African Journal of Food Science and Technology (ISSN: 2141-5455) Vol. 6(4) pp. 108-117, July, 2015
Available online @http://www.interesjournals.org/AJFST
DOI: http:/dx.doi.org/10.14303/ajfst.2015.039

Full Length Research Paper

Harnessing of banana ripening process for banana juice extraction in Uganda

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ABSTRACT

Banana is a very important staple food crop in Uganda. It is grown in every part of the country with the largest production recorded in western and central regions. Uganda is ranked the second largest producer of banana after India in the world. Bananas produced in Uganda are largely consumed locally as *matooke*with small amounts being exported as green banana or ripened to make juice, wine, beer or chips. There are variousmanual techniques of making banana juices in Uganda ranging from hands, foot and small scale mechanical machines which are not economical and hygienic. However, banana ripening poses a very big challenge to farmers and small scale processors. This has resulted in large quantities of banana loss, reduced shelf life and low economic returns to small scale farmers. In this review, different methods of natural, controlled banana ripening and ripening delay techniques are outlined. Controlled ripening of bananas is a key facet to good economic return in banana production as well as a stable and feasible strategy to ensure constant supply of ripe banana for banana juice processing.

Keywords: Banana, Natural ripening, Controlled ripening, Delayedripening, Shelf life

INTRODUCTION

Banana (*Musa spp.)* is tropical fruit belonging to the Musaceae family. It is the fourth world's most important food crop after rice, wheat and corn (Mahajan *et al.,* 2010). Banana is grown in small scale farms in developing countries where it contributes highly to socio-economic gain of the farmers because of its long production period. Banana production begins 14 months after planting and can yield up to 10 years, thus continuous harvesting of banana throughout the year provides the farmers with constant income source (Beer and Sigawa, 2010). Banana is the most consumed fruit in the world due to its nutrients composition; vitamins, mineralsand energy as shown in and also it is an important staple food worldwide (Adão and Glória, 2005).

Uganda is the second world's largest producer and consumer of banana with acountry's population of 36.6 million (Uganda Bureau of Statistics UBoS, 2014). The country's total area is 24,155,070 ha with 15.1 % of the total land covered by open water bodies, 1.9 % covered by wetlands and the remaining 83.0 % being the dry land area (UBoS, 2014). The total agricultural land is9,115,180 ha which is 45.5 % of the total dry land (UBOS, 2014). The country has different ecological zones and farming systems for various crops as shown in According to FAO (2013), banana production in Uganda (including plantain) is estimated at 4,375,000 metric tonnes (MT) per year. The production varies depending on the region and districts of growth as illustrated in Figure 1.

The bananas produced in the western region contribute to about 61 % of the country's total production (Komarek, 2010).The districts with the highest banana production per region are as follows; Isingiro (western) with 601,363 tonnes; Mubende (Central) with 204, 109 tonnes; Mbale (Eastern) with

Table 1. Nutritional composition of raw banana (USDA National Nutrion Database ,2014).

Nutient and unit	Value	Nutrient and unit	Value
Proximate (%)			
Water	74.91	Riboflavin (mg)	0.073
Energy (kcal)	89	Niacin (mg)	0.665
Protein (N x 6.25)	1.09	Pantothenic acid (mg)	0.334
Total lipid (fat)	0.33	Vitamin B-6 (mg)	0.367
Ash	0.82	Choline, total (mg)	9.8
Carbohydrate, by difference	22.84	Betaine (mg)	0.1
Fiber, total	2.6	Vitamin A, RAE (mog_RAE)	3
Sugars, total	12.23	Phytosterols (mg)	16
Sucrose	2.39	Carotene, beta (mog)	26
Glucose (dextrose)	4.98	Vitamin A, IU (IU)	64
Fructose	4.85	Vitamin E (alpha-tocopherol) (mg)	0.10
Starch	5.38		
Mineral (mg/100 g)		***Lipid (%)***	
Calcium, Ca	5	Fatty cids, total saturated	0.112
Iron, Fe	0.26	Fatty cids, total monosaturated	0.032
Magnesium, Mg	27	Fatty acids, tptal polyunsaturated	0.073
Phosphorus, P	22		
Potassium, K	358	***Amino acid (%)***	
Sodium, Na	1	Leucine	0.068
Zinc, Zn	0.15	Lysine	0.050
Copper, Cu	0.078	Phenylalanine	0.049
Manganese, Mn	0.270	Valine	0.047
		Arginine	0.049
		Histidine	0.077
Vitamin		Alanine	0.040
Vitamin C, total ascorbic acid (mg)	8.7	Aspertic acid	0.124
Thiamin (mg)	0.031	Glutamic acid	0.152

99,011 tonnes; and Arua (Northen) with 17,106 tonnes per annum (UBoS, 2014).

