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Potato processing in Uganda: A technical review

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Abstract

Uganda is the third largest producer of potato (*Solanum tuberosum*) in East Africa, after Rwanda and Kenya. In Uganda, annual potato production is estimated at 162,151 metric tonnes which puts the country in a strategic position to benefit from the regional growing demand for processed potato products such as French fries. This paper provides a technical review of the status, challenges and potential for the potato processing industry in Uganda. It is clear that limited knowledge, limited access to inputs, low production and productivity, limited access to postharvest and processing technologies are the major constraints to potato processing in Uganda. Although majority of potato varieties cultivated in Uganda have high dry matter content (20-30%), the tubers are usually small in size, round in shape and contain high levels of reducing sugars, exceeding the recommended 0.25%; not suitable for processing into French fries and crisps. To maximise gains from the benefits accruing the opportunities offered by the emerging markets, the following need to be put into consideration; (i) identify and promote varieties with good traits for processing; (ii) promote best agronomic practices, (iii) ensure availability and access to good quality seed by farmers (iv) promote appropriate postharvest handling technologies; (v) invest in processing and value addition technologies; and (vi) strengthen linkages among the various stakeholders involved in the potato value chain.

Key words: Crisps, dry matter, French fries, varieties

Introduction

Potato (*Solanum tuberosum*) is an important crop for food and income generation in Uganda, where it has been recognised as a strategic commodity with potential to make a significant contribution to increasing rural incomes and improving food and nutrition security (Mugisha *et al*., 2017). Despite the importance of potato in Uganda, its potential has not been fully realised. Use of non-improved or uncertified varieties and limited industrial processing/value addition of the crop are some of the major constraints affecting the potato value chain (Mbowa and Mwesigye, 2016a).

In Uganda, value addition to potatoes remains limited but is very critical in upgrading the entire potato value. Value addition provides a means to carry over surpluses from one season to another, contributes to increasing the shelf life, facilitates easy handling of the produce and helps reduce product transportation costs (Abong *et al*., 2010). Additionally, it has been noted that value addition bridges agriculture and industry, and creates employment. Abong *et al.* (2010) stated that value addition produces 'convenience' foods in response to changing lifestyles and provides products with improved nutritional content in response to the increasing public demand for healthy diets.

Globally, the selection of raw materials based on their physical and chemical characteristics is a critical and fundamental step in potato processing (Keijbets, 2008). Processors require potato varieties with specific characteristics to meet consumer demands that are the drivers of modern potato breeding (Singh and Kaur, 2016). This has created demand for unique potato varieties that may not be available in some potato seed systems involving smallholder farmers.

In Uganda, very little is known about the processing properties of the most common potato varieties grown. The situation is worsened by the fact that some of the information available is in non-electronic literature in form of project reports, and is thus not readily accessible. This paper provides a detailed review of the available information from both published and grey literature on physical and chemical characteristics of the major potato varieties cultivated in Uganda, their processing properties and potential for processing into various products.

Methodology

This review focuses on the major potato varieties grown in Uganda, with emphasis on potato supply and the challenges faced by the value chain actors; physical and chemical characteristics of the major potato varieties grown and the level of post-

harvest handling and processing. Most of the information was obtained from peer reviewed journal articles, books and reports. In addition, the review consolidated information from existing databases to illustrate the information gap and the imbalance between potato production and demand as well as the potential for the potato processing industry.

Results and discussion

Major potato varieties grown

Genetic make-up is one of the main factors influencing processing traits of potatoes. Characteristics like size and shape of tubers, skin and flesh colour, dry matter content, reducing sugars and starch contents are strongly linked to the genotype (Cottrell *et al.*, 1995; Arvanitoyannis *et al.*, 2012; Hara-Skrzypiec *et al.*, 2018). Thus, the suitability for processing potatoes into specific products is highly dependent on physical and chemical characteristics which are genotype specific.

In their investigation on investment, opportunities and challenges in the potato value chain in Uganda, Mbowa and Mwesigye (2016a) revealed that more than 11 potato varieties are grown in the Kigezi sub-region where over 60% of potato traded in Uganda are produced. The major varieties grown and ranked based on farmers preference and volumes traded were, (i) *Rwangum*e, (ii) *Victoria*, (iii) *Kinigi*, (iv) *Rwashaki*, (v) *Mumba*, (vi) *Sutama*, (vii) *Kimuli*, (viii) *Rutuku*, (ix) *Cruza*, (x) *Mitare* and (xi) *Kacport1* (Fig. 1). In another participatory assessment of potato

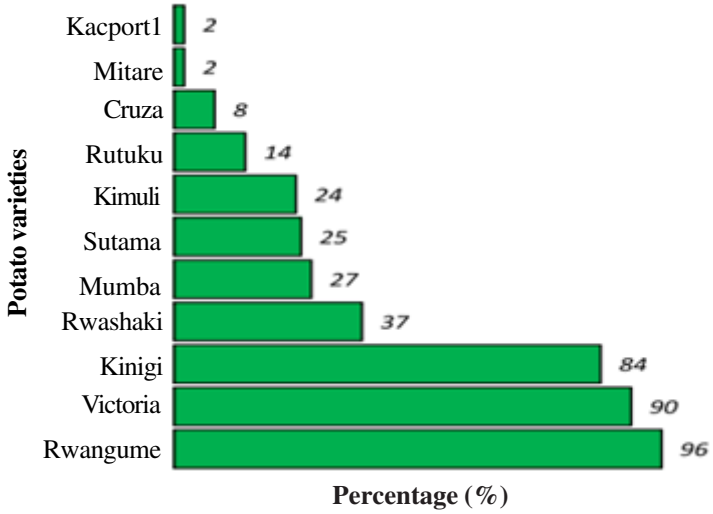

Figure 1. Major potato varieties grown in Kigezi sub-region in Uganda.

