be a possibility of price-setting and other anticompetitive behavior among the three companies.

Figure 13: Production capacity (million liters/year) of the three large scale ethanol producers in Uganda



Source: Authors' secondary data review

6.4 Potential market segments for effective commercialization of ethanol

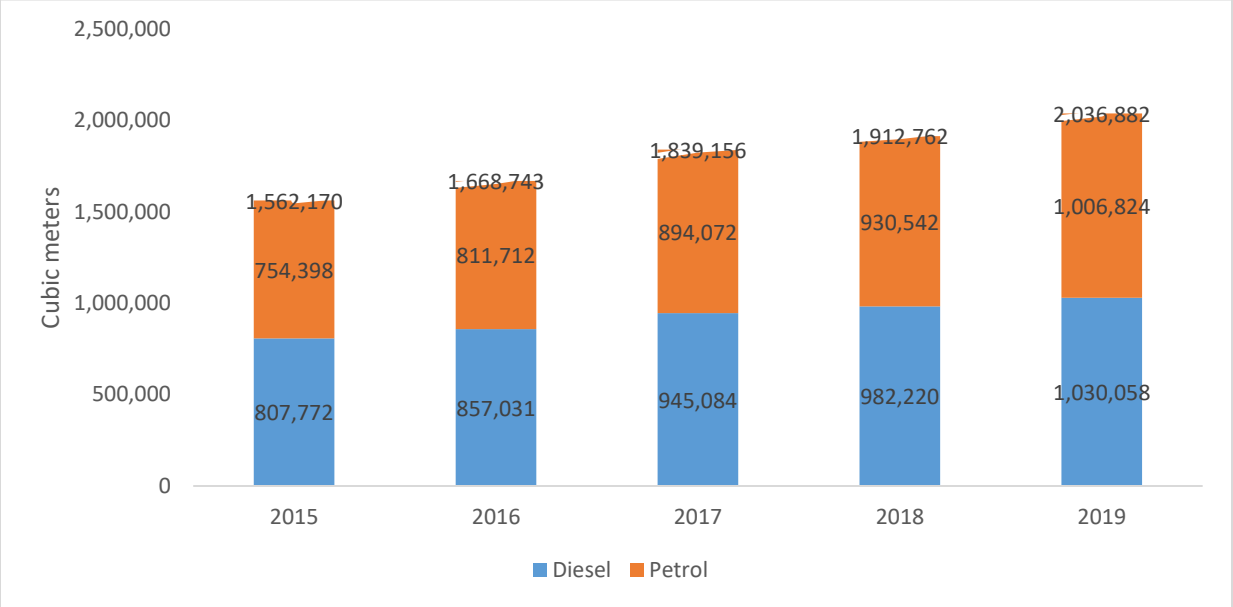
There are four potential market segments that commercialization of ethanol can focus on. These include: Biofuels, Extra-Neutral Alcohol, Ethanol Fuel for Clean Cook Stoves, and Ethanol-based Hand Sanitizers.

6.4.1 Biofuels

Biofuels are transportation and industrial process fuels that are made from biomass materials. They include ethanol (Anhydrous Alcohol [v/v>=99.6%]) and biodiesel. Production of biofuels has been motivated by concerns for energy sustainability, and the need to reduce greenhouse gas emissions.

Biofuels can and are usually blended with petroleum fuels to reduce the amount of crude oil imported from other countries to reduce the country's trade deficit. The attempt to promote renewable energy in Uganda was first spelled out in the provisions of the Energy Policy (Ministry of Energy and Mineral Development, 2002) and the Renewable Energy Policy (REP) (MEMD, 2007). One of the policy objectives in the latter is to promote the production and utilization of biofuels by setting a requirement of at least a 20% blend level. The biofuels Act was signed in 2018 to provide a supportive regulatory framework that would regulate the production, distribution, and use of biofuels. The Act, however, is yet to be operationalized.

