# Performance of the Pineapple Value Chain in South Western Uganda: Implications for Value Addition

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# Performance of the Pineapple Value Chain in South Western Uganda: Implications for Value Addition

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**ABSTRACT**

The pineapple value chain stands out as one that should be prioritized for promotion and improvement among the key fruit value chains for South Western Uganda as a result of its perennial nature with low pest/disease risk, low land requirement, importance for environmental and natural resources' sustainability, high profitability and history of having enhanced rural household incomes and non- restrictive to entry of rural poor. Mean monthly pineapple production peaks were bi-anual and matched the rainy season. Pineapple nutrient content revealed that fiber was highest in pineapples from Isingiro (6.29%) producing a significantly greater amount of pulp (mean: 510.4g/1000g of fresh fruit) than Ntungamo (2.03%: mean: 226.15g/1000g of fresh fruit) and Bushenyi (mean: 408.84 g/1000g of fresh fruit). Soil physico-chemical parameters varied significantly across the study sites, at 0.05% level of significance. A Pearson's correlation test between soil composition and nutrient content of pineapples from the various sites revealed that other than pH, Vitamin C however had a significant correlation with soil Nitrogen (p= 0.02), TDS with Magnesium (p=0.01); and fibre with soil organic matter (p= 0.04), Calcium (p= 0.01) and Magnesium (p= 0.02). Pineapples produced in Isingiro had the greatest percentage composition of crude fiber in dry pineapple pulp (mean: 29.6%) proving that dry pineapple pulp is a reliable source for crude fiber for utilization in product development that focuses on enriching human diet with dietary fiber. The high phosphorus and Total Dissolved Solute content (291.7 ppm) of Isingiro pineapples also gives them a strong flavor and a very sweet taste respectively for processing pineapples into dry sweet products and snacks. Pineapples from Ntungamo were best suited for juice extraction due to their high moisture content. The fresh Pineapple value chain in SW Uganda experiences a mean postharvest loss of 19.86% with highest loss hot spot being transportation. On average Ntungamo incurred significantly higher postharvest losses (26.9%) than the other two study sites. Solar drying of pineapples for the export was an easily adaptable

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value addition innovation for small scale chain actors alongside other potential value addition avenues such as pineapple wine and juice production for improvement and promotion to enhance pineapple value chain in South western Uganda.

*Key words: Pineapple; production; South Western Uganda; value addition.*

## 1. INTRODUCTION

Among the key economic activities sustaining human livelihood in the developing world, agriculture continues to stand out as “critical for human welfare and economic growth” [1]. In most of Sub-Saharan Africa, small- holder agriculture and its related services remains the major livelihood support activity for the people. This notwithstanding, the region is filled with many rural poor, yet also it is an area with the greatest potential for smallholder agriculture-led poverty reduction. In Eastern Africa, the agricultural sector is characterized by rudimentary technology utilization and low agricultural yields, in that many smallholders end up producing food mainly for self-consumption [2]. Uganda as an agricultural nation is no exception to this phenomenon; with the second-highest birth rate in Africa, and half of the population under 15 years, over 80% of the Ugandan population is employed in agriculture [3]. Most of the rural small-scale subsistence farmers and other small-scale agricultural value chain actors constitute the poorest 40% of the rural population in Uganda [4]. To address this challenge, most government and civil society efforts to raise rural incomes through agriculture have been focused primarily on improving agricultural productivity. This is usually based upon available empirical evidence, suggesting that agriculture-led growth has potential for broad-based poverty reduction for the developing world ([5]; [6]; [7]; [8]). However, without well-functioning value chains, productivity gains on the farm have only led to very temporary production surges and eventually prices collapsing miserably [9]. Along with this, the available markets are flooded with the same fresh produce, which easily undergo spoilage causing high postharvest losses. Such losses regrettably represent a comparable waste of land, inputs and labor used to produce the lost food [10]. The pineapple value chain in South Western Uganda is a typical fit for this description with very limited and under developed processing/packaging.

Over the last decade, small-holder farmers and SMEs in rural agrarian Uganda have been massively mobilized to purposefully engage in priority fruit value chains, to increase food security and eradicate poverty [11]). Unfortunately, many value chain actors involved in the already identified priority fruit value chains that are being promoted, have remained locked up in a vicious cycle evident of food insecurity, non-sustainable natural resource utilization and low-income earnings [12]. This is attributed to widespread poor post-harvest handling of agricultural produce, resulting in massive post-harvest food and income losses [13]. The government and civil society interventions being implemented bear minimal impact, in improving overall value chain performance [14], [15], [16], [17]). Postharvest losses of fresh produce remain extremely high: 20 to 50 % [18]. Up to 68% of the total postharvest losses in Sub-Saharan Africa are due to a lack of technology for appropriate handling to improve shelf life of the produce [19]. Fruit production is of impactful development importance, only if it can reach the final consumer in good condition to fetch a reasonable price, hence postharvest loss reduction has a strong bearing on final fruit availability [20].

Pineapple (*Ananus comosus* (L) Merr. Var. Smooth Cayene, ranks as the world's second most important fruit after bananas, contributing over 20 % of the world total production of tropical fruits [7]. Currently, nearly 70% of all pineapple is consumed as fresh fruit in its respective producing countries. Like other tropical fruit, pineapple is grown predominantly in developing countries- Uganda inclusive, where two thirds of rural people live on small - scale farms of less than two hectares [21]. According to [22], the world market for fresh pineapple has been growing rapidly during the past years, to the point that currently, pineapples dominate the world trade of tropical fruits, although other fruits have gained a market share too. FAO statistics from the year 2000 indicate that the pineapple trade took 51 % from a total of 2.1 million tons of the whole fruit market, with mangoes taking second place- 21.7 %. Pineapple production has been found to be concentrated in the tropical regions of the world [23].

Until recently, in Uganda, pineapple growing was mainly practiced in the central region, mostly in the districts of Masaka, Luweero and Kayunga. Gradually however, pineapple growing has now spread to some parts of Southwestern Uganda, majorly in the districts of Ntungamo, Isingiro and Bushenyi [24]. Just like in other parts of Uganda, pineapple growing in all these areas of SW Uganda is done mainly on a small-holder basis, despite the favorable climate that allows harvesting of pineapples twice a year [25]. Even with such high production potential however, Uganda contributes only 0.35% of East Africa`s pineapple production. Soil pH is the most relevant factor contributing to successful pineapple cultivation and a pH range of 4.5 to 6.5 is the best for pineapple cultivation [26]; [27], much as they can normally grow in acid soils. Pineapple also has a high demand for plant nutrients in the order K>N>Ca>Mg>S>P and Mn>Fe>Zn>B>Cu>Mo for macro and micro-nutrients respectively. Potassium, nitrogen and magnesium have the greatest effect on plant productivity and fruit quality [27]. Depending on soil physical chemical parameters, pineapple contains varying and considerable amounts of bioactive compounds, dietary fiber, minerals, and nutrients.

In recent years, there has been a growing trend towards finding new sources of dietary fiber, such as agronomic by-products, that can be used as ingredients in the food industry [28]; [29]. The most commonly consumed dietary fiber products are those derived from cereals, however, over the past decade, high dietary fiber materials from fruits are increasingly being sought after. Products that are rich in dietary fiber are becoming more widely demanded on the market [30], making readily available sources of dietary fiber a research necessity.

Much as pineapple has great potential for farm income enhancement, poverty alleviation, food security strengthening, and sustainable agriculture ([31], [32]), nearly 70% of the pineapple in SW Uganda is consumed as fresh fruit.

Inadequate value addition leads to postharvest losses [33]. The growing interest and investment in fruit production has not been matched by developments in supply chain management and vertical integration of production with processing [34], yet fresh produce processing increases market opportunities for actors and reduces postharvest losses. This study significantly adds to the scarcely available pineapple postharvest knowledge that is specific to south western (SW) Uganda. It generates relevant information, which is useful in planning for how to diversify the forms in which fresh pineapple can be consumed, and the possible obtainable processed products from pineapple. Identification of a wide variety of value-added products helps to make the pineapple value chain in SW Uganda a very profitable one [35].

## 2. MATERIALS AND METHODS

### 2.1 Study Area

A preliminary exploratory survey on pineapple production in SW Uganda, conducted at the commencement of this study, in which pineapple production areas in the region were mapped, had shown Isingiro, Bushenyi and Ntungamo districts to have the most widespread pineapple production coverage in the region with the areas of Kaberebere, Nyarugooti and Nyaruteme, to be the epicenters of pineapple production in each of the districts respectively (Fig. 1). This study was therefore conducted in these three purposively selected locations of South Western Uganda, where the pineapple value chain was already existent and operational over a two-year period 2017 to 2019. These were considered a reliable representation of the pineapple value chain in South Western Uganda. These Districts belong to three different agro-ecological zones; lowland or rift valley with altitude varying from 850 m to 1300 m above sea level with rainfall up to 40 inches annually, plateau zone with an altitude of 1300 m to 1700 m and an average rainfall greater than 40 inches, while the highland zone with a higher altitude (> 1800 m) averages more than 60 inches of rainfall annually. This region is home to over 3 million people living on about 14,500 km2 of land, leading to an average population density of 287 people per square Kilometer [36].

### 2.2 Data Collection Methods

The study employed a Cross-sectional descriptive research design with laboratory experimental approach. Non-probability methods including purposive sampling coupled with snowball were applied to recruit participants for the study [37]. The experimental approach on the other hand was mainly used to investigate how the Physico-chemical composition of pineapples relates to the soil physical chemical properties from the different study sites, and its implication for value addition.

