MORPHOLOGICAL AND PHYTOCHEMICAL COMPOSITION OF SELECTED POTATO (*Solanum tuberosum L.*)CULTIVARS GROWN IN RWANDA

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ABSTRACT
The aim of this study was to investigate morphological and functional properties of six varieties and four potato clones grown in Rwanda and their potential utilization in food products. The experiment was arranged in Randomized Complete Block Design (RCBD) with three replications. The research was conducted in Busogo farm in the year 2016/17. Morphological and phytochemical composition of potatoes were analyzed. Collected data were subjected to Analysis of variance (ANOVA) using SAS version 9.2. Means separation was done using Tukey's test at 5% level of significance. The skin colours included red, white, yellow, pink and purple, while the flesh was yellow and white. Shapes were oval, oblong and round. They had shallow and medium eyes with deep eyes for Kinigi and CIP392617.54. Number of eyes were 6-12. All cultivars had potato size > 40 mm exceptCIP399075.22with 90% of <40mm. Phytochemicals on fresh weight basis (FWB)were17.80-21.52 mg/100g for total phenols,0.24-1.46 mg/100g for total anthocyanins, 0.05- 0.19mg/100g for total carotenoids, 5.31-26.60 mg/100g for vitamin C. Orthogonal contrast revealed that varieties and clones were statistically significantly different at (P < 0.05). On average varieties had higher phenols and higher anthocyanins, while clones were higher in carotenoids and vitamin C. Skin and flesh colours were associated with phytochemicals which are good for health. Potato cultivars in this study can be used for manufacturing of different potato products due to morphological characteristics required for each product and they are source of phytonutrients with antioxidant properties.

Keywords: Phytochemicals, Phytonutrients, potato morphology, Rwanda

Received: 27.03.2019 Reviewed: 31.05.2019 Accepted: 09.06.2019

INTRODUCTION

Potato (*Solanum tuberosum L.*) is the fourth most important crop in the world after rice, wheat and maize. Potatoes produce more dry matter, protein and minerals per unit area and unit water comparing to cereals (Burke, 2016). It is a staple food in different countries. In the first world countries it provides 130 kcal/day per person and 41 Kcal per day per person in the third world countries (Ezekiel*et al*., 2013). In Rwanda consumption of potato is 125kg per capita (FAO, 2008). Rwanda is among the first in potato consumption in the world. In addition to being source of energy, potatoes contain secondary metabolites which are known to be beneficial to the health. Phytochemicals have been linked to protection against different types of diseases (Ezekiel *et al*., 2013). Skin and flesh colours were linked to certain type of phytochemicals present in potatoes (Ezekiel *et al*., 2013). Shape, size and eye characteristics are of concern during processing.

External parameters like skin colour, shape, size and eyes characteristics influence potato processing value. Potatoes with many and deep eyes and uneven shapes increase peeling losses. Moreover, potato shape is of importance in processing decisions. Crisps require oval and 45-80 mm of diameter, French fries requires oblong of above 75 mm length, round and oval potatoes are suitable for dehydrated products and oval for canned potatoes (Marwaha *et al.*, 2010). Round or oval, medium to large potatoes with shallow eyes are ideal for most potato products to minimize peeling losses (Marwaha*et al.*, 2010). Potato skin and flesh colours are also important in quality of potatoes and contribute to customer attraction of fresh potatoes. White flesh colour is mostly preferred for French fries and yellow for crisps.

Skin and flesh colours are linked to phytochemicals present in potatoes (Ezekiel *et al.*, 2013). Morphology contribute to the quality of potatoes and it is a good indicator of the potato quality where some colours are linked to some phytonutrients.