Figure 14: Annual Imports of Diesel and Petrol in Uganda (2015 to 2019)



Source: UBOS, 2020

Based on 2019 import figures of petrol (Figure 2), a 20% blend of petrol with ethanol would create a local demand of 201.4 million litres of ethanol. Considering an average annual increase in petrol imports of 7.5%, the local demand for ethanol would increase to 289.2 million litres by 2024.

There are currently three companies that have installed capacity to produce bioethanol. These are Kakira sugar works in Jinja with an installed capacity of 18 million liters/year; the Sugar Corporation of Uganda Limited in Lugazi with an installed capacity of 11 million liters/year; and Smart Start Industries in Masindi with an installed capacity of 3.6 million liters/year. This brings the current installed capacity of ethanol in Uganda at about 32.6 million liters/year. The installed capacity can meet only 16% of the demand for ethanol that can be created with the operationalization of the Biofuels Act. This will leave a deficit of 169 million liters of bioethanol. However, Uganda could generate USD 361 million from sale of ethanol if 20% of the petro imported in 2019 was blended with ethanol. It is important to note that this demand can only be available if the Biofuels Act is operationalized, leading to blending 20% of all imported petrol in Uganda.

6.4.2 Extra-Neutral Alcohol (ENA)

ENA is the primary raw material for making alcoholic beverages such as vodka and gins. It is highly concentrated ethanol distilled until it reaches a minimum ABV[15] of 95%. ENA is neutral in flavour, odour and colourless.

ENA also serves as an essential ingredient in the manufacture of cosmetics and personal care products such as perfumes, toiletries, hair sprays. Given its properties as a good solvent, ENA is utilised in the production of paints and ink for the printing industry, as well as in pharmaceutical products such as antiseptics, drugs, syrups, medicated sprays. This segment represents the second-best option (after alcohol-based hand sanitizers) for investment in commercialization of ethanol.

6.4.3 Ethanol Fuel for Clean Cook Stoves

Almost 90% of the population in Sub-Saharan Africa uses fuelwood-based forms of energy. However, its use is often unsustainable and is one driver of environmental degradation. Ethanol has been promoted as an alternative cooking fuel to fuelwood and charcoal as it can improve household cooking efficiency, as well as has substantial health and environmental benefits (Ohimain, 2012). Ethanol stoves are very efficient and clean compared to fuelwood commonly used for cooking, such as fuelwood and charcoal (Takama et al., 2011). Ethanol stoves produce substantially lower indoor air pollution than fuelwood and moderately lower indoor air pollution than charcoal stoves, reducing health impacts at the household level. In addition, ethanol stoves are potentially easier and more convenient to use (Practical Action Consulting, 2011), as they do not require much effort in preparing the fire or cleaning after cooking compared to charcoal and fuelwood stoves. As the scarcity of fuelwood increases, ethanol has a big potential to be an alternative source of household cooking energy for most of the households in sub-Saharan Africa.

6.4.4 Ethanol-based Hand Sanitisers (EBHS)

Since 2020, SARS-CoV-2, spread worldwide leading to the CoViD-19 pandemic. To prevent the spread of COVID-19, good hygiene and cleaning practices are fundamental. As a result, the

[15] ABV (Alcohol By Volume) is a standard measure of how much ethanol is contained in a given volume of an alcoholic beverage expressed as a volume percent.

demand for sanitizers has increased globally. This is because sanitizers (with at least 60 percent alcohol content) are extremely effective against COVID-19. As health agencies started to recommend the use of alcohol-based hand sanitizers, their demand and sale skyrocketed, leading to sudden shortages in most markets. Many infectious-disease researchers and virologists working on the coronavirus believe that the virus will become endemic (it will continue to circulate in the global population for years to come). Due to the soaring demand, and positive prospects, many cleaning product manufacturers have increased their production capacity to meet the ever-increasing demand for hand sanitizers. Likewise, some companies have added hand sanitizer into their product portfolio and entered new markets. For example, one U.S-based company, Bell International Laboratories, a vertically integrated cosmetics manufacturer, expanded its production of alcohol-based hand sanitizer by shifting all its production capabilities to hand sanitizer. The current and forecasted demand for ABHS presents a huge opportunity for increasing ethanol production. This therefore represents the best investment option in commercialization of ethanol.