Banana production in Uganda is mainly done by smallholder farmers with the total area harvested being 972,000 hectares which is 17 % of the total area occupied by food crops (5,743,000 ha), as shown in Figure 2. (UBoS, 2014). This make banana the most widely cultivated crop in the country.

The commonly grown varieties are the cooking banana (*matooke*) type of East African highland banana (EAHB) subgroup, the dessert bananas such as *Sukali Ndizi* and *Bogoya* and plantain species for roasting and *Kayinja* and *Kisubi*which are the most suitable for making fresh banana juice, wine and beers because they possess high concentration of natural sugars (Bagamba and Burger, 2007). Production of cooking banana (locally known as *matooke*) is approximated at 29.5 % of the world's banana production while dessert banana production is estimated to be 0.85 % of global production (REFORUM *et al.*, 2010).

Banana ripening process

As a climacteric fruit, banana is harvested while mature greenand then allowed to either ripen naturally or induced to ripen. The ripening process breaks down chlorophyll revealing the carotid pigments thereby yielding the golden yellow colour of the ripe fruit. This occurs as a result of normal climatic respiration and production of ethylene gas at temperature between 20^0C to 30^0C (Yang *et al.,* 2009).

During respiration, complex carbohydrate substrates are broken down to simpler molecules of carbon dioxide (CO_2) and water (H_2O). Respiration steps include glycolytic pathway of the cytoplasm, the tricarboxylic acid

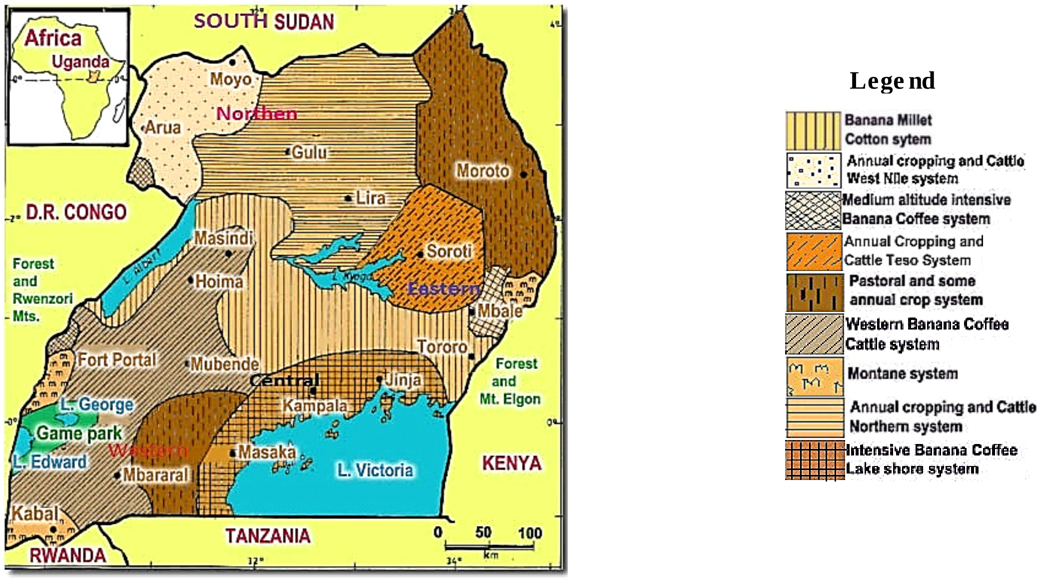

Figure 1. A map showing farming system in Uganda with interest in banana growing areas.