Phenolic compounds are secondary metabolites present in plants with health properties. Total phenols in potatoes range from 5 to 30mg/100g (Lister and Munro, 2000). They can also be as high as 123-441mg/100g (Singh and Kaur, 2009). They are influenced by genetic and environmental conditions (Lister and Munro, 2000; Ezekiel *et al.*, 2013). These compounds are produced by plant for defense against virus, bacteria, fungi and insects(Liu, 2013;Akyol *et al.*, 2016). Red and purple skin coloured potatoes were reported to have twice phenolic acids than white skin coloured, while red and purple flesh coloured potatoes had three to four times phenolic acids than white flesh colored potatoes (Ezekiel *et al.*, 2013). The amount of phenols is reduced during cooking and processing (Ezekiel *et al.*, 2013; Akyol *et al.*, 2016). Phenols were revealed to decrease risk of chronic disorders like cancer, heart diseases, and diabetes (Ezekiel *et al.*, 2013;Liu, 2013). Phenols are present in various amount in potatoes and they protect the body against different types of oxidative diseases.

Potatoes contain anthocyanins which are pigments in different colours. They are found into vacuoles and are accountable for red, purple/black colour of potato skin and occasionally flesh (Lister and Munro, 2000). The colouration can fluctuate from modest colouration of vascular ring to the pigmentation of the entire tuber. Anthocyanin content was reported to range from 1.56 mg/100g to 89.95 mg/100g (Lee *et al.*, 2016). Similarly, the range of anthocyanin content was reported to vary from 1.5 to 48mg/100g FWB (Brown *et al.*, 2008). Red and purple coloured potatoes contain more anthocyanins than yellow and white coloured (Ezekiel *et al.*, 2013). Anthocyanins have antioxidant activity and it follows thatred potatoes have more of antioxidants than non-coloured ones and hence better at combating oxidative stress. Potatoes with coloured flesh have more antioxidant than skin only coloured alone (Lister and Munro, 2000).

Carotenoids are plant pigments responsible for bright red, yellow and orange hues in many fruits and vegetables. More than 600 carotenoids with yellow, orange and red colours have been identified in fruits, vegetables, cereals and entire plants (Liu, 2013). The flesh of different varieties of potato tubers are generally coloured with yellow which is an indicator of carotenoids which is a class of plastid pigment (Lister and Munro, 2000). The predominant carotenoids in potatoes are lutein, zeaxanthin, violaxanthin and neoxanthin with betta carotenoids in very small amount (Ezekiel *et al.*, 2013). Zeaxanthin and lutein are responsible for orange and yellow colours respectively (Ezekiel *et al.*, 2013). Total carotenoids are associated with yellow flesh colour and it is genotype dependent. Total carotenoids range from 0.5 to 2 mg/100g (Singh and Kaur, 2009). Moreover, a wide range of carotenoid was reported varying from 50 to 100µg for white fleshed potatoes, 100 to 350 µg for yellow fleshed potatoes, 1000 µg and above for deep yellow or orange fleshed potatoes and the highest publication was 2600µg/100gFWB (Brown *et al.*, 2008). Carotenoids participate in defense against diverse disorders due to their ability to scavenge singlet oxygen generated during light induced lipid oxidation (Liu, 2013). Carotenoids contribute to the protection of the body against degenerative diseases emanating from oxidation.

Potatoes contain vitamin C in various amount. It is located mainly around the vascular system and less in the pith and skin (Lister and Munro, 2000). Potato contain 84-145 mg/100g of vitamin C on dry weight basis (Donnelly and Kubow, 2011). A potato of 150 g consumed entirely supplies half of vitamin C (Burke, 2016). Vitamin C is vital for absorption of iron and for immune system of the body(Iqbal *et al.*, 2004; Donnelly and Kubow, 2011; Burke, 2016). It is indispensable for hindrance of scurvy and an excellent antioxidant which helps in inhibition of oxidative stress (Iqbal *et*

al., 2004). It helps in formation of connective tissues, borne formation to sustain healthy gums and it has substantial role in wound healing and protection against infection (Iqbal *et al*., 2004).

Potatoes occupy a central role in Rwanda diet. They are consumed in proceed and unprocessed forms. Moreover, there is a wide range of potato cultivars and more are being developed due to the advancement of breeding to meet consumer's needs. Therefore, there is a need to understand characteristics of potato cultivars in order to predict their use. The objective of this study was to investigate morphological characteristics and phytochemical composition of selected potato varieties and clones grown in Rwanda.