First, a six pro-poor matrix criterion as adopted from [38] combined with key informant interviews with District Production Personnel were used to rank pineapple value chain performance among the most common fruits produced in South Western Uganda. The six critical criteria adapted for this study included 1)

Production potential, 2) potential of the chain to improve livelihoods of the poor, 3) market potential, 4) Natural resources and environment sustainability, 5) being in frame of existing national and provincial development strategies and 6) the extent to which the fruit value chain has been studied. Each of these pro-poor matrices had characteristic factors that were measured to rank each criterion. Under production potential, factors such as how widespread the production is (acreage and the present modest production were measured. Factors investigated under the potential of the chain to improve livelihood of the poor included ability to employ many poor people, poverty reduction, low risk to pests and disease, easy entry into the chain by the poor and affordability of labor. Market potential was investigated using available local and international market, possibility for private sector investment, diversification potential and possibility of market growth. The ranking of how the pineapple compares with other fruit value chains in terms of food security and environmental sustainability included multi-level food security, available natural resources for upscaling, environmental sustainability promotion and resilience to climate change. The fifth criterion was regarding how the pineapple fits in the existing developmental priorities and the factors looks at to rank this included whether it is gender inclusive, level at which it meets the national and international developmental priorities and utilization of indigenous knowledge. The last criterion extent of how some thematic areas have been researched the pineapple value chain is researched. These included crop production levels, level of actor organization, food security provision, post-harvest handling practices and access to markets. The ranking of the pineapple value chain according to the selected criteria was validated through an exploratory mini-survey that was conducted in all the 13 districts of South Western Uganda. Visits were made to fruit farming homesteads, farmer produce collection centers, weekly village markets, permanent urban and peri-urban markets, fruit processing centers, farmer support NGOs and District production offices. During the survey, information regarding relevance of the pineapple chain under the six criteria was documented. Basing on the findings from the exploratory mini-survey, the selected pineapple fruit value chain matrix was understood and documented in comparison with other fruit value chains.

Through an upstream chain/snow ball interview approach, actors at the different stages of the value chain were identified beginning with the retailers. Retailers were asked the name and contact of their primary source(s)-whole sellers of pineapples. From the list of whole sellers generated, a few were randomly selected, identified and asked to give the name and contact of their primary source of the product. This was expected to reveal a list of transporters. In the same way, transporters were randomly selected and asked the primary sources of their product. This revealed a list of farmers, mainly small-holder farmers. Overall, 26 small-holder farmers, 10 collectors/whole sellers, 10 transporters, 6 small processors, and 20 retailers were engaged in the study. At each stage of actor identification along the value chain, each interviewee was asked to estimate the quantity of pineapples they receive weekly. This helped to generate data on mean product flow quantities along the value chain and map the pineapple value chain in SW Uganda.

From each of the 3 study sites, farms where pineapple growing has been happening for at least five years was identified and marked. At the individual farms in each district, a predesigned farmer record sheet was used to obtain pineapple production data from pineapple farmers by cumulatively recording weekly pineapple harvests. The same data collection tool was used for collecting pineapple sales data from, pineapple amounts handled and weekly sales for actors at different stages of the chain (farmers, whole sellers, retailers and vendors). In addition, Cross sectional surveys, rapid participatory observation appraisals, and face to face interviews were used to gather information on pineapple performance and value addition avenues in the three districts of the three agroecological zones of south western Uganda.

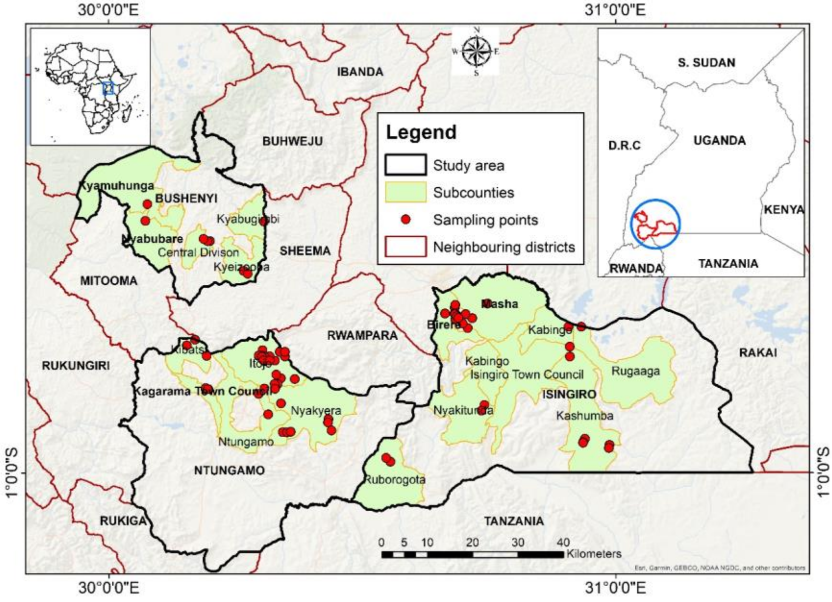



**Fig. 1. The study districts indicating the study sites**

Postharvest losses along the various stages of the pineapple value chain were assessed using a Commodity Systems Assessment (CSA) approach, which seeks to determine the sources, causes and economic value of post-harvest losses (PHL) at each stage along the value chain [39]. At farmer level, post-harvest loss was estimated as:

PHL= (Total amount harvested) - (Total amount sold) x 100/ (Total amount harvested)

At collectors, whole sellers and retailers' stages, PHLs were estimated as:

PHL= (Total amount purchased) - (Total amount sold) x 100/ (Total amount purchased)

Small losses resulting from personal consumption of the actor at a particular stage were assumed insignificant and hence negligible in the economic context. In this study, loss referred to produce unfit for human consumption, and excludes produce of lower quality that is still saleable. To obtain a value of loss experienced, actual loss in kilogram (kg) was multiplied with the average selling price achieved in each month or the harvest. This value was divided by the total amount produced or purchased by each value chain actor in kg to obtain a value of loss based on a uniform denominator and added across all agents in the value chain.

Values of PHLs obtained for each of the fruit value chain were then compared for the dry and wet seasons to cater for the effect of seasonality on PHLs. Sources, types and causes of the observed PHLs were also documented through observation and interviews with value chain actors at the respective stages of the value Chain. Following a review of the methodology for PHLs estimation based on a redefinition of PHLs, a framework was derived from a joint definition of PHLs from the researcher's perspective as stipulated in literature [40]; [41], [15] and the chain actors' perspective; reduction in product quantity from discarding product when found unfit for consumption and selling product at a much lower price than earlier intended due perceived decline in its quality.

From the jointly derived definition of PHLs above, quantitative losses in the pineapple chain of SW Uganda arose mainly from discarding some of the product initially intended for sale, when found to be unfit for human consumption. This implied that;

Quantitative loss = (amount of product, initially meant for sale, discarded as unfit for consumption) - (Amount meant for sale but discarded)/ (Total amount meant for sale at that time) X 100

Since qualitative losses are hard to measure directly but may be expressed in various measurable forms, from the realization that for the pineapple value chain in SW Uganda, a decline in perceived quality of the product by the buyer was the most outstanding factor causing the product to end up being sold at a much lower price than earlier intended, the percentage reduction in product price, stemming from decline in perceived product quality by the buyer, was considered to be the most important and relevant measure of qualitative loss in this Chain.

Qualitative loss therefore = (% reduction in product price due to decline in perceived product quality) = (mean initial intended product price) – (mean reduced product price)/ (mean initial intended product price) X 100

Since postharvest losses are expressed both qualitatively and quantitatively, this concept considered that the actual PHLs at any stage of the chain to be the summation of the qualitative and quantitative losses at that point in the chain:

PHL = (Qualitative loss) + (Quantitative loss)

The experimental approach on the other hand was mainly used to investigate how physico-chemical composition of pineapples relates to the soil physical chemical properties from the different study sites, and its implication for value addition. A pre-designed interview guide was used to obtain data on soil management practices on each of the marked pineapple farms, through key informant interviews with the farm owners. From each of the farms, five sampling plots were established, located a 20m apart. Two 500 g soil samples were then drawn from each study plot using a trowel at depths 0 – 20 cm and 20 – 40 cm respectively from the top layer [42]. This was done to cater for the variable distribution of soil components at different soil depths- mean composition of each component from the two collection depths were considered. Each sample was labeled to indicate the area, sample number, depth of extraction and the date and then carefully packed in a plastic bag for transfer to the laboratory. Unwanted material like fragments; twigs, glass, stones and plastic were removed and using increment sampling, appropriate sample sizes were obtained for specific analyses. Samples were pulverized and mixed to obtain homogeneity at a quality of <2.0 mm. To determine the soil texture, particle size analysis was performed using the Robinson pipette method and since soil texture refers to the relative proportions of sand, silt and clay particles in a mass of soil, Stokes` Law was applied in this method to measure the settling rates of the different soil particles [43]. The soil textural class estimation chart was employed as used by [44], using the different proportions of clay, sand and silt in each soil sample to derive the respective textural classes as classified according to CSSC, USDA where coarse and fine sand is 2.0 to 0.2 and 0.2 to 0.02 mm diameter respectively, silt is 0.02 to 0.002 mm diameter and clay is less than 0.002 mm diameter. The textural triangle was used to assign a textural class name to the different soils.