6.5 Regulatory and institutional factors with potential to influence the commercialization of ethanol

The Biofuels Act, 2018 has the biggest potential to influence commercialization of ethanol if implemented. The Act regulates the production, storage and transportation of biofuels and the blending of biofuels with petroleum products through Ministry of energy. If implemented, there is a big potential for bioethanol commercialization because it requires petroleum products to be blended with Biofuels.

UNBS also specifies standards for Neutral Spirits which have the potential to affect commercialization of ethanol. The quality requirements specified in the Neutral spirit Specification are shown in Table 13. Therefore, investors must meet these requirements to commercially production of ethanol on top of other quality standards for food grade items, specified by UNBS.

Table 18: UNBS Quality requirements for neutral spirit

Characteristic	**Requirement**
Ethanol content, percent by volume at 20^0C, min.	96
Volatile acids as acetic acid, mg/L absolute alcohol, max.	20
Total solids, % mg/L, max.	30
Methanol content, mg/L, max.	50
Higher alcohols (fusel oils) as amyl alcohol, mg/L of absolute alcohol, max.	10
Furfural content	To pass the test
Aldehydes (as acetaldehyde), mg/ L,max.	5

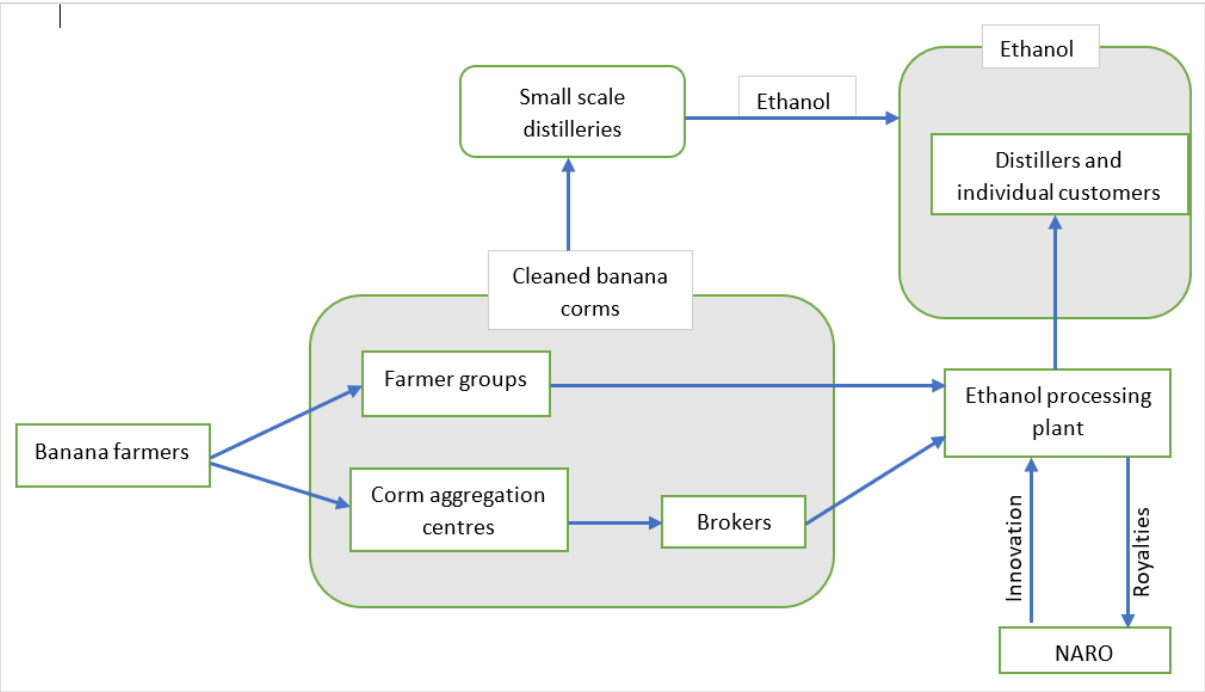
Source: UNBS, 2017

There are also incentives for investment in the ethanol production from banana corms. These are specified in the guide for tax incentives/exemptions for investors in Uganda[16] by URA. They include incentives and exemptions from income tax, VAT, stamp duties and others. For example, investment in processing agricultural products is exempt from VAT on the supply of feasibility study and design services and on the supply of locally produced raw materials and inputs under certain conditions.