Source: Mbowa and Mwesigye (2016a).

farming systems, production constraints and cultivar preferences in Uganda, Namugga *et al.* (2017) corroborated the ranking of the potato varieties previously reported by Mbowa and Mwesigye (2016a) but emphasized that the preferences for varieties may slightly differ from one region to another.

Physical characteristics

Size, shape, colour and eye depth are the most important physical characteristics that affect potato processing. These traits are strongly dependent on the genotype and are very important in determining the usage of a given variety of potatoes. According to Bonabana-Wabbi *et al.* (2013), traders in Uganda consider variety as the most important grading criterion, followed by size and colour.

Potato size. Potato varieties that are 'big' in size were reported to be preferred by processors and consumers, thus emphasizing that tuber size is one of the four important reasons for varietal adoption in Uganda (Low, 1997; Mbowa and Mwesigye, 2016a; Namugga *et al*., 2017). Studies by Ferris *et al.* (2001), Tindimubona *et al.* (2015) and Mbowa and Mwesigye (2016a) provided a qualititative description of potato tubers for the major varieties grown in Uganda (Table 1). Tubers with medium sizes are preffered for processing crisps and French fries; while small tubers are only suitable for fresh consumption (boiled potato) and processing into flour and starch for which the size of tubers does not really matter. As illustrated in Table 1, Mbowa and Mwesigye (2016a), Tindimubona *et al.* (2015) and Ferris (2001) reported varieties like *Rwangume*, *Kinigi*, *Kachport 1*, *Cruza*, *Victoria* and *Rutuku* as having big to medium sized tubers, with *Kachpot 1* and *Rwangume* being preferred by processors. However, all these studies did not provide any specific information on the diameter of the tubers which is needed by processors to design the sorting and grading equipment in order to avoid rejection of tubers on subjective basis as well as losses during processing. In another evaluation, Kwaka *et al.* (2017) established a brief characterisation of potato tubers produced in Uganda, providing a quantitative description of the tuber size. All the varieties were scored as having very small tubers with diameters less than 3 cm. These results confirmed the observations made by Tindimubona *et al.* (2015) on varieties like *Kachpot1* and *Rwangume,* but contradicted the conclusions of Ferris *et al.* (2001), Tindimubona *et al.* (2015) and Mbowa and Mwesigye (2016a) on tuber size of *Cruza, Kinigi, Rutuku*, and *Victoria*. The contradicting information on the size of the tubers from different varieties could be attributed to differences in the agronomic practices in the different study areas, the environmental conditions especially rainfall amounts received during the growing season and the levels of nutrients in the soil. It is therefore important to note that for the potato value chain to meet the size requirements of the processing industry, there is need to invest in good agronomic practices to ensure that production is done under optimum conditions.

Table 1. Physical characteristics of major potato varieties grown in Uganda

Variety	Size	Diameter (cm)	Colour		Shape	Processing potential
			Skin	Flesh		
Cruza	Large[d,e]	2-4[b]	White[f] Light red[d] White mottled[e]	White-purple[f] Cream[d] White ringed[e]	Short-oval[f] Oval round[d] Round[b] Oval[e]	Boiled, mashed, flour
Kachpot1	Big[a]- Medium[e]	4-6[b]	White[f] Red[e]	White[f] Cream[e]	Globe[f] Round[b,e]	Crisps: Boiled, mashed, flour French fries: Boiled, mashed, flour
Kinigi	Big[a]	4-6[b]	Purple[f] Red[c]	Cream[c,f]	Globe[f] Rounded[c] Round[b]	Crisps: Boiled, mashed, flour French fries: Boiled, mashed, flour
Rutuku	Large[e]	4-6[b]	Red[f] Light red[e]	Cream[e,f]	Oval[f] Round[b] Oval round[e]	Crisps: Boiled, mashed, flour French fries: Boiled, mashed, flour
Rwangume	Big[a]- Medium[e]	4-6[b]	Red[e,f]	Cream[e,f]	Globe[f] Round[b,e]	Crisps: Boiled, mashed, flour French fries: Boiled, mashed, flour
Rwashaki	-	4-6[b]	Pink[f]	Cream[f]	Globe[f] Round[b]	Boiled, mashed, flour
Victoria	Large[d,e]	4-6[b]	Pink[c] Red[d,e]	Cream[c] Yellow light[d] Light cream[e]	Compressed[c] Round[b,d,e]	Crisps: Boiled, mashed, flour French fries: Boiled, mashed, flour

Source: [a]Mbowa and Mwesigye (2016), [b]Kwaka *et al.,* (2017), [c]Oswald and Calvo (2009), [d]Ferris *et al.* (2001), [e]Tindimubona *et al.* *(*2015), [f](Muhumuza *et al.*, 2020); ; information on Kimuli and Mitare was not available and have been left out of the table.