The soil was then heated using a hot plate in a porcelain to evaporate any liquids (60 to 1100C). The organic matter content was determined by a method of loss in mass using ash values. Samples were heated within temperature ranges of 450 to $650^0$C to avoid loss of non-volatile components. Ashing aids- nitrate, were added to assist oxidation and loosen ash, sulphate to prevent volatilization of chlorides and alkaline earth hydroxides to prevent loss of anions. The dried sample were allowed an hour to cool and it`s mass weighed repeatedly after each drying and cooling until the weighing agreed within 4 % of the mass [45].

Soil organic matter was then calculated as:

**% Organic carbon = (B – S) x N x 0.003 x 100/Wt. of soil (oven dry)**

Where, B = ml of std. 0.5 N ferrous ammonium sulphate required for blank.
S = ml of std. 0.5 N ferrous ammonium sulphate required for soil sample.
N = Normality of std. ferrous ammonium sulphate (0.5N).

Soil pH was determined using a pH meter; with the electrode immersed in standard pH buffer, the potentiometer was set to pH 7.00 of the first buffer solution. The electrode was rinsed, and the calibration repeated using a second pH buffer. The electrode was rinsed and immersed in 1 to 20 ml of the soil sample solution (contained in a 50 ml plastic beaker along with micro-size, Teflon-coated magnetic stirring bar), and the automatic titration operation was initiated using the full titration display curve mode. The initial potential recorded on the strip chart gave the sample pH.

The volumes of titrant delivered to produce the inflection points for $CO_3^{2-}$ and $HCO_3^-$ were also obtained from the titration curve (pH vs. volume of standard acid delivered from automatic burette) as:

**$CO_3^{2-}$ in meq/liter = 2*PN* 1,000/aliquot**

Where:

P; the number of millimeters of standard HCl of normality N to reach the $CO_3^{2-}$ inflection point (pH = 8.3), and aliquot will be the sample volume in millimeters.
$HCO_3^-$ in meq/litre = (T - 2P) N 1,000/aliquot

Where:

T; the number of millimeters of standard HCl of normality N to reach the $HCO_3^-$ inflection point (pH = 4.5), P; the number of millimeters of standard HCl required to reach the $CO_3^{2-}$ inflection point, and aliquot will be the sample volume in millimeters.

The blank was determined using $CO_3^{2-}$ free distilled water.

Soil nitrogen content as determined using the modified [46]). Potassium and Magnesium were determined using the Atomic spectrometer. For Pineapple nutrient determination, fresh pineapple was chopped into small pieces and blended together with 50ml of distilled water. The pulp obtained was strained through a muciline cloth and the extract obtained was made to 100 ml by adding distilled water in a volumetric flask. All subsequent laboratory determinations were carried out in triplicate. The PH was determined by dipping a PH meter in samples of the extract thrice and the average of the value read was taken to be the PH of the sample. 20ml aliquots of the solution were titrated against 0.005M iodine solution, using starch indicator, until a dark blue-black color persists. Total Dissolved Solutes (TDS) was determined using a pre-calibrated TDS meter and for each sample, the reading was taken thrice, after which the average of the obtained values was considered the TDS of the sample. Dietary fiber was determined gravimetrically, whereby digestible carbohydrates in a known mass of fresh pineapple pulp, lipids, and proteins were selectively solubilized by chemicals. The non-solubilized and/or nondigested materials were then collected by filtration, and the fiber residue is recovered, dried, and weighed. For the Total Titrable Acid, three 20ml samples of the pineapple juice extract were transferred into a 100ml beaker and 50mls of distilled water was added to each. Each sample was titrated against 0.1M Sodium Hydroxide solution, with a PH meter dipped in the mixture, until a PH of 8.2 is obtained. This is the endpoint. Titrable acid was then calculated as:

**% acid** = *[mls NaOH used] x [0.1 N NaOH] x [milliequivalent factor] x [100] grams of sample*

Composition of selected minerals; N, P, K, Mg, Ca and Fe, in fresh pineapple was determined by atomic absorption spectrometry (AAS) using flame atomic absorption spectroscopy (FAAS). This system was equipped with a hollow monoelement cathode lamp (Hollow Cathode Lamp, England) for each element analyzed. An air-acetylene flame was used with a ratio ranging from 3.0 kg $cm^{-2}$ to 1.2 kg $cm^{-2}$ and from 0.7 kg $cm^{-2}$ to 1.2 kg $cm^{-2}$ for air and acetylene respectively.

For pineapple dry pulp production, Pineapples for the experiment were collected in equal amounts from the 3 study sites (52 per site); 156 fruits altogether, washed with soap, peeled, sliced into smaller pieces and blended. The juice was then filtered out of the pulp using a muciline cloth. Sub- samples of the cleaned pulp were then soaked in varying concentrations of food – grade calcium hydroxide for 15 minutes, followed by 15 minutes soaking in water, to modify the pH of the pulp. 1000 g of the pulp was soaked in 2000 ml of the $Ca(OH)_2$ solution to reduce the stickiness due to the sugars. All determinations were carried out in triplicate. The concentration of the solution was varied from 0.01 M - 0.1 M to obtain a desired close to neutral pH. The pulp samples were then air dried by spreading the pulp out on a tray and exposing it to a constant air current generated by 2 electric fans, at 25 degrees Celsius for over 5 hours after which the dry pineapple pulp was hammer-milled into the final product (dry pineapple pulp) and measured.

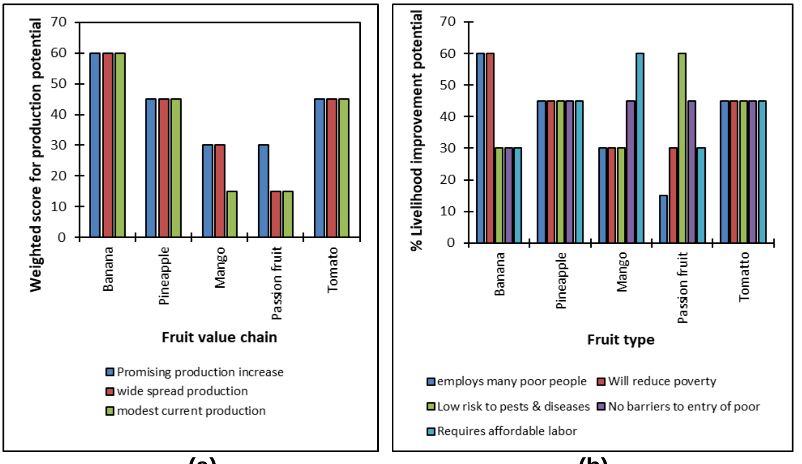
## 2.3 Data Analysis

Transcripts of interviews and text record from participant observation were analyzed using content analysis, where all the qualitative data collected was categorized into themes, subcategories created and coded, and finally inferences derived based on the codes/themes.

For the quantitative data, the mean values of various parameters investigated during the study were compared among the study sites and among the different stages of the value chain using One way Analysis of Variance (ANOVA), followed by a posthoc comparison test for those mean comparisons that had been found to be significant at $p < .05$ level, employing statistical package for social scientists (SPSS) software, utilizing SPSS software version 10, to asses for significance in their differences. The parameters whose means were compared included; pineapple production among the different site, pineapple sale prices among the different sites, chemical composition of fresh pineapples among different sites, postharvest loss levels among chain actors, amounts of dry pulp produced from pineapples from different sites. A Pearsons's rank correlation r was obtained to investigate the relationship between pineapple production and mean monthly sales.

## 3. RESULTS

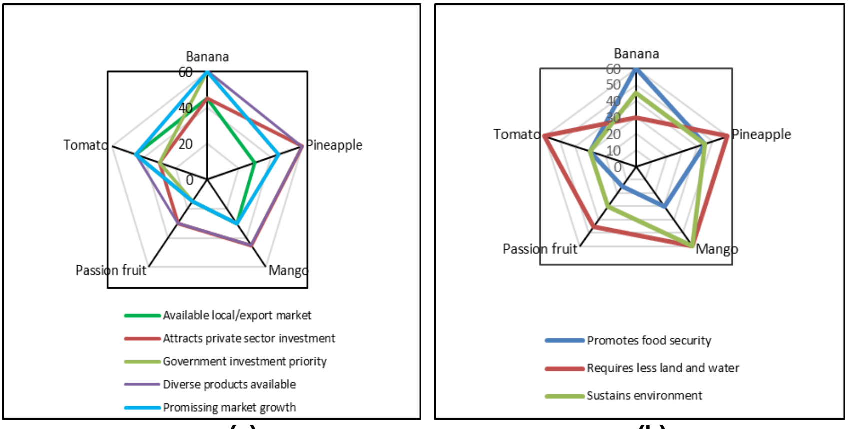
**Ranking of the pineapple fruit value chain among other fruit chains for improvement in postharvest handling:** Considering production potential, quantities produced and coverage, pineapple were found to rank second to banana in the rating of the existing value chains. Banana was being replaced by pineapple due to the banana bacterial wilt that is currently affecting bananas (Fig. 2a). On assessing how the engagement of poor people in South Western Uganda into one of the five selected fruit value chains would contribute to improving their livelihood, the study revealed that since banana growing was labor intensive, it had the highest potential for employing many poor people (60%), regardless of whose farm they would be working on. This was followed by pineapple and tomato (47%), which also in addition, both had a greater resilience to risk in terms of diseases and price fluctuation, having the least barrier to entry of poor people into the chain, in terms of capital and knowledge required, plus being much less costly than banana with regard to using hired labor (Fig. 2b).