6.6 Recommended business model for private sector investments and commercialization of ethanol

Proximity to raw materials is an important determinant of location of a processing plant. Sufficient quantities of the proposed raw materials (banana corms) are located in the major banana producing areas of the country. For economic purposes, the processing plants should be established in the major banana producing regions. Figure 2 shows the details of the recommended business model.

Figure 15: Recommended business model for ethanol commercialization



The first level will involve uprooting and cleaning of corms by banana farmers. The cleaned corms will then follow two possible channels. The first channel will involve transportation of the cleaned corms from farm level to aggregation centers. Brokers will then load the cleaned corms from the aggregation centers and transport them to the processing plant.

The second channel will be used for farmers who are in farmer groups. The cleaned corms will be aggregated by the farmer group which will in turn sell directly to the processing plant. This

[16] Uganda Investment Authority, 2021. Accessible Here.

channel will most likely be the most important in improving farmers' incomes because it eliminates the brokers who normally take a big share of the final price.
NARO will sell the processing innovation to the ethanol processing plants which will in turn produce ethanol using the developed technology. In return the processing firms will pay royalty fees to NARO on net sales from Ethanol made using the corms. To reduce on the transportation cost, processing plants can be established in each of the major banana growing regions. The processed ethanol will then be sold to distiller and other individual customers. The distillers will use ethanol to produce different products such as Whisks, gins, sanitizers etc.

6.7 Gender specific opportunities that might arise from the development of ethanol from banana corms

Processing ethanol from banana corms will generate several opportunities, especially at farm level. This is because of the several processes required before the corms are processed into ethanol. The processes include: Uprooting the corms, preparing, and cleaning the corms, and transporting the cleaned corms to aggregation centres. All these processes will be conducted at farm level, generating opportunities and incomes to farmers. More opportunities for men are likely to be created compared to women. This is because most of the pre-processing activities are manual and require physical strength.

6.8 Potential research, capacity building, market, and value chain development partnerships for successful commercialization of ethanol from banana corms

The first and most important area for research and capacity building is to improve the efficiency of the ethanol production process from banana corms. Currently, the production process at the leading ENA producer is seven times more efficient. The current production process needs to increase by 615% (from 34 liters/tonne to 243 liters/tonne) to compete with already existing distillers.

The second area of research should focus on use of wastes that will be generated from the production process. The existing companies use sugarcane as their substrate. The process generates bagasse which is used to make electricity and sold to the national grid. There is a possibility that the waste generated after extracting ethanol from corms can also be used to generate electricity.

6.9 Conclusion and recommendations

Uganda is one of the leading producers of bananas and plantains in the world. However, bananas and plantains are cultivated mainly for their fruits. This leaves several tonnes of underused by-products and wastes. The by-products and wastes include damaged fruits, peels, peduncles, leaves, fibres, pseudo-stem, and corms. These wastes and by-products have a potential to act as raw materials to produce other value-added products that can create jobs and increase farmers' incomes.

One of the value-added products that can be made from banana wastes is ethanol. Scientists at NARO have already proved that ethanol can be made from banana corms. Ethanol/ alcohol/ethyl

alcohol (C_2H_5OH) is an industrial chemical used as a solvent in the synthesis of other organic chemicals, as an additive to automotive gasoline, and as the intoxicating ingredient of many alcoholic beverages such as beer, wine, and distilled spirits. Although scientists at NARO have proved that ethanol can be produced from corms, most banana farmers still leave their corms in the ground after harvest and there have been no efforts both at commercial and small scale to produce ethanol from corms in Uganda. The market study provides a comprehensive understanding of the market dynamics of the ethanol market in Uganda and recommend effective ways to increase sales, market share, and competitive advantage of ethanol made from corms.