Colour. Majority of potato varieties grown in Uganda have red skin and cream flesh colour (Table 1). Potato skin colour does not affect processing suitability. However, flesh colour is one of the main quality attributes assessed by processors and consumers for acceptability (Singh and Kaur, 2016). Tubers with cream/yellow flesh colour are suitable for processing of French fries and crisps because they produce a product with light golden colour that is preferred by consumers.

Shape. Shape is one of the most important external quality traits of tubers for fresh market potatoes but it also has an impact on the processing quality. According to Singh and Kaur (2016), round tubers are generally preferred by the chips industry. This is because the round shape facilitates peeling with minimal loss. The long or oblong type is preferred by the French fry industry.

In their investigation on markets for fresh and frozen potato chips in the eastern and central African countries (ECA), among which is Uganda, Tesfaye *et al.* (2010) observed that availability of sufficient amounts of potatoes that meet the required quality attributes including oval or elongated shape is generally limited. This observation corroborates the information in Table 1 which indicates that majority of the potato varieties grown in Uganda are round. Kaganzi *et al.* (2009) also observed that tuber shape was among the major issues that need to be paid attention to if the potential for commercial production and processing was to be enhanced.

Chemical properties

Dry matter, reducing sugars and amino acid content are the main chemical properties that affect the processing of potato into different products. Dry matter is a key determinant for starch content, while the content of reducing sugars and total amino acids in raw potatoes are closely related to the final colour of baked and fried potatoes, as they contribute in the Maillard browning reaction (Singh and Kaur, 2016). Chemical properties of most common potato varieties grown in Uganda, as well as some of the most traded and processed varieties in Africa and worldwide are presented in Table 2.

Dry matter. The dry matter of potato varieties grown in Uganda varies from 17.16-24.60% in *Rutuku* to 19.13-30.5% in *Kachpot1*. With exception of *Mitare* and *Kimuli* for which no data was available and depending on the authors, most cultivars have a dry matter above 20%, indicating that they are ideal for processing into diverse potato products, with *Kachpot1, Victoria, Kinigi* and *Rutuku* having the highest dry matter content of 19.7-30.5, 22.42-28.25, 20.26-28.35 and 17.16-24.50%, respectively (Table 2). When compared with other common varieties grown around the world like *Titoni* and *Kenya Baraka* in Kenya, *Darius* and *Frodo* in South-

Table 2. Chemical properties of major potato varieties grown in Uganda

Variety	Dry matter (%)	Reducing sugars (%)	Processing potential
Cruza	19.54[m]	0.24[m]	Boiled, Mashed, Flour
	20.20[b]		
Kachpot1	19.73[m]	0.48[m]	Crisps, French fries, Boiled, Mashed, Flour
	25.30[a]	0.045[c]	
	30.50[c]		
Kinigi	20.26[m]	0.26[m]	Boiled, Mashed, Flour
	22.22[b]	0.471[c]	
	28.35[c]		
Rutuku	17.16[m]	0.58[m]	Boiled, Mashed, Flour
	24.50[a]		
Rwangume	17.72[m]	0.66[m]	Crisps, French fries, Boiled, Mashed, Flour
	21.73[b]	0.011[b]	
Rwashaki	19.23[m]	0.21[m]	Crisps, French fries, Boiled, Mashed, Flour
	20.84[b]	0.07[b]	
Victoria	22.42[b]	0.21[b]	Crisps, French fries, Boiled, Mashed, Flour
	28.25[c]	0.084[c]	
Tigoni (Kenya)	22.22[g]	0.05[g]	Crisps, French fries, Boiled, Mashed, Flour
Kenya Baraka (Kenya)	23.10[g]	0.10[g]	Crisps, French fries, Boiled, Mashed, Flour
Darius (South Africa)	26.50[e]	0.017[d]	Crisps, French fries, Boiled, Mashed, Flour
	29.39[f]		
Frodo (South Africa)	28.58[f]	0.067[d]	Crisps, French fries, Boiled, Mashed, Flour
Russet Burbank (USA and UE)	24.60[h]	0.016[k]	Crisps, French fries, Boiled, Mashed, Flour
Agria (UE)	22.15[j]	0.07[j]	Crisps, French fries, Boiled, Mashed, Flour
Kufri Chipsona-1 (India)	22.50[l]	0.015[l]	Crisps, French fries, Boiled, Mashed, Flour

Source: [a]Kesiime (2014), [b]Senkumba *et al.* (2017), [c]Nuwamanya *et al.* (2011), [d]Steyn *et al.,* (2009), [e]Niekerk (2015), [f]Geremew *et al.* (2007), [g]Abong *et al.* (2010), [h]Pritchard and Scanlon (1997), [i]Ah-Hen *et al.* (2012), [j]Mareek *et al.* (2013), [k]Wetzstein and Sterling (1979), [l]Singh *et al.* (2008), [m]Muhumuza *et al.* (2020)