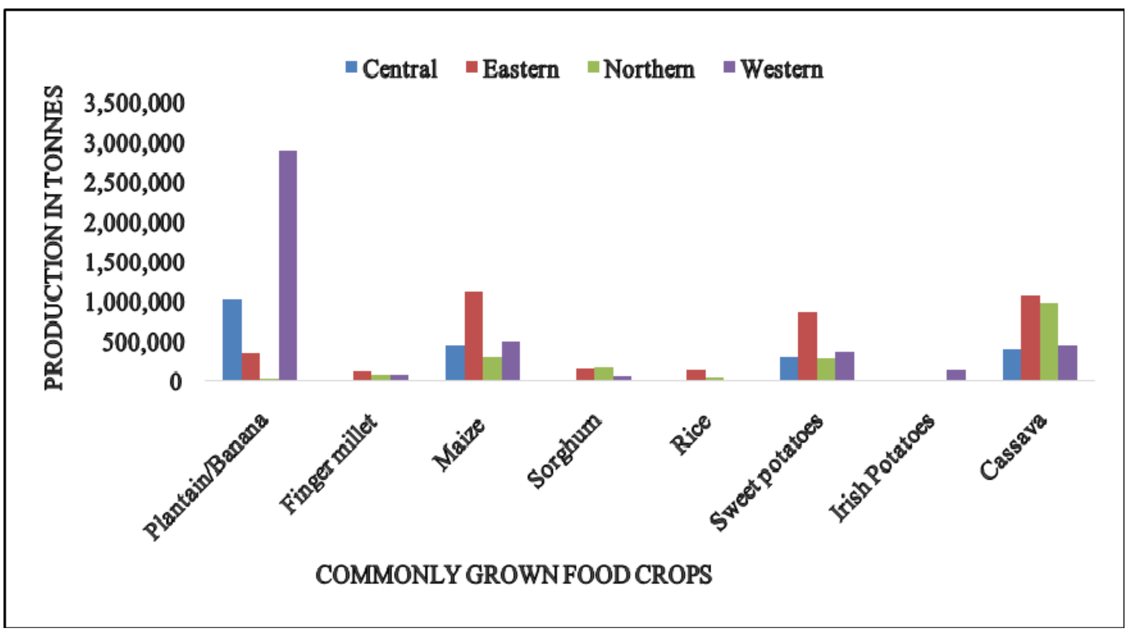

Figure 1. Production of Banana in comparison to other food crops in different regions of Uganda in 2013. ***Source:***(UBOS and MAAIF, 2013).

cycle, pentose phosphate pathway and electron transport system, respectively (Sen, 2012). Since banana is a climacteric fruit there is a sudden increase of respiration rate during ripening as shown in Figure 3, which leads to bursting of ethylene production at the onset of climacteric peak. This is enzyme controlled (Salveit, 2004).

Precooling and delayed ripening of bananas

According to Imahori *et al.* (2013),mature green banana fruitscan be curbed from ripening during storage and transportation. Pre-cooling of bananas to 13^{0}C by use of refrigeration techniques maintain a low temperature

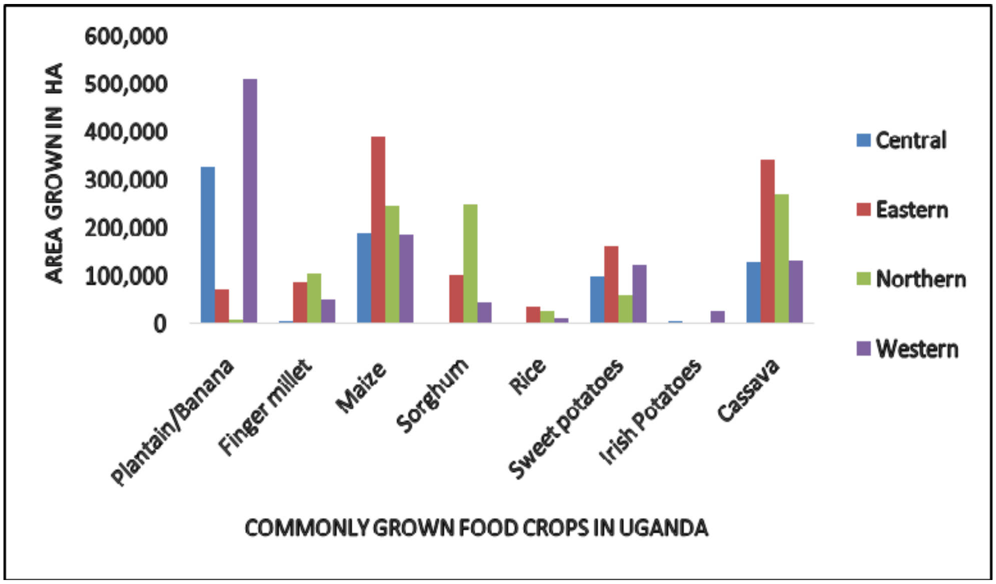

Figure 2. Area in Ha of commonly grown food crops in Uganda in 2013.
Source: (UBOS and MAAIF, 2013).

during the storage period.Controlled atmospheres (CA) and modified atmospheres (MA) extend the storage life of mature green bananas (Palomer*et al.,* 2005) by reducing metabolic rate; peel de-greening and limiting fruit's decay. Similarly, low oxygen pre-treatment can delay ripening of bananas during storage and transportation by exposing mature green banana fruits to low Oxygen (O_2) for two days (Imahori *et al.,* 2013).However, these processes arevery costly to the small scale farmers in developing countries especially Uganda and thus an alternative low-cost method that delays ripening would be useful.