**(a)** **(b)**

**Fig. 2. Ranking production potential (a) and potential of selected fruit value chains to improve livelihoods (b) in SW Uganda**

Much as the market for pineapples and mangoes was also appreciably available, the market potential of each of the five fruits in South western Uganda, revealed bananas and tomatoes to have the most readily available local market (weighted score 60). However, the private sector had mostly invested in pineapple and it was most considered viable for diversification into various products; dried fruit, pulp and juices (Fig. 3 (a). An assessment of the five fruit types for their contribution to food security and environmental sustainability showed that bananas, pineapple makes an appreciable contribution, though a little lower than bananas. Unlike bananas though, for pineapples, mangoes and tomatoes, less land and water for expanding investment in the value chains was required, while mangoes being trees by nature, made the greatest contribution to environmental sustainability (Fig. 3(b).




(a) (b)

**Fig. 3. Comparison of market potentials and ranking of climate resilience of selected fruits in SW Uganda**

Other than mangoes and passion fruits, all the other three fruit value chains including pineapple widely employed women and children, in addition to the widespread utilization of indigenous farming knowledge, mainly during fruit production, storage and transportation (Fig. 4). Therefore, pineapple contributes to fulfilling the current development agenda in Uganda, gender inclusiveness, utilization of appropriate indigenous knowledge through Agricultural Advisory Services.

**The structure of the pineapple value chain in South Western Uganda:** The pineapple value chain in SW Uganda was composed of a sequential arrangement of chain actors, receiving and passing on pineapples and pineapple products to the next actor in line, most of the times with very little value added. It begun with pineapple farmers (63%) that form the majority while processors were the least (3%) as depicted in a value chain map (Fig. 5). All these chain actors reported that their primary motivation and goal for engaging in the pineapple value chain was to earn income to be used in improvement of their livelihood. Along with the farmers are the pineapple value chain input dealers who supply most planting materials and farm implements to the farmers. The pineapple farmers prepare land for planting, plant, weed and care for the plants until harvest. They also harvest the mature fruits. The chain also contains a collector (middleman), who usually buys produce from various farmers, bulks it and sells to the wholesale market at a profit. Along the chain, fresh pineapple fruit was the major form in which pineapple was handled, save for a few other products; juice, wine, herbal drinks and solar dried snacks. The transport medium within the local communities was largely bicycle; large trucks were used to transport produce to the larger markets to the main cities. In South Western Uganda, there were only a few processors; some carrying out small scale solar drying of pineapple to make snacks for export, others doing juice extraction and most use the pineapples to manufacture herbal drinks. Only a few processors have been able to establish large scale wineries that also utilize the pineapples.

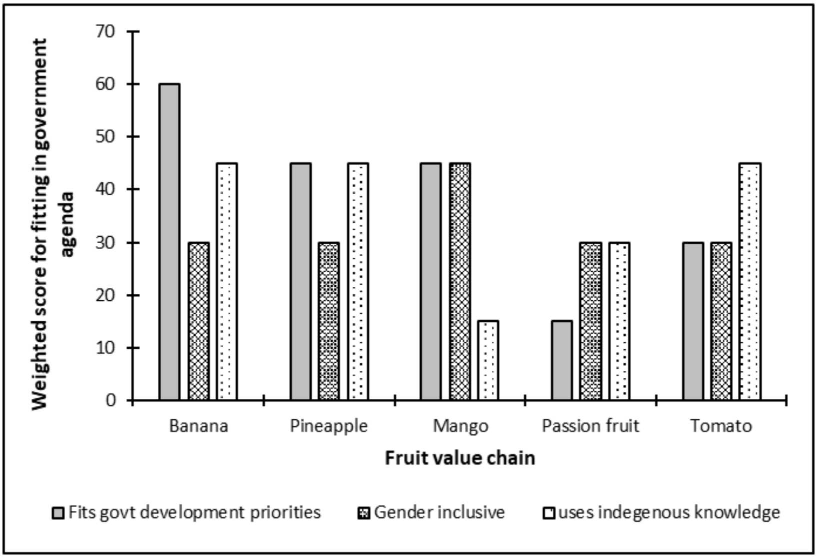



**Fig. 4. Ranking of selected fruit chains in SW Uganda to fit into current development agenda**

**Production and Sales' trends along the pineapple value chain in SW Uganda:** For all the three study areas, mean monthly pineapple production varied according to the same trend and was characterized by two production peaks; the highest occurring in the months October to November and the second in the period March to May. The lowest production occurred in April and again in January (Fig. 6a). The peak production periods were observed to match with the peak rainy season, while the off-peak production season matched the dry season. Among the three study locations, Ntungamo had the highest mean monthly pineapple production (15,516 fruits/Ha), while Isingiro had the lowest (14,622. fruits/Ha). From all the three pineapple production locations, the sales were highest in the period July-September and January –February a period that corresponds to the dry season and off-peak pineapple production. The lowest mean monthly sale price per fruit was in the period March-May and October-December a period that corresponds to the rain season, which is also the peak pineapple production period in this region, (Fig. 6b). Comparing mean pineapple sales prices using one-way ANOVA indicated that the sales prices did not differ significantly across the three study sites, at p at 0.05% level of significance; [F (27) = 0.239, p =0.79].