Study results show that with the current production efficiencies at NARO proof of concept, Uganda can generate 158 million liters of ENA per year from banana corms, worth USD 281 million. With improvements in the production efficiency to reach that at Kakira Sugar Works, the potential annual supply of ethanol can increase up to 1,134 million liters worth USD 2,016 million per year. Using the adoption rate of 27% for corm removal, the actual ethanol that can be generated from banana corms in Uganda is 43 million litres, worth USD 76 million. With the same adoption rate of 27% and production efficiencies at KSW, the quantity of ENA that can be generated will increase to 306 million litres, worth USD 544 million.

The potential local demand for ethanol in Uganda is estimated at 7.4 million litres (2.6 million liters for alcoholic beverages and 4.8 million liters for hand sanitizer) worth USD 13.3 million (4.6 million from alcohol beverages and USD 8.7 million for hand sanitizer). Considering the potential supply of 306 million litres per year (when considering efficiency at KSW), this leaves a surplus of 299 million litres of ethanol that will need to be exported. If this surplus is exported, it can generate USD 535 million in foreign exchange per year.

The study identified four potential market segments that commercialization of ethanol can focus on. These include: Extra-Neutral Alcohol for alcoholic beverages, Biofuels, Ethanol Fuel for Clean Cook Stoves, and Ethanol-based Hand Sanitizers. The best entry point is ethanol for alcoholic beverages and ethanol-based hand sanitizers. This is because there is an existing market demand in the two segments.

The study however notes that the oligopoly structure of the current ethanol industry in Uganda and the industry may not have sufficient competition among actors, with a possibility of price-setting and other anticompetitive behavior. These conditions together with high initial investment cost may be hard for companies that may want to invest into commercialization of ethanol from corms hard.

7.0 RANKING THE FOUR PRODUCTS BASED ON THE STUDY FINDINGS

Based on the study findings, fibre products were ranked first with the greatest potential for commercialization considering that several Small and Medium Enterprises have already experience and have invested in fibre extraction, processing and marketing of different fibre products who are currently not meeting the demand. Moreover, the extraction and processing technologies are relatively cheap and can easily be adopted by farmer, women and youth groups as a way of reducing unemployment. However, more research is needed to increase the extraction efficiency, production technologies such as producing softer fabric and mass awareness campaigns to create local demand for banana fibre products since current production is mostly for the export market.

Resistant starch was ranked second because it is a very high value product on the international markets and our local cultivars have a very high concentration of RS. Additionally, production of RS will not affect food security since marketed bananas currently lost through PHL can be used in the production of RS. Also, the demand for RS is only expected to increase due to the increased promotion for health living and the increasing number of people with diabetes who will need to substitute their starch intake with RS. However, for effective commercialization, there is need for product certification, research to reduce production costs and laying strategies for penetrating international markets where the health benefits of RS are already known.

Peeled and preserved bananas was ranked third because locally it faces great competition from the readily available fresh peeled and unpeeled bananas on the market. Moreover, most consumers of peeled bananas prefer that peeling is done in their presence to ensure that they get the right quality, variety and do not incur extra costs for peeling. Therefore, fresh peeled would locally only appeal to a small segment of consumers in the high and middle class willing to pay a premium price for a product that is ready for preparation and is marketed under high hygiene standards. This product would suit the export market because it can potentially reduce the weight-based freight costs and ultimately the cost of doing business for the exporter though export volumes are relatively low because the targeted market in Europe is informal and generally targets Ugandans in diaspora. Therefore, there will be a need for mass awareness campaigns to build consumer confidence and create local demand for peeled and preserved bananas. Similarly, research is needed to identify the most appropriate packaging material for fresh peeled Nano-technology preserved bananas and strategizing to enter the international markets for bananas.