In Uganda, many small scale farmers rely on natural ripening of banana. This is very uneconomical and unsustainable for banana juice extraction processing. As a result, many ripened bananas are spoilt and lost due to poor storage and ripening conditions.This paper seeks to review existing banana ripening and delay techniques and how they can be applied to small scale farmers in Uganda. In addition, the paper seeks to explore the feasibility of harnessing controlled banana ripeningto sustain banana juice extraction in Uganda.

Overview Of Banana Ripening Techniques And Their Relevance To Uganda

Natural Ripening

Mature banana fruits ripen naturally due to climatic respiration and production of ethylene gas (Yang *et al.,* 2009).Banana is largely ripened naturally in Uganda through several traditional methods.Hanging the bunches on racks in cool dry stores or digging pits out on farms and covering banana bunches with leaves are some of the techniques used in ripening. Under these conditions the banana ripened are generally not satisfactory for juice processing since the bananas are ripened at poor hygiene and at uncontrolled temperatures (KyamuhangireandPehrson, 1999).

According to Kyamuhangire *et al.* (2002), Ugandan Kayinja bananas (ABB genotype) used majorly for juice extraction is harvested at maturity based on the fullness of the fingers. The bananas are put in the ripening room at 28^0C and 90-95% RH without the use of ethylene until the peel becomes completely yellow, about stage 7, visual scale. Natural banana ripening produces natural quality ripened bananas althoughis not reliable and cannot be sustainable for large scale juice extraction process. Similarly, large quantities of banana are wasted due to uncontrolled nature of natural ripening.

Controlled ripening

Treatment with Ethylene and Ethephon gases

Ethylene is a colourless, odourless and tasteless gas introduced to plants as hormonesin very small amounts (parts per million)(Sen*et al.,* 2012), while ethephon gas is converted to ethylene gas upon metabolism by plants, and they are used for banana ripening.According to

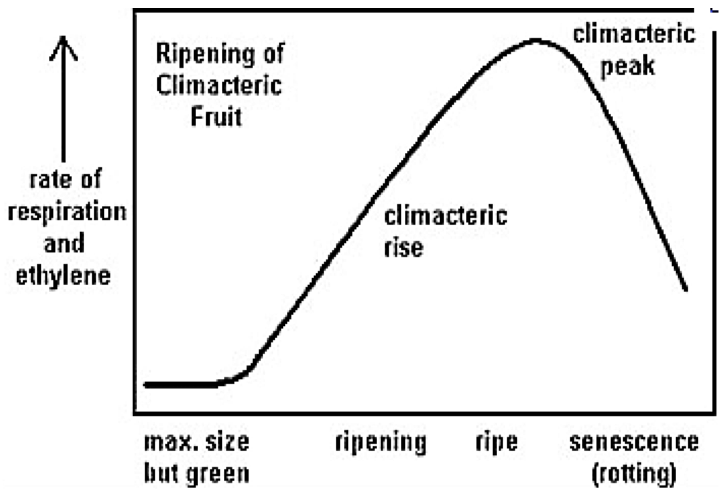

Figure 3. Climacteric vs Non-climacteric Ripening (Salveit, 2004).

(Mahajan *et al.,* 2010), banana fruits are harvested at green mature stage and kept under the shed slanting in a way to improve delatexing and to prevent blackening of banana fingers. Consequently,these bananas areexposed to ethylene gas (100 ppm) for 24 hours using portable ethylene gas generator inside the ripening chamber maintained at 18^0C and 90-95% relative humidity (RH). Similarly, the bananas can be likewise dipped in aqueous solutions of ethephon in different proportions for a period offive minutes.

These treated bananas are then dried by air and stacked in plastic crates then put in ripening chambers maintained at 18^0C and 90-95% RH (Mahajan *et al.,* 2010). The ethylene and ethephon gases result in adequate ripening of banana fruits within four days, with uniform colour, pleasant flavour, desirable firmness and acceptable quality and better shelf-life(Larotonda *et al.,* 2008).

These techniques have been used in India (Mahajan *et al.,* 2010), Brazil (Larotonda *et al.,* 2008) and Australia (Will *et al.,* 2001), but not in Uganda. Therefore, these techniques of banana ripening can be a good strategyto boost the capacity of banana ripening for juice extraction in Uganda thereby improving the productivityof small scale farmers.