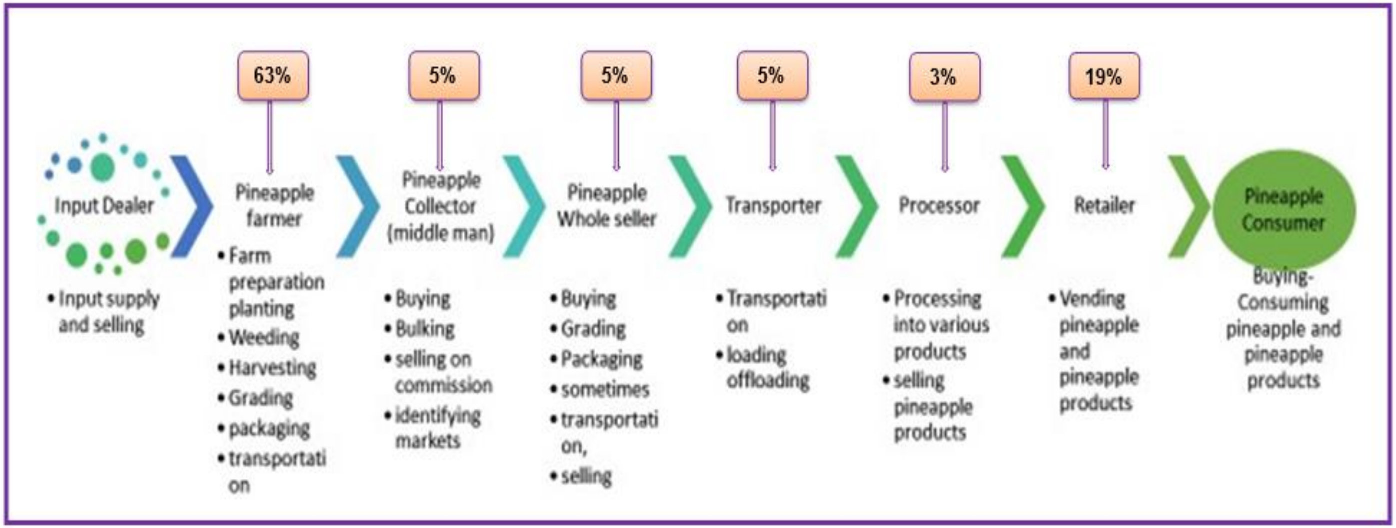



**Fig. 5. Value chain map for Pineapple value chain in SW Uganda**

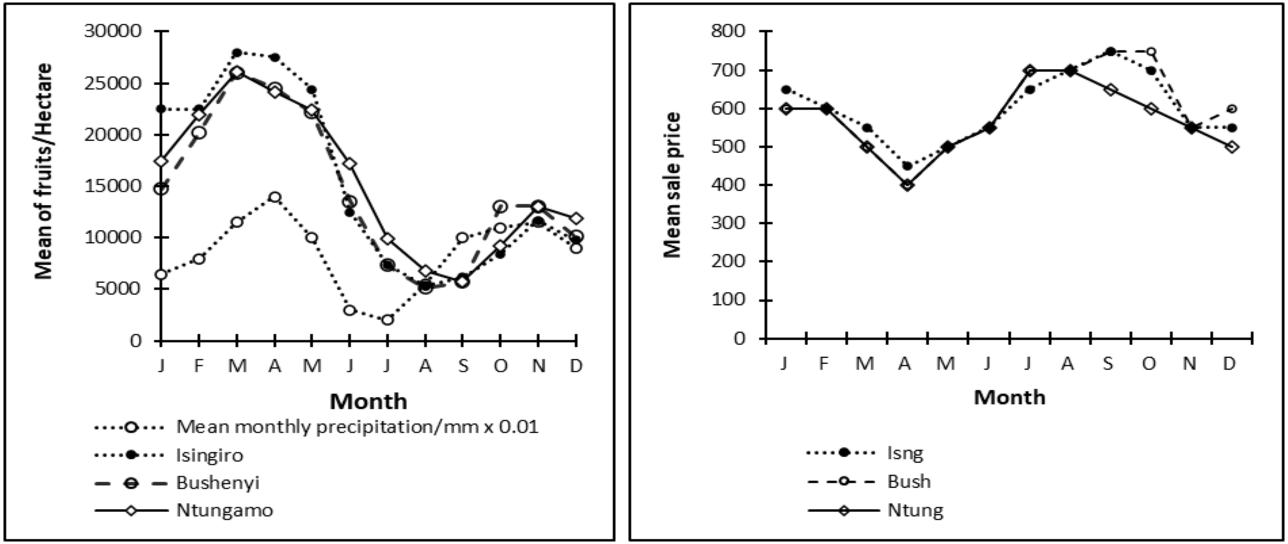



**Fig. 6. Mean monthly pineapple production in SW Uganda**

Post-harvest loss hot spots along the pineapple value chain in SW Uganda: More intensive advisory and extension agricultural services in the fruit sector has been mainly in the production effort (Fig. 7) that has greatly increased production as seen in Fig. 6. During the peak season, a lot of postharvest losses are incurred due to lack of value addition and enhancing shelf-life avenues. From this study, it was observed that post-harvest losses along the pineapple value chain in SW Uganda occurs in two forms; 1) Qualitative post-harvest losses which arise from reduction in the intended price of the produce, due to deterioration in the physical quality of the fruits, as a result of improper post-harvest handling expressed in change of color, smell, test and aesthetic appeal of the fruit (the foregone economic benefits of the chain actor) and 2) the quantitative post-harvest losses-which arise due to discarding of produce initially intended for sale but has undergone spoilage to the point that it is currently in an inedible state (expressed itself as rotten fruits). The mean post-harvest loss presented here as an arithmetic summation of the qualitative and the quantitative losses incurred by the chain actors at each pineapple value chain stage indicated that about 19.86% of all the produce handled at the different stages is lost before reaching the final consumer. Of this mean post-harvest loss, 14.68% arises from qualitative losses as a result of improper post-harvest handling while the quantitative losses were at 5.2%. Qualitative loss therefore contributed significantly much more to the observed post-harvest loss in pineapples as compared to the quantitative losses ($p=.0034$). One-way Analysis of variance test revealed that there was a significant difference in mean postharvest losses among the three sites at 0.05% level of significance: [$F(9) = 1240.9$, $p = .00$]. From the study, it was also discovered that along this value chain, damage to fresh pineapples was due to improper post-harvest handling that led to the observed post-harvest losses. A comparison of mean post-harvest loss levels among the various, actors along the pineapple value chain in SW Uganda revealed that regardless of the value chain stage, post-harvest losses were highest in Ntungamo. Throughout all the three pineapple production locations of SW Uganda, on average, transporters incurred the highest post-harvest losses (23.03%) while consumers incurred the least post-harvest losses (1.43%) (Fig. 8). A comparison of mean postharvest losses among pineapple value chain actors using One-way- ANOVA revealed that there was no significant difference in postharvest loses between whole sellers and all other chain actors at 0.05% level of significance [$F(77) =1.09$, $p = 0.372$].

**Table 1. Comparison of chemical composition of pineapples from different production locations in SW Uganda**

| Parameter | Location | | | |
|---|---|---|---|---|
| | **Ntungamo** | **Bushenyi** | **Isingiro** | **p-value** |
| Vitc/ppm | 1.41±0.03 | 0.72±0.04 | 2.73±0.04 | 0.000 |
| TDS/ppm | 261.22±0.42 | 272.50±0.70 | 291.7±1.05 | 0.000 |
| %Fibre | 2.03±0.09 | 3.82±0.07 | 6.29±0.16 | 0.000 |
| TTA/ppm | 3.59±0.07 | 5.42±0.18 | 7.14±0.29 | 0.000 |
| pH | 3.97±0.21 | 3.92±0.18 | 3.91±0.13 | 0.973 |

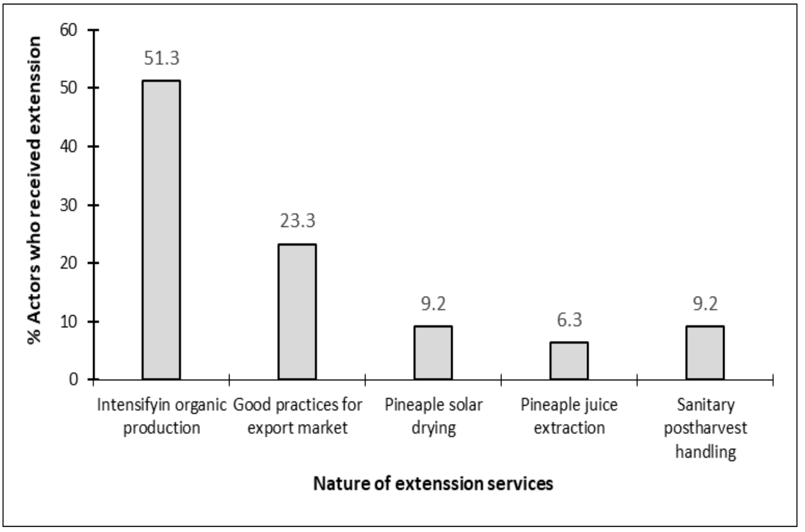



**Fig. 7. Extension support rendered to pineapple value chain in SW Uganda**

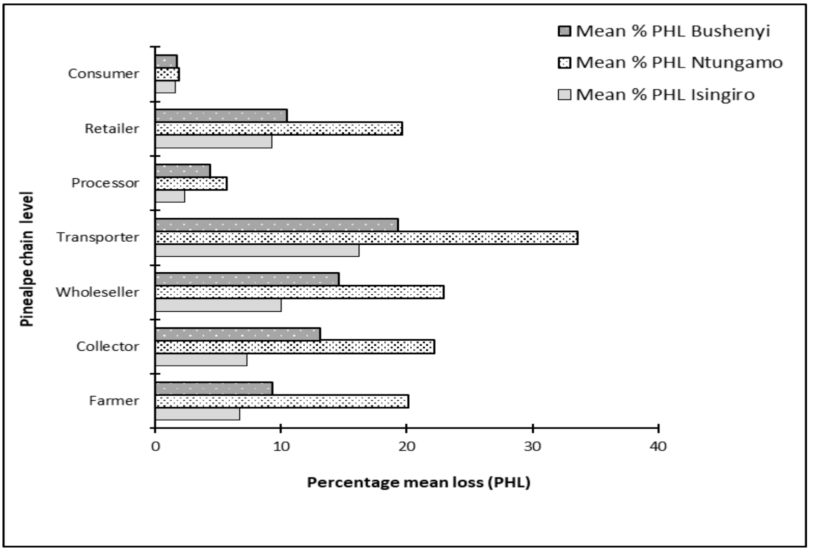



**Fig. 8. Mean percentage post-harvest loss levels at the different stages of the pineapple value chain in SW Uganda**

**Selected physico-chemical properties of pineapples from the three pineapples and how they relate to soil parameters:** The physical chemical properties investigated included vitamin C, Total dissolved solutes, fiber, total

Titrable acids, pH and pulp production. The mean Vitamin C content was found to be highest in fresh pineapple fruits produced in Isingiro (0.87 ppm) and lowest among those from Ntungamo. Total dissolved solutes were found to be highest in fresh pineapples produced in Isingiro (293.3 ppm) and lowest among those produced in Ntungamo (260.0 ppm), while percentage fiber content is highest in fresh pineapple fruits produced in Isingiro and lowest in fruits produced in Ntungamo. Fresh pineapple fruits produced in Isingiro were found to contain the highest amount of Titrable acid (7.8 ppm), while those produced in Ntungamo contained the least amount (3.6 ppm). Pineapple fruits produced in Ntungamo had the highest pH (mean = 4.06), while those produced in Isingiro had the lowest pH (mean = 3.8) – (Table 1). The study revealed that the fresh pineapple fruits produced in Ntungamo contained the highest percentage of Calcium, Iron and Zinc, those produced in Bushenyi contained the highest percentage of Nitrogen, Potassium and Magnesium while those produced from Isingiro contained the least amounts of most elements, apart from Phosphorous, for which it had the highest percentage content. A comparison of mean chemical content for N, P, K, Ca, Mg, Fe and Zn using a paired one-way ANOVA revealed that there was no significant difference in the mean concentration of these minerals in fresh pineapples across all the sites [$F$ (17) = 257.31, $p$ = 0.31] (Table 2). However, comparing mean amounts of pulp produced per 100g of fresh pineapple revealed that amount of pulp produced was significantly different across the study site, [$F$ = (2,18) = 1131.89, $p$ = 0]. Pineapple produced from Ntungamo gave the least amount of dry pulp (mean: 226.15g/1000g of fresh fruit, compare to 408.84g/1000g and 510.4g per 10000g in Bushenyi and Isingiro respectively. A posthoc comparison test further indicated that the mean quantity of pulp produced per 100g of fresh pineapple was significantly different across the sites.

Soil texture analysis on soil samples obtained from the three pineapple producing locations of South Western Uganda revealed that all locations generally had a sandy clay loam texture, save for slight variations in composition, whereby Isingiro had the highest amount of sand and Ntungamo the least, Bushenyi had the highest amount of clay, while Ntungamo showed the highest amount of silt as well, as Bushenyi contained the least amount. Soil management on the pineapple farms in Ntungamo included a common farming practice of mulching and application of green manure once in a while. The farms in Bushenyi followed fairly employed these two practices in their soil management but were rarely applied in Isingiro. There was however no application of inorganic fertilizers to the soil. It was also noted that pineapple farms in Ntungamo remain productive over an average of 13 years, those in Bushenyi for an average of 8.5 while the pineapple farms in Isingiro remained viable over the shortest period of an average of 4 years. This had an implication over the physical chemical parameters for instance analysis of selected chemical constituents in soil samples obtained from the three-pineapple producing location of SW Uganda indicated that soils from Ntungamo contained the highest amounts of Organic matter, Soil Nitrogen and Phosphorous, followed by Bushenyi and the least amounts of all these constituents were found in soils obtained from Isingiro. These may be as a result of the differences in the production management practices. On the other hand, parameters dependent on weathering of parent material such as Calcium, Magnesium and Potassium were highest in Isingiro and least in Ntungamo. A comparison of mean composition of the selected soil components through a one-way analysis of variance revealed they all varied significantly across the study sites, at 0.05% level of significance (Table 2).