Finally, ethanol was ranked fourth because of the high capital investments needed for its production at commercial scale and the demand for high quality ethanol is also low due to many sources of ethanol from different raw materials including sugarcane and cassava. Moreover, the market for ENA is very oligopolistic implying that existing producers can easily collude and drive new entrants out of business. However, great value can be achieved if biofuel law is implemented in its entirety. Consideration can be made in the promotion of use of ethanol fuel for clean cook stoves by bench marking it against experiences in Ethiopia

Table 19: Ranking of the four products considered for this market study

Product	**Fibres**	**Resistant Starch**	**Peeled bananas**	**Ethanol**
Product rank	**1**	**2**	**3**	**4**
Reason for rank	1. SMEs already extracting fibre 2. Easy entry (relatively low start-up capital required) 3. High potential in job creation 4. High demand for the products 5. High potential for foreign exchange earning	1. High competitive advantage to produce RS (Local varieties have high RS content) 2. Increasing population that demand RS 3. High potential to reduce banana post-harvest losses. 4. Relatively low investment cost	1. Potential to reduce banana post-harvest loss 2. Relatively cheap technology 3. Potential to reduce urban waste 4. Potential to reduce nutrient export from banana farms	1. High capital investment cost 2. Limited local demand for ENA (over 60% exported) 3. Need for specialized skills. 4. High chances of collusion due to oligopolistic nature of the market.
Recommendations for commercialization	1. Improving extraction efficiency 2. Improving energy efficiency 3. Waste management 4. Mass awareness creation for the products 5. Research into new products from fibre like softer fabrics.	1. More research to reduce cost of production 2. Meeting quality standards (certification) both local and international 3. Strategies to enter international markets 4. Mass awareness creation for RS 5. CBA	1. Mass awareness to build consumer confidence 2. More research on appropriate packages 3. Willingness to pay study for preserved & peeled bananas	1. Improving processing efficiency 2. High potential if Biofuels law is implemented 3. Production to focus on international 4. High potential for Ethanol fuel for clean cook stoves 5.CBA

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APPENDIX 1. Data types used for the four products

	Fibres	Resistant starch	Peeled bananas	Ethanol
Key informant interviews (processors, exporters, traders, researchers, Consumers, pharmacists)	20	5	15	4
Secondary data (URA, UBOS and FAO)	Yes	yes	yes	yes
Desk review	Yes	Yes	yes	yes

Appendix 2: Terms of reference for the market study

TERMS OF REFERENCE FOR LOCAL CONSULTANCY TO CONDUCT A MARKET STUDY OF 4 BANANA TARGETED PRODUCTS AND TECHNOLOGIES

1.0 ACTIVITY OVERVIEW:

The National Agricultural Research Organization (NARO) through the National Agricultural Research Laboratories (NARL) is implementing a five-year Banana Commercialization Project under the USAID's Feed the Future (FTF) - NARO Funding Framework whose aim is to promote the use and commercialization of Banana technologies and/or products. In order to achieve this objective, the Activity will focus on the continued Banana variety improvement, integrated pest and disease management, development and commercialization of innovative Banana products and technologies in response to social, emerging threats and market demands.

1.1 Overall Activity goal

The goal of the Activity is to promote the use and commercialization of improved Banana varieties and technologies with yield and nutritional enhancing characteristics.

1.1.1 Specific activity objectives

i. Facilitate the release and commercialization of Banana varieties developed under previous and ongoing research efforts.
ii. Develop improved Banana production and management technologies in response to emerging threats and market demands.
iii. Consolidate previous gains in institutional and human capacity development to align research with market needs, and mobilize domestic resources that will displace current development partner funding.

1.2 Develop market for four Banana products and technologies: Market research

The Banana Activity is implementing a series of activities that aim at improving local and international access of 4 innovative banana products and technologies to markets. The

range of implemented activities also extends to include increasing supply and demand of potential products and technologies for small scale farmers and processors from Matooke or cooking banana.