MATERIALS AND METHODS

Potatoes were grown in Busogo farm of the University of Rwanda located in Musanze District, Northern Province of Rwanda. It is geographically located at 1°33'26'' S and 29°32'39''E. The site is characterized by Andosol due to volcanic soil. The average temperature is 16.2°C with average annual rainfall of 1420mm(Climate-Data.Org, 2016).The experiment was laid out in Randomized Complete Block Design (RCBD) in three replications and ten treatments representing cultivars. Experimental unit of 2.8 x 1.8 m^2 was used and adjacent plots were separated by guard rows of 0.8 m and spacing was 80 cm between the rows and 30 cm within the rows. They included six varieties such as Kirundo, Mabondo, Gikungu, Kigega, Kinigi and Sangema and four clones which are CIP399075.22, CIP392617.54, CIP 393251.64 and CIP399062.115. They were grown under standard cultural condition in the year of 2016/17. Fertilization rate was 300 kg of compound fertilizer 17-17-17 per hectare.

Sample preparation for chemical analysis

Fresh potatoes were washed in tap water to remove all the soils, grated into small particles and sun dried for one day. They were then ground into powder, kept in clean dry containers and refrigerated (4±2)°C for further analysis.

Morphological quality of potatoes

Skin colour, flesh colour, eye depth, size and shape were analyzed using the method used by Abong *et al*.(2010). Ten tubers from each variety were picked at random and their skin colours were described as red, yellow, white, pink or purple. The potato was then cut into halves and the flesh was described as yellow or white. Tuber shapes were characterized as oblong, round and oval. Eyes were measured using a Vernier caliper (NSK Nippon Sokutei, Japan) and a ruler. They were classified as shallow (0.00-0.20 mm), medium (0.20- 0.50 mm) or deep (>0.50 mm). For potato size, potatoes from ten hills of the central of the plot were used to measure tuber size after washing them in tap water. The size was classified into four categories based on their potential utilization and they included < 40mm, 40-50mm, 50-60mm and >60mm diameters. Grading was done using grids made for that purpose. Tubers in each grade were weighed and percentage was calculated.

Determination of total phenols

The method used by Sun *et al*.(2015) was adopted. About 1 g of potato flour was added to 20 ml of water and shaken for 5 hours at 80 g followed by centrifugation (HERMLE Labnet, model Z382K, Germany) at 400g for 5 minutes. Extract of 0.5ml of potato powder was mixed with 2 N 0.5 mL of Folin-Ciocalteu reagent for 6 min. Thereafter, 1.5 mL 20% Na_2CO_3 was added and the volume was made to 10 ml with distilled water and incubation was done for 10 minutes at room temperature. Absorbance was read at 765 nm with spectrophotometer (JENWAY 7315). Standard curve of 0, 0.2, 0.4, 0.6, 0.8 and 1 mg/100g gallic acid was plotted and total phenol was expressed as milligram of gallic acid equivalent per 100 gram of potato (mg GAE/100 g).

Determination of total anthocyanins

The method described by Tokusoglu and Yildirim (2012) was used. About 0.2 g of potato flour was extracted with 10 ml of 80% ethanol solution. Centrifugation (HERMLE Labnet, model Z382K, Germany) was done at 4000g for 5 minutes at 4°C. Thereafter, 1ml of extract was diluted with 20ml of water. From

diluted aliquot, 0.5ml was pipetted and mixed with 4ml of 10% formic acid. The absorbance was read at 530 nm in spectrophotometer (JENWAY 7315). The anthocyanin content was calculated on the basis of the equation below and expressed as cyanidin-3-glucose equivalent (C3GE). Anthocyanin content (mg/100g of dry matter) = A × MW× DF × 100 / (ε × W) as C3GE mg/L. Where A =absorbance, MW= molecular weight of Cyanidin 3-glucoside ($C_{21}H_{21}ClO_{11}$, 449.2), DF = dilution factor, ε = molar absorptivity of Cyanidin 3-glucoside (26900), W= weight of the sample.