**Table 2. Mean ± Standard error values of soil chemical composition on pineapple farms in SW Uganda**

| Soil Parameter | Location | | | |
|---|---|---|---|---|
| | **Isingiro (n=10)** | **Bushenyi (n=10)** | **Ntungamo (n=10)** | **p-value** |
| Organic matter | 7.05±0.04 | 2.50±0.01 | 16.60±0.06 | 0.000 |
| Nitrogen | 0.32±0.00 | 0.54±0.01 | 0.70±0.01 | 0.000 |
| Phosphorous | 4.53±0.02 | 9.92±0.01 | 13.43±0.04 | 0.000 |
| Calcium | 398.54±0.18 | 0.02±0.00 | 143.80±0.05 | 0.000 |
| Magnesium | 158.10±0.09 | 0.03±0.01 | 64.76±0.06 | 0.000 |
| Potassium | 25.29±0.13 | 0.02±0.00 | 21.47±0.03 | 0.000 |

Could the selected pineapple nutrients be explained by the physical chemical properties of soil? A Pearson's correlation test between soil composition and nutrient content of pineapples from the various sites revealed that pH of the fresh pineapple had no significant correlation with any of the soil parameters investigated. Vitamin C however had a significant correlation with soil Nitrogen (P = 0.02), TDS was significantly correlated with Magnesium (P=0.01), while Fibre had a significant correlation with; soil organic matter (P= 0.04), Calcium (P= 0.01) and Magnesium (P= 0.02). The Total Titrable Acid (TTA) had a significant correlation with soil organic matter (P= 0.02) and Calcium (p= 0.03) (Table 3).

**Pineapple utilization and value addition avenues for SW Uganda:** This study revealed that there was very limited ongoing pineapple processing in the whole region, hence along the value chain, pineapple is mainly handled and transferred from one stage of the chain to the next in form of fresh pineapple fruit. Pineapples from Isingiro were the most preferred by consumers for slicing and eating because of their very sweet taste. Pineapples produced from Ntungamo, on the other hand, were most preferred by consumers for juice extraction, because of their exceptionally very juicy pulp. Pineapple processing at household scale was only evident in Ntungamo, where a few chain actors were involved in solar drying of pineapples, mainly to supply a hard-to access export market through a bigger agro-exporter located in Kampala. Attempts to set up a juice extraction factory were still underway at this study site. A winery had however been set up in Bushenyi and in Isingiro, two factories extracting pineapple juice for use in manufacture of herbal drinks were present. There are quite a number of potential value addition avenues associated to pineapples as a way of minimizing post-harvest losses especially during the periods of peak production as justified in Table 4.

## Table 3. Correlation matrix for soil composition and nutrient content of pineapples

| | | %Nutrient Composition | | | | | Soil parameters mg/Kg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| % | | **TDS** | **Fibre** | **TTA** | **PH** | **Organic matter** | **Nitrogen** | **Phosphorous** | **Calcium** | **Magnesium** | **Potassium** |
| Vitc | Correlation | .746** | .711** | .617* | -.063 | .142 | -.656* | -.741** | .996** | .994** | .837** |
| | p-value | .005 | .010 | .033 | .847 | .659 | .021 | .006 | .000 | .000 | .001 |
| TDS | Correlation | | .981** | .963** | -.069 | -.541 | -.980** | -.993** | .735** | .697* | .273 |
| | p-value | | .000 | .000 | .830 | .070 | .000 | .000 | .006 | .012 | .391 |
| Fibre | Correlation | | | .962** | -.124 | -.587* | -.992** | -.994** | .696* | .656* | .220 |
| | p-value | | | .000 | .701 | .045 | .000 | .000 | .012 | .021 | .492 |
| TTA | Correlation | | | | -.053 | -.655* | -.975** | -.958** | .601* | .557 | .113 |
| | p-value | | | | .871 | .021 | .000 | .000 | .039 | .060 | .728 |
| PH | Correlation | | | | | .069 | .106 | .075 | -.022 | -.017 | .013 |
| | p-value | | | | | .831 | .743 | .817 | .945 | .957 | .967 |
| Organic matter | Correlation | | | | | | .642* | .555 | .162 | .217 | .657* |
| | p-value | | | | | | .024 | .061 | .615 | .498 | .020 |
| Nitrogen | Correlation | | | | | | | .988** | -.645* | -.601* | -.151 |
| | p-value | | | | | | | .000 | .024 | .039 | .640 |
| Phosphorous | Correlation | | | | | | | | -.730** | -.691* | -.261 |
| | p-value | | | | | | | | .007 | .013 | .412 |
| Calcium | Correlation | | | | | | | | | .998** | .850** |
| | p-value | | | | | | | | | .000 | .000 |
| Magnesium | Correlation | | | | | | | | | | .878** |
| | p-value | | | | | | | | | | .000 |

***. Correlation is significant at the 0.01 level (2-tailed).*
**. Correlation is significant at the 0.05 level (2-tailed).*

## Table 4. Pineapple value addition initiatives in SW Uganda

| Location | Pineapple method of preparation | Value addition avenue | Scale of actor involved | Attribute for value addition |
|---|---|---|---|---|
| **Ntungamo** | Slicing pulp | Solar dried Pineapple for export | • Small chain actor group<br>• Individual actors<br>• Cottage industry | ▪ Fast drying due to low total dissolved solids<br>▪ Enough solar energy<br>▪ Affordable solar dryers<br>▪ Excellent source of vitamin calcium, iron and zinc |
| | Juice extraction | Juice for packaging | Innovation platform (Industrial scale still under construction) | ▪ High moisture content<br>▪ Excellent source of vitamin C, calcium, iron and zinc<br>▪ Low Ph<br>▪ Low titrable acids<br>▪ Increased chain actor cohesion |
| | | "Munanansi" (juice from pulp) | • Individual actors<br>• Cottage industry | ▪ High moisture content<br>▪ Low pH<br>▪ Excellent source of vitamin C<br>▪ Low titrable acids<br>▪ High calcium, iron and zinc content |
| **Bushenyi** | Juice extraction | Wine production | Factory proprietor (Industrial scale) | ▪ High moisture content<br>▪ Moderate pH<br>▪ Moderate titrable acids<br>▪ Increased chain actor cohesion |
| | | Pulp production | None | ▪ Moderate amounts of digestible fiber<br>▪ Moderate total dissolved solids<br>▪ Moderate pulp content |
| **Isingiro** | Juice extraction | Juice extraction for herbal drinks | 2 factory proprietors (Industrial scale) | ▪ High moisture content<br>▪ High Ph<br>▪ High titrable acids |

| Location | Pineapple method of preparation | Value addition avenue | Scale of actor involved | Attribute for value addition |
|---|---|---|---|---|
| | | Peels for livestock fodder | Erratic Individual actors | ▪ Excellent source of vitamin C, which plays a crucial role in boosting the immune system<br>▪ Crude protein content<br>▪ High digestible fiber<br>▪ High calcium, magnesium, potassium and phosphorus contents |
| | | Pulp production | None | ▪ High digestible fibre<br>▪ High total solute content<br>▪ High pulp content |

## 4. DISCUSSION

**Ranking of the pineapple fruit value chain among other fruit chains for improvement in postharvest handling:** Among the five most visible fruit value chains in South Western Uganda, the pineapple value chain stood out as one that should be prioritized for promotion and improvement. This chain was non-restrictive to entry of new rural poor, since even with a relatively small land size and a fairly affordable capital, one could easily establish a pineapple farm. The operational requirements of this value chain were typical of those that operate organic agricultural chains in the developing world, as observed by [47], in that they require less financial input and rely more on the available natural and human resources which can be afforded by the many smallholder farmers. Since land, financial capital and labor are well known limiting factors for investment in agricultural value chains [48], the pineapple value chain with such affordable establishment and operational requirements is indeed worth prioritizing for promotion and improvement. Several other studies have shown small scale pineapple production to be a profitable agricultural venture with low, land, financial capital and labor requirements [49]; [50]; [51].

In South Western Uganda, pineapples have been grown at household level for home consumption for a long time [52]. Promoting and improving it would largely be building onto already existing structures of indigenous knowledge which are already contextually fitting and familiar for this setting. Just as was observed by [53], smallholder farmers in Uganda have only begun to look towards pineapple for income generation recently, especially when banana that had strongly been an income generating crop for south western Uganda, was attacked by banana bacterial wilt.