Africa, *Agria* in UE, *Russet Burbank* in UE and USA, or *Kufri Chipsona-1* in India, most of the cultivars grown in Uganda have the required dry matter for fresh market potato and processing. Nevertheless, the dry matter content, as well as their ranking vary from one author to another or from one region to another. For instance, Kesiime (2014) determined the dry matter of three potato varieties grown in Uganda and found that the highest dry matter content across watering regimes was in *Kachpot1* (25.3%) and *Rutuku* (24.5%). The lowest mean dry matter (20.16%) was recorded in *Victoria*. These results were partially corroborated by Senkumba *et al*. (2017), who reported that most of the varieties grown in Uganda had a dry matter content of 20-24%; indicating that they were ideal for processing into products such as chips

and crisps. According to Senkumba *et al.* (2017), *Victoria* had the highest dry matter of 22.42%, followed by *Kinigi* (22.22%), *Rwangume* (21.73%), *Rwashaki (*20.84%) and *Cruza* 20.2%. However, both Kesiime (2014) and Senkumba *et al*. (2017) did not use potatoes grown under standard agronomic practices.

Nuwamanya *et al.* (2011) and Muhumuza *et al.* (2020) analysed common potato varieties grown under standard agronomic practices at Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI) in Kabale, South- Western Uganda and reported different and contradictory results on physicochemical properties. According to Nuwamanya *et al.* (2011), all the varieties had a dry matter content of over 27%, with *Kachpot1* having the highest dry matter (30.50%), followed by *Kinigi* (28.35%) and *Victoria* (28.25%); whereas Muhumuza *et al*. (2020) recorded an overall mean of 19.19% among common Uganda varieties. The differences in the physico-chemical properties reported in this study can be attributed to the growing seasons as well as the agronomic practices like fertiliser application, use of good quality seeds, irrigation and the soil fertility. For instance, availability of phosphorus in soil is positively correlated with high dry matter in the tubers (Leonel *et al.,* 2017); nitrogen has a positive correlation with dry matter but is variety specific (Muttucumaru *et al.,* 2013); while potassium and dry matter are negatively correlated (Kavvadias *et al.,* 2014).

Dry matter content along with other components such reducing sugars, amino acids and micronutrients including phenolic compounds and vitamins affect the quality of potatoes and their products to a significant extent (Singh and Kaur, 2016; Furrer, *et al*., 2017). Dry matter is a key determinant for starch production in terms of quality and quantity; but also significantly affects the texture of potato processed products like crisps and French fries. Generally, high dry matter content is preferred by processors involved in starch, flour and crisps production, while medium dry matter content is required for processing French fries.

Reducing sugars. Reducing sugars and amino acid in raw potatoes are closely related to the final colour of baked and fried potatoes; as they contribute in the Maillard browning reaction (Damodaran *et al.*, 2008). Presence of excessive amounts of reducing sugars in potato tubers has been shown to result in unacceptably brown coloured or darker and bitter tasting fried products (Pritchard and Scanlon, 1997) and other adverse effects in boiled, fried or baked potatoes such as the formation of acrylamide, a substance suspected to cause cancer in humans (Muttucumaru *et al.*, 2014).

The information from previous studies (Table 2) indicates that the reducing sugar content (0.011 – 0.084%) for most of the potato varieties cultivated in Uganda

compares well with those of the common varieties grown worldwide like *Titoni* in Kenya (0.05%), *Darius* in South-Africa (0.017%), *Agria* in UE (0.07%), *Russet Burbank* in UE and USA (0.016%), or *Kufri Chipsona-1* in India (0.015%), with exceptions such as *Kinigi* (0.471%). Currently there is no data on the levels of reducing sugars for *Cruza, Kimuli, Mitare* and *Rutuku* potato varieties.

Although the content of reducing sugars in the potato varieties produced in Uganda is within acceptable limits at the time of harvesting, there is concern that the levels increase during storage. Senkumba *et al*. (2017) observed a general increase in the reducing sugar content in the tubers during storage. Between week 6 and 9, the reducing sugars increased from 0.021 to 0.12% for *Victoria*, 0.007 to 0.047% for *Rwashaki* and 0.011 to 0.109%, for *Rwangume*. This indicates that caution needs to be taken during storage of the tubers to ensure that there is no significant increase in reducing sugars. In order to avoid health risks associated with browning of potato products, the maximum reducing sugars content has been set at 0.5 g per 100 g and 0.25 g per 100 g of fresh potato for processing into French fries and crisps, respectively (Abong *et al*., 2010).