Using Edible Coatings

In this technique, varied percentages of chitosan, gibberellic acid 100 ppm, jojoba wax, and glycerol (98%) coatings are applied to mature banana fruits before being stored at a temperature of 34 ± 1^0C and 70-75 % RH. These coatings prevent weight loss, decay, total soluble solids, pH, sugar accumulation, pigment degradation and ascorbic acid of the bananas more than the uncoated ones. This technique prolongs banana shelf life, controls decay percentage and improves postharvest quality characteristics of bananas (Gol andRao, 2011).

This technique is mostly done in India (Gol andRao, 2011)and Indonesia (Suseno *et al.,* 2014)though not in use in Uganda. It is a very feasible method of managing decay, weight loss and ripening of banana. Thus in Uganda it can be very useful not only for controlled ripening but also for increasing the shelf life of banana for export.

Overview Of Ripening Delay Techniques And Their Relevance To Uganda

Modified Atmosphere Packaging (MAP)

Once bananas are harvested they require good hygienic handling. Modified atmosphere packaging (MAP) techniques help to minimize thephysiological and microbial decay. According to Sen *et al.,* 2012, Modified Atmosphere (MA) is different from the normal air since its compositions are not the same. Therefore,MAP cancontrol the physiological and microbial decay of perishable fruits. The modification of internal atmosphere composition takes place at total pressure or partial pressures levels of gas components by either directly flushing the gas or by respiration of the enclosed product.

There is a continuous depletion of oxygen (O_2) in respiring fruits with the increase of carbon dioxide (CO_2) and water vapour creating a passive MAP. If the required gas composition mixture is introduced to package area after evacuation or by a continuous flow of gas mixture to replace the air, it creates an active MAP(Gonzalez-Aguilar *et al.,* 2010). MAP technique is used widely in commercial banana transportation especially in India

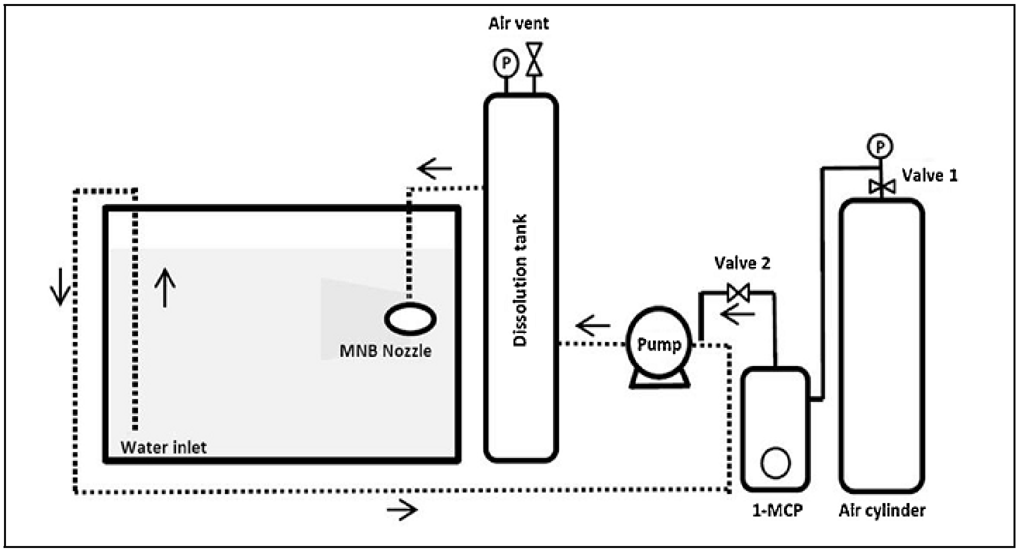

Figure 4. Schematic diagram of 1-MCP microbubble generation system.
Source:(Pongprasertand Srilaong, 2014).

(Sen *et al.,* 2012), Jamaica, Canada (Stewart *et al.,* 2005), Uruguay and Chile (Silveira*et al.,* 2014)though it is not yet used in Uganda. MAP of banana fruits increase their shelf life with minimal effect on the qualityduring handling, transportation and storage, thus can be very useful if used by farmers in Uganda to improve their income.

Treatment with high Nitrous oxide (N_2O) and low Oxygen (O_2)combinations

A combinationof nitrous oxide (N_2O) andreduced levels of oxygen (O_2) have an effect on the postharvest ripening ofmature green banana fruit. The fruits are stored at a room temperature of 20^0C, in a flow-through system, to various proportions of N_2O and $O_2$for 10 days (Palomer *et al.,*2005). N_2O delays banana fruit ripening significantly as evaluated by ethylene synthesis and respiration associated with changes in colour, acidity and softening.