As is the case with many regions of Uganda, over 70% of the population in South Western Uganda depends on agriculture and agricultural related activities for generating the income for survival and livelihood improvement [54]. Pineapples from South Western Uganda were on high demand by both the local and international available market, as they were exported to Rwanda, South Sudan and Kenya. [55] emphasized that the demand for agricultural produce by the available market will always push prices higher, allowing producers to earn much more income from their sale of the produce. This high demand for pineapples and pineapple products is expected to continue and is proof to the fact that if actors continue to participate in the pineapple value chain in South Western Uganda, they would earn appreciable income, enabling them to improve their livelihood standards. In this regard, [53] contends that in Uganda, engagement in the pineapple enterprise gives an opportunity to many, including women, to earn an income and may contribute up to 55% of the household income. As a very rudimentary value chain, along which there was hardly any significant value addition and product diversification, but majorly transfer of the fresh fruits from one stage of the chain to the next, the chain provides an underexploited open window for investment and development of various new pineapple products, based on the existing demand within the available market. In this respect, if Ugandan agricultural value chains are to become more competitive in the environments where they exist, the value of products would have to increase as they are transferred along the chains [56]. Processing the raw produce into various products as demanded by the available market is one major means of adding value to these agricultural chains.

The pineapple value chain in South Western Uganda exhibited high potential for low capital investment in product diversification, through small scale solar drying of the fruit, juice and wine production. There are untapped ventures for innovatively developing valuable products from pineapple and its wastes in Uganda. All these could potentially be up-scaled to benefit more rural value chain actors and harness opportunities more diverse opportunities within the domestic and international consumer market segments. According to [57], for example, the export market for Ugandan dried pineapple has been progressively growing but fruits and vegetable processing in Uganda remains largely underexploited [58]. The Pineapple value chain in SW Uganda was composed of a sequential arrangement of chain actors, receiving and passing on fresh pineapples and some pineapple products most of the times with very little value added. Only a limited number of processors and exporters were involved in the enterprise of pineapple processing [59]. Value addition was thus still a big problem for the farmers to the level that other than a few pineapple chain actors who dry their pineapples using solar, most pineapples were simply sold off in fresh form. There is limited capacity of chain actors to add value made but this notwithstanding, many Ugandans are being motivated to join marketing of pineapples and pineapple products.

**Pineapple production and sales:** The peak of pineapple production season in SW Uganda falls in the period May-June and November, and in this season, pineapple prices are not only very low but sometimes the market for fresh pineapple is saturated and farmers cannot sell the pineapples as noticed in other agricultural areas [60]. [61] explained that lack of assured markets affects production of fruits considerably in Africa and when there is a bumper crop, growers find it difficult to sell their produce [62]. This implies that as is with market dynamics of most fresh fruit produce in rural Uganda, produce scarcity drives prices higher, as prices fall flat during seasons of excess production. [63] further argues that this sale price fluctuation also stems from the fact that along the conventional pineapple value chain in Uganda, processing and adequate preservation technology is hardly available [64]. This low processing capacity predisposes the fresh pineapple-which is highly perishable, to rapid spoilage and eventually, chain actors easily make huge losses [57]. As a way of mitigating against this, during the peak seasons, chain actors are compelled to sell their produce at give-away prices, lest they spoil before they are sold. Seasonality of pineapples, a highly perishable commodity, can be overcome by small scale processing, such as drying and juice extraction [63]. This would as well provide very important leverage for mitigating against the seasonal supply and price fluctuation. Pineapple value chain actors should thus explore value-adding avenues in order to reduce the risks associated with postharvest losses, and also take advantage of better prices during the off-peak season. In the meantime, emphasis should be put on the importance of staggering harvesting seasons, which could be achieved through more deliberate farm planning, in that planting is done in such a manner that different farmers' fields are able to reach maturity at different times during the year.

**Post-harvest loss hot spots along the pineapple value chain:** Inadequate support in building capacities of small-scale agriculturalists is greatly stifling effective utilization of the potential of agriculture, as an enterprise, to improve rural incomes and reduce loses. It is worth noting that in many examples of successful efforts to raise smallholder agricultural productivity, a variety of farmer support services were provided simultaneously [65]. The observation that along the pineapple value chain in South Western Uganda, even where extension services had been provided, most actors along this value chain do not recognize the relevance of extension support in equipping them with skills to add value especially during the bumper harvest [66] to avoid postharvest losses. From this study, qualitative loss contributed significantly much more to the observed mean post-harvest loss in pineapples as compared to the quantitative losses, an implication to handling practices [13]. Several scholars have estimated postharvest loss levels in fresh fruits as 20 to 40% in developing countries depending on the crop and the season [20] [67]; [68]; [69]. However, postharvest losses in developing countries sometimes run even higher because of poor storage and handling technologies [70]. Within similar ranges, this study also revealed that on average, about 19.86% of all fresh pineapple from SW Uganda is lost before reaching the final consumer. Post-harvest losses incurred by pineapple chain actors in Ntungamo were significantly much higher than those incurred by chain actors of the other two pineapple producing locations of SW Uganda probably due to their high moisture content and low acidity. They easily undergo spoilage leading to loss, unlike those from Isingiro which have a low moisture content. [71] gives a related argument stating that the higher acidity in fresh pineapples of Smooth Cayenne implies a longer storage life and a possible higher astringency index. He also points out that this property may be very useful for juice processors as longer shelf life allows sufficient time for handling, processing and selling, an implication that for interventions geared at improving postharvest handling along the pineapple value chain in South Western Uganda. Interventions based upon this observation are most viable for Ntungamo whereby post-harvest handling of pineapples is seemingly at its poorest and value addition at its lowest. Isingiro and Bushenyi, on the other hand, have some emerging small-scale processing that may to a limited extent offset the potential postharvest losses through this product diversification. [59] supports this argument as he states that in most parts of rural Uganda, pineapple processing facilities are unavailable, and this limits capacity to extend the pineapple shelf life.

In many parts of rural East Africa, adequate and appropriate storage of fruits remains a challenge; it is done inadequately or inappropriately, and as a result, the fruit value chain sustains significant losses [72]. Although fresh products are often quickly sold, storage in a suitable environment is needed for fresh produce so as to eliminate deterioration and maximize shelf life. In Uganda, pineapples for example, are mostly stored in shelter shades, baskets, under banana leaves and may sometimes be sprinkled with cold water, [73]; [72]. Along this value chain, damage to fresh pineapples due to improper post-harvest handling led to the observed post-harvest losses, mainly originated from bruising, compression, and dehydration as already documented as the most frequent cause of loose [74]; [13]. The damage exposes the fresh produce to rapid biological deterioration, hence becoming unworthy for consumption. Inadequate postharvest handling therefore may cause injuries on fruits, accelerate ethylene production [75]; [77], causing an increase of the ripening and decay rate. Exposure to high temperature also increases the biological reactions in fruits such as metabolism and respiration [75]. Also, mechanical injury can lead to post-harvest decay by microorganisms in many cases [76]. Furthermore, some of the consequences of physical damage are internal quality loss with flavor and nutritional changes [78]. For some fruits also, loss of acid content caused by mechanical impact [78]; [79]; [80]; [81]) predisposes the fresh fruits to faster bio-deterioration. Among all stages of the pineapple chain in SW Uganda, bicycle transportation of fresh pineapples stood out as a postharvest loss hotspot. This mainly occurred when the overloaded bicycles lost balance and fell, as pineapples were being transported over long poor condition roads to the markets. This implies that much as use of bicycles is the most readily available means of transporting fresh pineapples in South Western Uganda, it is not the most appropriate, as most markets are located far, and the heavily overloaded bicycles are unstable over the poor rural roads. This increases damage to the fresh fruits by bruising and compression.

**Pineapple nutrient properties as influenced by soil physical chemical parameters:** All pineapple producing locations in South Western Uganda generally had a sandy clay loam texture, save for slight variations in composition. Isingiro had the highest amount of sand and Ntungamo the least, Bushenyi the highest amount of clay, while Ntungamo showed the highest amount of silt as well. This implies that the water holding, drainage and aeration capacities of soils in pineapple producing areas in Uganda, are largely the same, and the few observed differences are probably as a result of using different soil management practices.

This study revealed that Vitamin C content was highest in fresh pineapple fruits produced in Isingiro (0.87 ppm) and lowest among those from Ntungamo, a variation that may point to various reasons including differences in climatic and pre/post-harvest management factors; precipitation, irradiation and soil Nitrogen, all of which influence vitamin C levels in fruits. The influence of these climatic variations on pineapple chemical composition was however probably very minimal, since climatic conditions, in the same way, did not vary significantly across the region. The lower vitamin C content in pineapples from Ntungamo could also be due to a higher Nitrogen content in soil, as compared to that in soils of Isingiro, owing to the fact that amount of Nitrogen in the soil has been found to have a significant correlation with vitamin C content in fruits grown in such soils ($P=0.02$). Reduced levels of vitamin C in juices of oranges, lemons, grapefruits, and mandarins resulted from the application of high levels of nitrogen fertilizer to those crops [82].

Similarly, the amount of Total dissolved solids (TDS) was highest in fresh pineapples produced in Isingiro (293.3 ppm) and lowest among those produced in Ntungamo. According to Village Square The higher the TDS score, the more ingredients and less water contained in the fruit. Since Total dissolved solids assesses the actual amount of ingredients versus the amount of water in the fruit, pineapples from Isingiro contained less water and more sugars and other soluble ingredients, as compared to pineapples from Ntungamo, which contained comparably more water, and less soluble ingredients. TDS is a measure of the percent solids (Total Soluble Solids) in a given weight of plant juice. It is actually a summation of the amount of sucrose, fructose, vitamins, minerals, amino acids, proteins, hormones, and other solids in one hundred pounds of any particular plant juice [83]. During the development of the flesh of a fruit, in many species, nutrients are deposited as starch, which during the ripening process is transformed into sugars. Soluble solids are therefore also known to impact sweetness index in fresh fruits, much more than does the total sugars [27]. The soluble solids content is thus sometimes used as an indication of fruit maturity and quality [84] for pineapples and may influence taste flavor, nutritional status, and postharvest storage potential of fresh produce [85]. Since TDS has direct positive influence on sweetness of pineapple [86], it could explain the superior sweetness and appealing flavor of pineapples from Isingiro than those from Ntungamo.