Potato postharvest handling

Harvesting of potatoes in Uganda is a manual process where the tubers are picked up from the soil with hoes or hands depending on the soil texture (Wasukira *et al.*, 2017). Tubers are lifted together with soil, vines and other superfluous material. The tubers are then detached by shaking the vines and separated from the soil manually. Sorting, which involves the identification and removal of visibly tiny tubers and those with visibly undesirable characteristics is done in the field. The sorted tubers are collected and packed in polypylene bags or baskets and transported to storage facilities if available or directly to the market for sale. In most cases, no rigorous precautions are followed during harvesting, packaging and transportation to control and reduce physical damage. As a result, a large proportion of the tubers get damaged through cuts and bruises during harvesting and handling, which creates storage problems because the damages increase the rate of respiration and create avenues for microbial infestation.

Most potato value chain actors in Uganda use rudimentary storage facilities that are not able to provide the optimum storage conditions. Thus, in addition to high respiration and microbial infestation resulting from poor handling during harvesting and transportation, there is a substantial increase in reducing sugar content associated with high storage temperatures (Hyde and Morrison, 1964; Matsuura-Endo *et al*., 2006). The increase in reducing sugars is directly associated with reduction in the dry matter content as a result of conversion of starch to simple sugars. Consequently,

the tubers become soft and watery which significantly reduces their processing quality (Tatwangire and Nabukeera, 2017).

The poor postharvest handling and lack of appropriate storage facilities affects farmers, traders and processors (Mbowa and Mwesigye, 2016a) since it results into high postharvest losses and reduced income. Tatwangire and Nabukeera (2017) estimated that the highest physical losses are experienced by ware potato processors at 4-31%, followed by farmers (9-16%), traders (11%), and consumers (5-9%). The authors reported that farmers registered the highest economic loss (6-17%) due to the quantity of poor quality potatoes sold at discounted price; followed by traders (9-12%); while processors lost 6- 8%. The losses incurred by farmers greatly affect the potato processing industry in terms of prices and availability of adequate quantities for processing.

In order to address the challenges associated with lack of appropriate storage technologies among the farmers, Senkumba *et al.* (2017) introduced ambient storage structures and studied their effects on the storage stability and processing quality of some potato varieties being promoted in Eastern Uganda. The authors reported that all the varieties tested had sufficient dormancy of two months or more when stored in the ambient structures. The results also indicated that the temperature inside ambient storage structures was always lower than the surrounding environment; while the humidity was higher. Majority of the potato varieties tested were also able to maintain good processing quality for 6-9 weeks, indicating that generally, the ambient storage structures were able to provide suitable storage conditions for the ware potatoes. However, the adoption and utilisation of the ambient storage structures by the value chain actors has not yet occurred. As a result, farmers are forced to sell potatoes at low prices immediately after harvest to avoid losses.

Status of potato processing in Uganda

In Uganda, value addition that is critical in transforming the entire potato value chain remains limited. Unlike developed countries where the largest proportion of the potatoes is more dedicated for processed products than for fresh consumption (Keijbets, 2008), potatoes in Uganda are mainly produced for fresh consumption. The existing processors largely operate on very small scale, using simple tools and limited facilities to mainly produce chips and crisps (Kyomugisha *et al.*, 2017; Mugisha *et al.*, 2017). The crisps industry is more developed with a range of product brands sold in the supermarkets. However, majority of the processors are still small scale using batch equipment with limited food control systems. The key steps involved in processing of potato crisps in Uganda are summarised in Figure 2. Majority of the processors use deep fryers that have no temperature control mechanisms and recycle

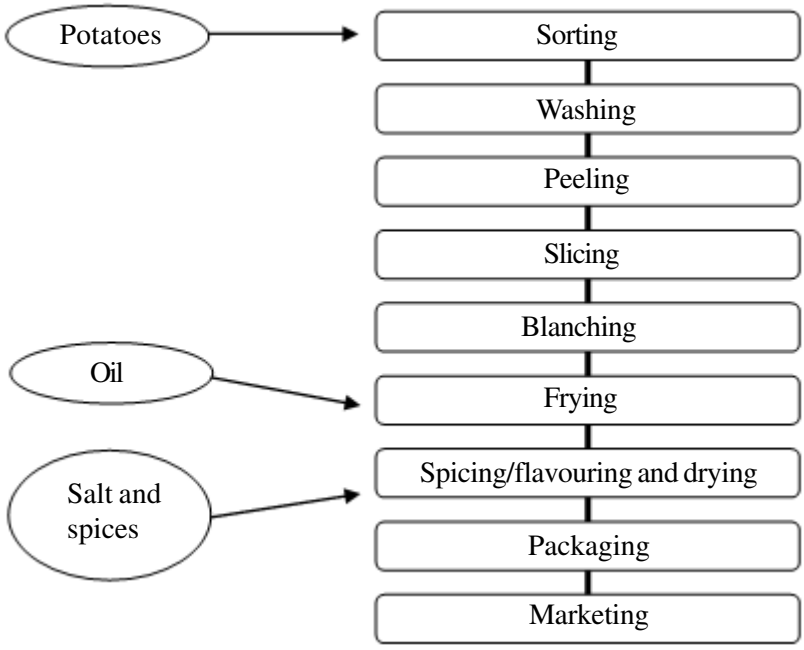

Figure 2. Flow chart for production of crisps in Uganda.

the oil several times. Lack of temperature control and oil recycling have a negative effect on the colour and texture of the final product, respectively.