This ripening delay technique is widely used in Europe especially in Spain (Palomer *et al.,*2005) and also in China (Cheng *et al.,* 2008)though it has not been used in Uganda. This technique similarly is a potential tool that can be used to improve the shelf life of banana fruits and thus improve ripening in turn improving the potential of banana juice extraction.

ControlledTemperature and Air Flow Rate Method

Exposing banana to low temperaturesextends the green-life of the fruit by reducing the metabolic rate of the fruit, consequently deteriorating senescence and decay (Peroni-Okita *et al.,* 2013). The shortest shelf life of banana at low temperature of 15^0C to 21^0C and airflow rate of 0.3 m^3/s.kg is between 12 and 25 days (Abdallah, 2012). Therefore, subjecting bananas to low temperatures slows ripening rate and increases their shelf life(Bagnato et al., 2002).This technique is most commonly used worldwide for precooling and controlled ripening(Der-Agopian *et al.,* 2011). In Uganda it is used especially to extend the lifespan of the *matooke*which are exported to USA and Europe(UBoS, 2014).

Novel Technique of using 1-Methylcyclopropene (1-MCP) Micro Bubbles

This technique uses micro bubble technology to delay the ripening of banana. During banana ripening, 1-Methylcyclopropene (1-MCP) is used in the form of aqueous micro bubble (MBs) solution. The banana fruits are then dipped in500 nL/L^{-1} of aqueous 1-MCP microbubbles (1-MCP-MBs) as in Figure 4 or fumigated with 500 nL/L^{-1} 1-MCP. They are then storedin ripening chamber at 25 ^{0}C for eight days(Pongprasert and Srilaong, 2014). According to (Harris *et al.,* 2000), it is a very effective techniquein delaying the postharvest ripening of bananas because 1-MCP-MBs reducesthe respiration rate and production of ethylene. Similarly, it slowed yellowingmaintaining firmness of banana fruit during storage. It is majorly used in Thailand (Pongprasert and Srilaong, 2014) and Australia (Harris *et al.,* 2000) but not much in Africa especially Uganda.

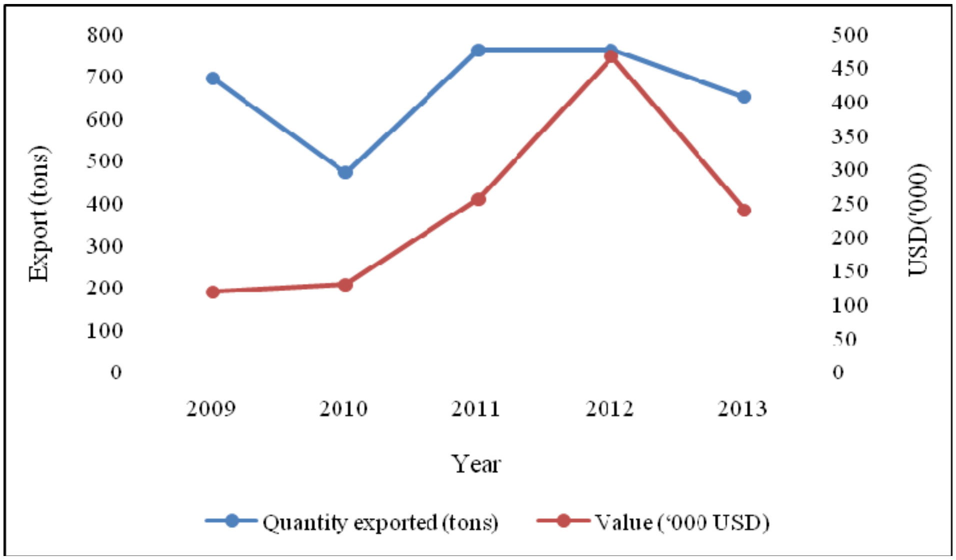

Figure 5. Banana Exports by Quantity vs Value earned (x1000 USD), 2009-2013.
Source:(Uganda Bearuea of Statistics, 2014).

This technique can be a good option for delayingthe postharvest ripening of banana fruit for both the small scale farmers and commercial ripening houses in Uganda.