In this regard the Banana Activity is seeking a qualified consultant/technical person to conduct a market study on four identified products and technology in Uganda. The study aims to understand the local market by conducting an extensive, yet focused, market research/study for four products and technology which are: Resistant/green/natural starch, Fresh and preserved cooking banana, industrial ethanol (from corms), and banana fibers The study shall look at and recommend effective ways to increase sales and market

share and competitive advantage of selected commodities and technology through direct and indirect sales (supply to major retailers and/or wholesalers and food processors).The study shall be both supply and demand oriented addressing the objectives therein ,and able to identify the following:

- Current and potential supply and demand of the four identified products and technology at the national and regional and global markets
- Highlight any gender- based constraints and needs to be addressed by the proposed products
- Specifications and detailed description of existing competing products in the local market
- Recommendations to increase direct and indirect sale of the four identified commodities at the local market.

1.3 The Objectives of the Market Study are:

- Quantify the current and projected supply and demand of the 4 selected products.
- Profile and document the most important producers and market share structure of each of the 4 products and technology as well as most prevalent marketing channels.
- Identify and map the existence of any local and imported products that compete with the 4 products and technology and document the characteristics of the identified competing products.
- Assess the potential market segments for effective commercialization of the four products and technology
- Analyze and document the regulatory and institutional factors with potential to influence the commercialization of selected products and technologies.

- Profile and determine potential research, capacity building, market, and value chain development partnerships for successful commercialization of the selected products
- Develop a business model for private sector investments and commercialization of the products.
- Identify innovative financing opportunities for the commercialization of the selected products.
- Identify the key gender constraints, needs, and priorities and gender-specific opportunities that might arise from the development of the selected products
- Capture community perceptions on the existing similar products and explore the unintended outcomes of the selected products on gender relations and women empowerment.

1.4 Deliverables:

i. Detailed work-plan
ii. Detailed research and assessment tools
iii. Biweekly progress report of the assignment
iv. Complete analysis results of all gathered data
v. First and final drafts of the study reports

Specific terms and conditions

The Consultant/Technical expert shall be required to:

i. Conduct desk research to review related literature, reports and studies. The Banana Activity will support in providing the consultant with available related documents.
ii. Conduct key informant interviews with the key stakeholders, and target group including market players, producers, consumers, and other relevant institutions and bodies including NGO's and private sector representative bodies.
iii. Conduct a gender analysis as part of the market assessment to facilitate development of products that meets the needs of diverse social groups and adresss gender inequalities.
iv. Utilize any other necessary primary research tools
v. Draft the structure of the market study in consultation with the Banana Activity.
vi. Draft and finalize the market study. The consultant shall be required to incorporate all comments received from the banana Activity after the submission of the preliminary drafts.

1.5 Target Area

The study will target Kampala and all the major cities and municipalities around the Country.

1.6 Duration of assignment

The assignment is to be completed in period not exceeding total of 40 days.

1.7 Fees and Cost estimate

The fees to be paid for the assignment will depend on the provided technical and financial proposals which must be based on the terms of Reference outlined above.

1.8 Required Consultant qualifications, skills and experience

Minimum of a Master Degree in any of the following disciplines:

i. Agribusiness management
ii. Agriculture Economics and or Marketing

Knowledge and Experience

- Strong research abilities and able to collect and synthesize information into useful data used to solve business problems.
- Strong background in market research and business assessment.
- Very Good knowledge of obstacles and main challenges facing the local products in market penetration and increasing market share in Uganda.
- Proven experience in conducting market research and gender analysis
- Good public relations network with private and public sector institutions operating in Uganda.

1.9 Response Process

Interested potential Consultants should submit their proposal (both technical and financial) and the updated profiles, clearly highlighting how they intend to successfully conduct the market study. Proposals should be sent to jkubiriba2012,bwesiygep@gmail and copy (cc) abkaggwa@gmail.com with the subject line **'Conduct a market study of 4 banana targeted products and technologies '.**