To date, Uganda has one modern processor of potato crisps in Kabale district established by the Uganda Industrial Research Institute (Mugisha *et al*., 2017). The factory, however, faces a challenge of inadequate supply of appropriate potato varieties to support its business operations (Mbowa and Mwesigye, 2016a).

Due to the recent surge in urbanisation and increase in the middle income population in Uganda, consumption of potato as food is shifting from fresh potatoes to value added and convenient products. Despite the increasing demand for convenient foods, the potato value chain in Uganda has not fully tapped into the business opportunity as most of the varieties used by farmers are not suitable for production of French fries. A number of fast restaurants are coming up in the urban and peri-urban areas where French fries are a common product preferred by the youth. There is no particular preference to the varieties of potatoes used in the restaurants. The focus is mainly on size of the tubers and the outer appearance. Besides lack of appropriate varieties, the processors of French fries do not have adequate knowledge on the optimum processing conditions to produce high quality products. There is no monitoring of the oil temperature during frying and the oil is used for a long period or reused on a

number of occasions. As a result, the quality of the French fries produced and consumed in Uganda is still below average.

To overcome the challenge associated with access to quality potatoes, frozen potato chips are imported from South Africa and Egypt to supply both fast food restaurants and large supermarkets (Witte, 2013) at a price three times higher than those produced in Uganda using locally produced potatoes (Tesfaye *et al.,* 2010). This has led to an increase in price of the final product, with a plate of French fries going for US $3 in a high scale restaurant while a sack of raw potatoes (approx. 100 kg) goes between US $14 and 28 in the city markets (Mangusho, 2015).

There is, thus an urgent need for the value chain actors to invest in enhancing production and productivity of suitable potato varieties to support the growing demand for potato based value added products.

Challenges and opportunities

Challenges. Potato processing in Uganda is constrained by knowledge gap, lack of facilities and inputs namely suitable potato varieties and quality of tubers, low production and limited access to financing, amongst others and these are elaborately discussed below.

Lack of suitable varieties. Value addition is constrained by unreliable supply of potato seed from varieties suitable for processing (Mbowa and Mwesigye, 2016b). Indeed, the information summarised in Tables 1 and 2 and discussed in previous sections of this review revealed that the two major potato varieties produced in Uganda (*Victoria* and *Kinigi*) represent over 70% of volume of potatoes traded in Uganda, are more suitable for processing of chips/crisps compared to French fries because of their round shapes. In addition, *Kinigi* which is preferred by majority of the farmers and represents 58% of the potatoes traded in Uganda, has good dry matter (22-28%), but too much reducing sugars (0.340-0.471%) which contribute to browning of French fries via the Maillard reaction (Damodaran *et al.*, 2008; Mestdagh *et al.*, 2008).

Studies have also indicated substantial increase in the levels of reducing sugars in both *Kinigi* and *Victoria* over a 9-week storage period. Senkumba *et al*. (2016) observed that the reducing sugar content of *Kinigi* increased by 41% from the 6th to 9th week of storage in an ambient structure. Meanwhile varieties with suitable traits such as high dry matter content, low reducing sugar concentration, large tuber size, oblong shape and shallow eyes are not preferred and currently are not grown by Ugandan farmers, and represent an insignificant volume of potato traded in Uganda.

This is the case with *Kachpot1* which has a dry matter content of 25.3-30.5% and very low levels of reducing sugars (0.045%) but is not preferred by majority of the farmers. Currently, *Kachpot1* represents less than 1% of the total volume of potatoes traded in Uganda.

Knowledge gap. Lack of sufficient and consistent information on the major varieties grown in Uganda is also a serious challenge to the potato processing industry. Knowledge of the physicochemical properties of the potatoes, which are strongly linked to the variety (genotype) is one of the critical steps to developing and testing innovative potato-based value added products. However, limited research has been undertaken to link the potato varieties preferred specific markets to the farmers. As a result, majority of the farmers plant seeds available to them without putting into consideration the market requirements. There is a need to establish a comprehensive database of potato varieties grown in Uganda that provides, for each variety, basic information such as tuber size and shape, eye depth, skin and flesh colour, dry matter and reducing sugar content, specific gravity as well as the agronomy requirements.

In addition, there is a knowledge gap on the effect of different agronomic practices along with the postharvest handling techniques on the quality of potatoes and the resultant products. There is, thus need to create strong linkages between the potato industry, researchers and farmers to ensure that value chain activities like breeding, production and postharvest handling are linked to specific markets. The integrated approach involving forward and backward linkages along the value chain will ensure enough and good quality raw materials.