Pineapple being an acidic fruit, the pH was generally less than 7. The two major organic acids in pineapple are citric and malic acids [87]. From this study however, fresh pineapple fruits produced in Ntungamo had the highest pH (mean = 4.06), while those produced in Isingiro had the lowest pH. This showed that pineapples from Isingiro were more acidic than those from Ntungamo. Since Titrable acid is also used as an indicator for the amount of acid in the fruit, as well as the shelf life of the fresh fruit, fresh pineapples from Isingiro are expected take a longer time before getting spoilt- have longer shelf life, as compared to those from Ntungamo with a lower amount of Titrable acid, due to having a higher acid content. This observation agrees with [71], who argue that the higher acidity in fresh pineapples of Smooth Cayenne implies a longer storage life and a possible higher astringency index. The pH values also reflect a significant extent to the microbial stability of the various fruits. More acidic fruits are more stable to microbial activity and would thus take a longer time to get spoilt- have a longer shelf life. This factor is important for processors and fresh fruit sellers in determining how long the fruit will remain viable for the available market. [88] explain that fruit pH value as a measure of the acidity or alkalinity of a product, can be used primarily to estimate consumption quality in pineapples. Since pineapple along this value chain was handled for a long time as unprocessed fresh fruit before being sold off, the fruits from Isingiro were better suited for transportation to distant markets because their low moisture and high acidity content makes them last longer before getting spoilt. The fruits from Ntungamo were better suited for transportation to nearer markets, as they are expected to get spoilt faster.

Fiber content was also found highest in fresh pineapple fruits produced in Isingiro and lowest in pineapple fruits produced in Ntungamo. Differences in fiber content of fresh pineapples can be attributed to differences in cultivars and growing conditions [89]. Regarding South Western Uganda, Smooth Cayenne is more or less the only pineapple cultivar being grown, and thus the observed difference in fiber content in pineapples from Isingiro and Ntungamo is most probably due to differences in the pineapple growing conditions in the two different locations.

From this study, Vitamin C, TDS and Fibre had a significant correlation with soil Nitrogen, Magnesium and soil organic matter respectively, while Total Titrable Acid (TTA) had a significant correlation with soil organic matter and Calcium. Various other scholars have explained such relationships as key in understanding how soil chemical composition influences fruit development. According to [90], Nitrogen is one of the most important elements influencing fruit mass and quality in relation to each other and in relation to climate. Although, it is not always possible to distinguish between the specific effect of Nitrogen alone on fruit quality and its general effect on overall plant growth and health, an increase in Nitrogen increases the diameters of the core and the peduncle and the length of the peduncle in pineapples. High levels of Nitrogen in soil also results in a reduction in free acids ([91]; [90]), but may or may not reduce fruit total soluble solids (TSS). Total Dissolved Solids decreases with increasing Nitrogen when Potassium was optimum but had no effect when Potassium was suboptimum. Increasing Magnesium supply on Magnesium-deficient sites on the other hand, tends to increase the quality of agricultural crops, particularly when the formation of quality traits is dependent on Magnesium-driven photosynthesis within the plant. In fruits, ratios of Magnesium to other nutrients like Calcium and Potassium were shown to be a more reliable indicator of the quality response than the Magnesium status alone [92].

Pineapples from Isingiro have a greater potential of being utilized in product development that focuses on enriching human diet with dietary fiber. [79]) explain that about 76% of pineapple byproduct (peel and heart) is fiber, from which 99.2% is the insoluble fraction and 0.8% is the soluble fraction. As pineapple pomace contains valuable sources of dietary fiber, they could be used as a potential food ingredient to improve nutritional quality of foods. [93] further explains that fibers have technological properties, such as water holding capacity (WHC), swelling capacity (SWC) and oil holding capacity, which can be useful in products that require hydration, to avoid syneresis, improve yield, stabilize high fat food products and emulsions, and also to modify texture and viscosity. It is also well-known that dietary fiber plays an important role in human health, promoting several physiological and metabolic positive effects [94]. The insoluble dietary fiber acts as a bulking agent, normalizing intestinal motility, preventing constipation while soluble fiber is associated to decreasing the intestinal absorption of cholesterol and glucose [95]. Due to all of these benefits of dietary fiber intake, a tendency in the development of products enriched with fiber or with specific fiber claims has already been observed for some time. Fresh pineapples are also renowned sources of both vitamins and a variety of minerals for human dietary requirements [32]. These results also indicate that when deciding on pineapples to use for mineral enrichment of human diet, pineapples from Ntungamo would be best suited for enrichment of food with Calcium, Iron and Zinc, pineapples from Bushenyi would provide a good source for Nitrogen, Potassium and Magnesium, while those produced in Isingiro would be most useful for enriching food with Phosphorous. [96] explain that the composition of minerals in fresh fruits may vary due to differences in climatic conditions and nature of soils where they were grown, as well as maturity levels of the fruits.

Soils from Ntungamo pineapple farms contained the highest amounts of Organic matter, Soil Nitrogen and Phosphorous, indicating that the soils are much more fertile than those from any other pineapple growing area in the same region. These three soil properties are key indicators of fertility, as highlighted by [43], who also observed that high levels of soil organic matter often related to high rates of input of organic materials into the soil through decomposition and mineralization of plant residues compared to just natural conditions [96]. These high levels of organic matter and soil Nitrogen are also indicative of regular use of plant materials as mulch, a common practice in Ntungamo, unlike Bushenyi and Isingiro. The observation that soils from Isingiro contained the highest amounts of Calcium, Magnesium and Potassium points to low rates of replenishing organic matter into the soil as well as high erosive activity, due to the ground being left bare, yet with continued heavy utilization. This explains why the farms cannot even stay productive for more than five years. Thus, if no alternative sources of organic matter are found, perennial crop yields will inevitably continue to fail after a few years, leading towards a potentially unsustainable pineapple production system.

**Pineapple utilization and value addition avenues:** According to findings from this study, fresh pineapples from Isingiro were the most preferred by consumers for slicing and eating because of their very sweet taste, while pineapples produced from Ntungamo, were most preferred by consumers for juice extraction, because of their exceptionally very juicy pulp. This observation is very important with regard to the value addition potential of pineapples in South western Uganda. The observation that the sweeter pineapples from Isingiro are more preferred by consumers for eating also points to the fact that they should be having a much superior flavor, than others that are perceived as less sweet. According to [97], interpreting the effect of pineapple flavor intensity and sweetness is a little more complicated because of the interaction among taste factors (sweetness and sourness) and between taste factors and aroma factors. He further explains that because sweetness and sourness are so important in driving acceptability, it is important to understand some of the factors involved in judging sweetness and sourness, one of them being sweetness suppression by acid, much as this effect is often found to be small [98], or only present at very high acid levels [99] an implication of the likability of fresh pineapple from Isingiro. The preferred high juice content in pineapples produced in Ntungamo are an indication of high-water content in these fruits. However, this makes them very susceptible to post-harvest deterioration and would thus require faster processing into preserved packaged juice with a longer shelf life other than the boiled pineapple juice (Munanasi). Moisture content is used to screen the postharvest quality of fruits since is the tendency for the fruit to deteriorate at a faster rate is when it has high moisture content due to the high-water activity that supports the thriving of microorganisms [81]. There was also no significant difference in the moisture content of the final dry pineapple pulp from the different production sites. Pulp from pineapples produced in Ntungamo however dried slightly faster than that from all the other two sites. The lower total solute content in pineapples produced from Ntungamo may be the reason for this variation in drying time of the pulp and the more reason why actors are into dried pineapple snacks. The air-drying method used in this study is however recommended since the pineapple pulp can retain most nutrients like Ascorbic acid that are required for consumption and food fortification process in industry that would otherwise be destroyed by heat. Pineapple pulp also contains high dietary fiber of about 23 % and 48 % of acid and neutral detergent fiber respectively that are important in the dietary fortification industry. With the highest fiber and pulp content, pineapples produced from Isingiro are recommended for this investment to diversify value addition and increase pineapple demand for better incomes [100].

## 5. CONCLUSION

The pineapple value chain stands out as one that should be prioritized for promotion and improvement because it is non- restrictive to entry of rural poor and is gender inclusive. It has great potential to contribute to household income therefore extension services through the wealth creation would yield great results once encouraged in the pineapple sector especially where banana is facing decline as an income generating crop. The pineapple farmers must look into the context of soil management since better organically manured soils were found to sustain production for longer periods and also have an influence on the contents of pineapple nutrients' that in the long run have an implication to value addition avenues. Adequate extension support for site based appropriate processing technologies, a factor that is greatly stifling effective innovation and engagement in this chain, as an enterprise is required. Solar drying of pineapples is an affordable and easily adaptable value addition innovation for small scale chain actors, since Uganda has abundant solar energy, a major determinant for the viability of such an enterprise especially in pineapples grown in Ntungamo. Feasibility to produce sufficient fiber and dry pineapple pulp, pineapples grown in Isingiro give the better option because of a higher soluble solids content, which has potential to positively influence taste and flavor. Such value addition avenues would go a long way in reducing losses and increase incomes and other benefits for farmer and all actors in the already promising pineapple value chain.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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