Storing banana fruits treated in exogenous oxalic acid

This is achieved by dipping banana fruits into solutions of 20 mM oxalic acid for a period of 10 min then storing them at room temperature of (23 ± 2 ^{0}C) and 75–90% RH(Huang *et al.,* 2013). The oxalic acid application to bananas curbed deterioration in storage, limited the respiration rates and production of ethylene, as well as reduced rate of firmness, hue angle, and maximal chlorophyll fluorescence loss. This treatment generally best prevents postharvest losses in banana due to faster ripening and can therefore be a good commercial tool to help store bananas in large scale (Huang *et al.,* 2013). It is predominantly used in China, India and Pakistan with very limited application in Africa (Huang *et al.,* 2013). This technique can be a very good way of controlling banana ripening in Uganda since its simpler and cheap.

Estimating The Potential Of Controlledbanana Ripening And Juice Extraction In Uganda

Appropriate controlled ripening and delayed techniques and their economic impact to Uganda

it is of great interest for farmers to reap maximum benefits from their produce. Potentially banana juice extraction depends on the ripening techniques. The predominant ripening techniques used in Uganda is natural ripening which is not sustainable (KyamuhangireandPehrson, 1999). Therefore, introduction of controlled ripening and delaying techniques can contribute greatly to the amount of ripened banana available for juice, wine and beer processing.

In view of the different ripening and delay techniques illustrated in this paper, not all of them can be applied in Uganda. The use of ethylene gas can be a good strategy to boost banana ripening for industrial use. This is because, ethylene gas can be easily afforded by many small scale farmers. On the other hand, for delayed ripening controlled temperature and air flow rate is the most appropriate techniques that small scale farmers can adopt in Uganda. This is because despite poor electricity distribution, several cold store centres in small towns in the proximity of farmers can serve well.

In addition, controlled ripening and cold storage techniques can boost foreign exchange earned from banana export which is in a decreasing trend as illustrated in Figure 5 .

With improved banana ripening and juice processing techniques, average employment opportunities and labour cost indexin Uganda can increase substantially as shown in Figure 6, implying an increased income rate for farmers and better pay for workers attached to processing firm. Owing to the robust production of banana in the country,

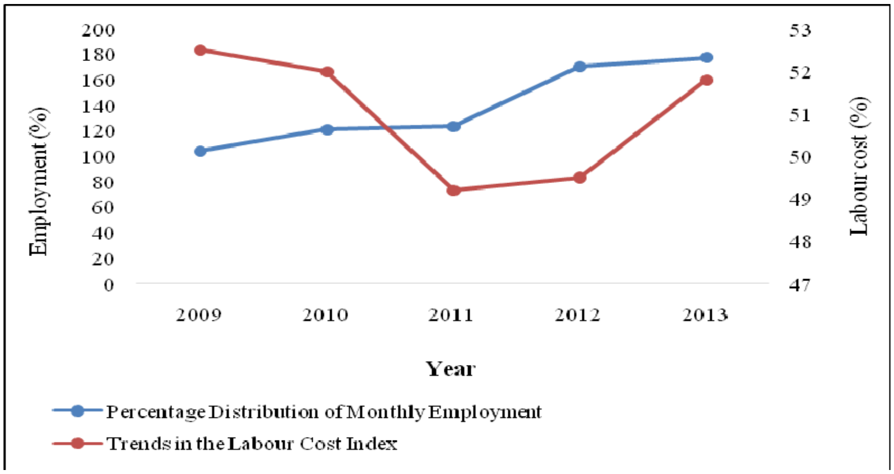

Figure 6. Percentage Distribution of Monthly Employment vs Trends in the Labour Cost Index (for Food processing and beverages).
Source:(Establishment survey, UBOS, 2014).