Low production. Despite a substantial increase in land allocated to potato, substantial decrease in yield has been registered since 2008 resulting in a gap between potato production and demand. Information in Figure 3 indicates that from 1961 to 2007 production increased as demand also increased, but since 2008 the production has dropped sharply and stagnated at around 200,000 metric tonnes, while the demand kept increasing, reaching 400,000 metric tonnes. Since 2017, potato yield in Uganda has decreased from 7.5 to 3.5 MT ha^{-1} due to cumulative effects of poor quality seed, lack of fertiliser and pesticide use, pests and diseases alongside inadequate agronomic practices (Namugga *et al.,* 2017). Combined with seasonal production and lack of appropriate storage technologies, low production constitutes one of the most important challenges to the Ugandan potato industry as it considerably affects price stability (Ferris *et al.,* 2001). Most processors (over 63%), traders and consumers experience shortages in potato supply during the off-season and this affects the general stability of transactions and prices on the market. As a result, potato processors in Uganda with huge investments such the Kisoro Potato Processing

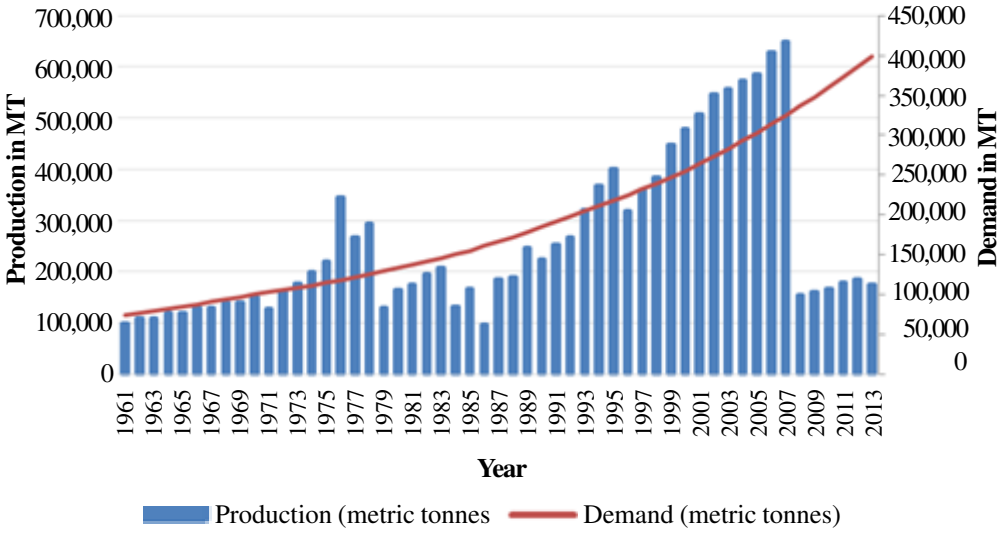

Figure 3. Potato production and demand trends in Uganda, 1961-2013.

Source: Authors' computation using World Bank data and FAOSTAT.

Note: Potato demand for each year was calculated by multiplying the average consumption per capita per year (10.62Kg/capita/year FAOSTAT 2018) times the total population for each particular year.

Industry are often on the list of distressed companies seeking for private and public bailout (Kaketo, 2016) in order to overcome the challenges associated with limited supply of raw materials.

Lack of storage and processing facilities. Lack of storage and processing facilities to ensure good quality products is one of the major challenges affecting the potato processing industry in Uganda (Ferris *et al.*, 2001). The processors do not have access to modern potato postharvest handling technologies and therefore, are not able to stock enough quantities during the bumper harvest to avoid price fluctuations associated with the high perishability and seasonality of potatoes. In addition, the processors do not have access to modern potato processing technology. This is mainly attributed to lack of capital to invest in importing state of the art processing technologies from Europe, Asia or America (Mbowa and Mwesigwa, 2016). Majority of the processors operate as cottage industries using appropriate technologies that only produce for the local markets.

Access to financing. Credit is necessary to finance acquisition of the necessary technologies for processing and value addition. However, farmers and processors in

the potato value chain have limited access to credit due to the lengthy procedures and high interest rates (Mukhwana *et al.*, 2005; Kaganzi *et al.*, 2009; Bonabana-Wabbi *et al.*, 2013). For example, in 2016 the only one modern and private potato processing plant was reported in need of a lifeline after collapsing due to lack of adequate processing facilities and high credit interest rates of the loans taken initially to finance the establishment of the factory (Kaketo, 2016). The situation is worsened by lack of financing models tailored to agro-processing that requires long term soft loans. The major providers of credit facilities are mainly commercial banks that offer short term and high interest rate credit facilities.

Opportunities

The growing demand for potato processed products and the increased research efforts to develop improved varieties provide opportunities for the potato industry in Uganda. The growing demand can encourage the stakeholders to stay in the business; while research and development of improved varieties is the pathway for production of adequate quantities of high quality raw materials to support the processing industry and increase the diversity of processed products.

Demand for potato products

Consumption of potatoes in Uganda is on the increase and focusing more on processed products. Witte (2013) reported that in Uganda, there is potential for higher consumption rates in the near future due to increase in the middle income working population with very busy work schedules and, therefore, preferring convenient foods. To date, processed potatoes are increasingly consumed in hotels, restaurants and other retail outlets.

In 2017, Uganda formally imported 159 metric tonnes of raw potatoes for a value of $71,438 in order to meet the market demand (Kasemiire, 2019), while the value of informal imports from neighbouring countries were estimated at $1.6 million (UBOS, 2019). More comprehensive data from Trade Map (Fig. 4) indicate that more than 18,000 metric tonnes of fresh or chilled potatoes were imported in 2017 for a value of over $4.8 million.

The import figures (Fig. 4) indicate that the consumption of chilled potato chips is on the increase, which provides an opportunity for the establishing local potato processing industries to fill the demand gap. The increase in demand for chilled potato chips is driven by increase in population, restaurants, hotels, supermarkets and franchised fast-food restaurants that mainly specialise in French fries (Mangusho,2015 and Witte, 2013).

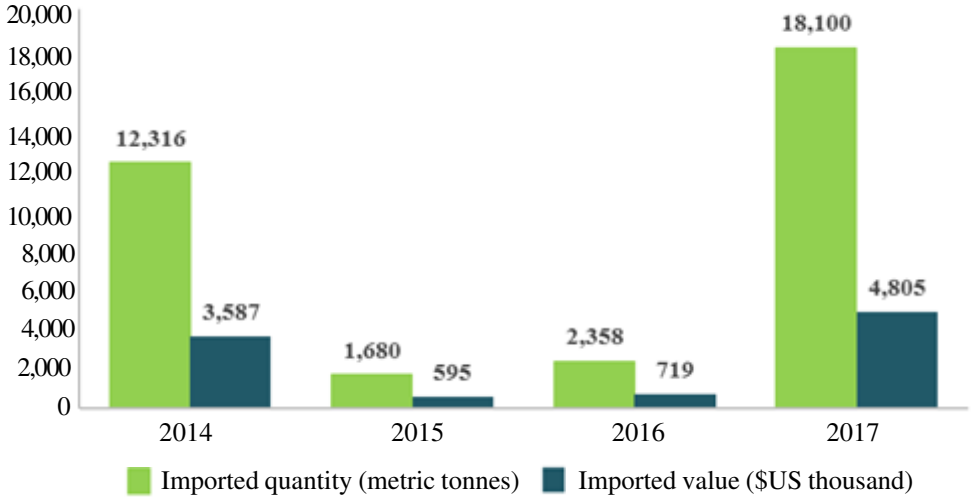

Figure 4. Chilled potatoes imported in Uganda, 2014-2017.

Source: Computation using Trade Map data (Trade Map, 2019).

Research and development on improved varieties

There is increased interest by the Government of Uganda and other development partners to invest in research aimed at enhancing production and productivity of potatoes. Kachwekano Zonal Agriculture Research Institute (KAZARDI), which is under the National Agricultural Research Organization (NARO), is developing new disease-resistant potato varieties and employing biotechnology to release high yielding varieties to enhance production and productivity (Muhereza, 2016). In the same perspective, the identification of stable and adapted genotypes for the different agro-ecologies in Uganda has been done (Abalo *et al.*, 2003) as well as the assessment of agronomic performance of elite potato genotypes in South-western Uganda (Abalo *et al.*, 2001). However, more research is required to improve the quality traits such as dry matter content, starch and reducing sugar percentage as well as tuber shape, eye depth and tuber size. These attributes are key determinant of the use of potato in processing as demonstrated in this paper. Novel biotechnology tools and techniques can help identify and combine genes contributing to the characteristics of tuber such as shape, size, dry matter and other physicochemical properties (Ezekiel *et al.*, 2013) needed by processors and final consumers. The research and development of new and improved varieties using advanced biotechnology is a huge opportunity for the potato industry in Uganda because it will address some of the most important bottlenecks such as low production, poor quality tubers and inadequate supply of suitable varieties.

Future of potato processing in Uganda

There is a huge potential for the potato processing industry in Uganda due to the increasing population, changing life styles and demand for convenient products. There is also a large market for potatoes and potato based products in the neighbouring countries most especially Democratic Republic of Congo, Rwanda and Kenya (Tesfaye *et al*., 2010). In these countries, potato is increasingly becoming a staple food with Rwanda having the highest demand estimated at 125 kg per capita/year (International Potato Center, 2011). From 2010 to 2017, potato imports by the three countries increased fivefold from 3,733 to 20,656 metric tonnes (FAO, 2020). However, to fully tap into this potential, there is need for substantial investment in the entire potato value chain to enhance production and productivity, put in place efficient postharvest handling systems that will ensure availability of potatoes throughout the year and establish processing industries with ability to develop and produce potato based products that meet local, regional and international consumer market standards.

Conclusion

Potato processing in Uganda has great potential to make a significant contribution to food security and household income in Uganda. However, due to lack of postharvest technologies to prolong the shelf life of the potatoes, majority of the farmers currently sell fresh potatoes at low prices. The low returns discourage further investment in potato production as farmers turn their attention to other farming enterprises that generate better returns. Investment in potato processing is limited by the inadequate supply of potatoes and the volatile price fluctuations arising from seasonality of the crop and the huge demand from the fresh market. To fully tap the potential of the potato value chain, there is need to promote production of varieties with good traits for processing, use best agronomic practices including quality seed, promote appropriate postharvest handling technologies along the value chain, and invest in processing and value addition technologies. The proposed strategies will motivate farmers since there will be a stable market for their produce and will ensure regular and adequate supply of raw materials to support the processing industry.

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