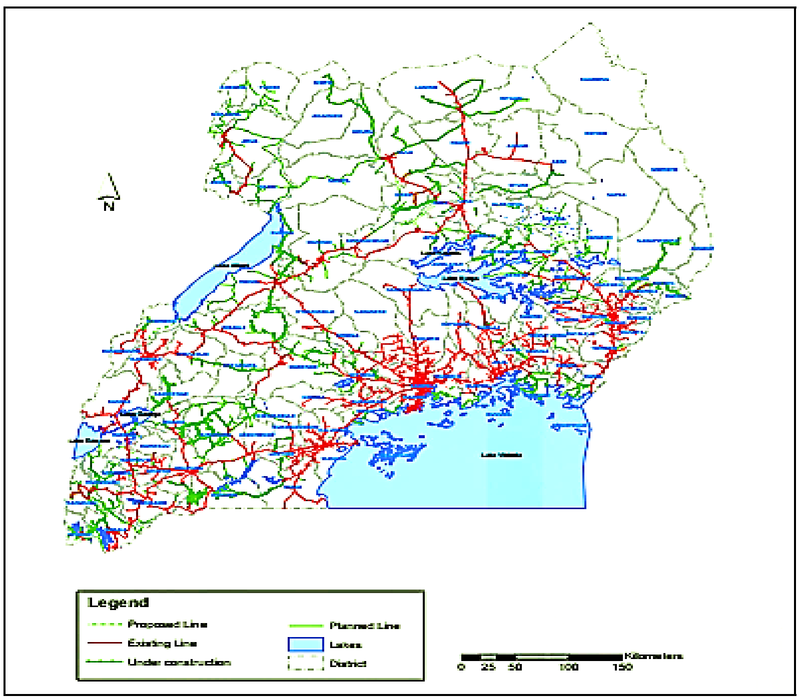

Figure 7. Electrical Distribution Map: Existing, Under Construction and Proposed Lines in Uganda.
*Sources:*Ministry of Energy and Mineral Development, 2010.

Feasibility of Banana Juice extraction and its Economic Impact to Uganda

Banana juice extraction in Uganda has been done on small scale using simple hand driven machines (Kasozi and Kasisira, 2005) and manually using hands and foots(REFORUM *et al.,* 2010). Nevertheless, in the bid to industrialize banana juice processing, the Matooke Markets Development Project (MMDP) under the Presidential Initiative for Banana Industrial Development (PIBID) introduced several initiatives (REFORUM *et al.,* 2010). With the pilot plantin Makerere University at the school of Food Technology, Nutrition and Bio-Engineering (Poverty Alleviation Department, 2008), the project was found suitable. Therefore, the proper industrialized banana juice processing can contribute to the country's Gross Domestic Product (GDP) earned by food crops sector which stands at 12.2 % in fiscal year 2013/14 (UBoS, 2014).

Similarly, according to Ssonko, SsebulibaandJager (2005), banana juice production can boost daily per capita fruit consumption in Uganda. Ssonko *et al.*(2005)noted that thedaily fruit consumption per person in Uganda is 29.4 g which is far below the recommended amounts by nutritionists for a single person at 80g/day.

However, according UBoS (2014), the average annual growth rate and annual yield of bananas areestimated at 0.8 %and 4.5 ton/ha respectivelywith a decreasing trend in production in the last decade (REFORUM *et al.,* 2010). Consequently, with the current banana production rate of 4,375,000 tonnes per year (2013), the possibility of sustaining large scale banana juice production is limited. According to (Komarek, 2010), the average dailyconsumption of banana per individual in Uganda is 0.7 kg/capita/day. Thus, with a population growth rate of 3.2 % (UBoS, 2014)and the adverse climatic changes, the bananas produced cannot be sustainable to feed the country's population and supply the processing plants with raw materials. It is projected that with the current banana growth rate as compared to the population growth rate, the production is not sufficient to feed the population as illustrated in**.**This consequently can be made worse if banana was to be diverted to industrialized juice processing.

On the other hand, both the ripening and extraction techniques largely depend on the availability of electricity. According (The Government of the Republic of Uganda, 2012) rural electrification plan, only 5 % of the rural are connected to electricity grid as shown in Figure 7

In addition Kaijuka (2007), noted that rural electrification in Uganda is very slow majorly because of the low population densitiesin the rural areas and their poverty state. This has been a big drawback for private sector investment because of exorbitant initial capital and operating costs. Consequently, this can cause a challenge in establishment of juice extraction plants in the rural areas where bananas are produced and as a result high initial cost.

CONCLUSIONS AND RECOMMENDATIONS

Controlled banana ripening is a very important technique that should be adopted by both small scale and large scale farmers in Uganda. Though the initial costs might be exorbitant, the benefits arelong term. Banana as a major food cropin Uganda is a source of income to scale farmers, therefore, proper controlled ripening techniques can improve the farmer's income and reduce wastages due to poor storage and ripening conditions. However, industrialized banana juice processing might not be sustainable due increase population growth but reduced banana yield with time. Therefore, for sustainable industrialized banana juice processing to be feasible.

However, the possibility of sustainable industrialized juice processing is pegged upon increasing the production of banana by enlarging the uncultivated fallow lands and using improved banana varieties. Similarly, due to the increased drought brought about by climate change, intensified commercial agriculture steered by proper irrigation can be a sufficient strategy to improve production. Lastly, proper balance in production and consumption between banana and other food crops within the country should be achievedto help control the over dependence on banana.

ACKNOWLEDGEMENTS

The scientific responsibility is accredited to the authors.

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