Determination of total carotenoids

The method used by Robles-Ramírez *et al.* (2016) was adopted. About 10 g of potato powder was used for extraction with 100 ml of 80% ethanol at room temperature overnight in orbital shaker at 80 g. Thereafter, extracts were recovered by centrifuging (HERMLE Labnet, model Z382K, Germany) at 6182 g for 15 minutes at 4^{o}C and the residues were re-extracted in the similar conditions and the two extracts were mixed. Sample extracts of 10 ml was added in assay tube wrapped with aluminum foil containing 10 ml of hexane. The tubes were introduced in an ice bath and shaken in an orbital shaker at 80 g for 15 min. Thereafter, 3ml of deionized water were added to each tube and shaken for 5 more minutes. The tubes were then allowed to stand at room temperature until phase separation occurred. The absorbance of hexane top layer (A) was read at 450 nm in spectrophotometer (JENWAY 7315). The total carotenoids (TC) concentration was calculated using the formula below: TC (mg/kg) = (A x V x 104) / (A1% x W); where A is the absorbance at 450 nm, V is the hexane volume, A1% is the extinction coefficient for total carotenoids (2500), and W is the weight of the sample in the extract.

Determination of vitamin C content

Ascorbic acid was analyzed using themethod described by Grudzińska *et al.*(2016). About 2 g of laboratory sample of potato tuber were extracted with a solution 40 ml of 0.4% oxalic acid and homogenized at 6750g for 3 minutes. The extract was filtered with filter paper and topped up to 100 ml with the same extracting solution. Thereafter, 5 ml of the extracts were allowed to react with 2 ml of 2, 6-dichloroindophenol (1.6%) for 2 min. The absorbance was measured at 500 nm using a spectrophotometer (JENWAY 7315). The blank consisted of oxalic acid and 2 ml of 2, 6-dichloroindophenol (1.6%). The ascorbic acid concentration was quantified by using a standard curve of 0, 0.2, 0.5, 0.8 and 1 mg/100mlof ascorbic acid. Ascorbic acid content was reported as mg/100 g.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) and means separated by the Turkey's test at 5% level of significance using Statistical Analysis System (SAS version 9.2) with General Linear Model (GLM) procedure. Orthogonal contrast was performed on existing varieties vs clones(SAS institute Inc., 2008).

RESULTS AND DISCUSSION

Morphological characteristics of potatoes

The size of studied potatoes had the highest percentage of potatoes above 40mm in almost all cultivars. The difference in potato size was statistically significant at ($P < 0.05$). Mabondo had the lowest percentage 85.67% and the highest was forCIP392617.54 at 93.33% of tubers above 40 mm and the exception was onCIP399075.22 where 90% of tubers were below 40 mm and 10% remaining ranged from 40 to 50mm of diameter as presented in Table 1. Based on the classification of Kabira and Lemaga (2003) crisps processing requires potatoes of 40 to 60mm and French fries above 50 mm. In this regards, all the potatoes studied had suitable size for crisps and French fries processing except CIP399075.22. Boiling and baking also require potatoes of 40mm of diameter and above. However, the size of CIP399075.22 is convenient for canned potatoes which requires 20 to 35 mm (Marwaha *et al.*, 2010). Potato products require different size depending on their nature.

Table 1. Potato size in diameter

	Cultivars	<40 mm	40-50mm	50-60mm	>60mm
Varieties	Gikungu	12.67±1.20^{b}	12.67±1.45^{abc}	46.33±3.18^{ab}	28.33±1.67^{bc}
	Kigega	13.33±6.01^{b}	13.33±1.67^{abc}	30.33±2.91^{e}	43.00±3.00^{a}
	Kinigi	8.33±1.67^{b}	6.00±1.00^{c}	47.33±1.45^{ab}	38.33±1.67^{ab}
	Kirundo	8.33±3.33^{b}	12.00±1.53^{abc}	33.00±1.53^{de}	46.67±3.33^{a}
	Mabondo	14.33±0.67^{b}	12.00±2.00^{abc}	53.67±1.86^{a}	20.00±2.89^{c}
	Sangema	11.00±1.00^{b}	18.67±1.86^{ab}	42.00±1.53^{bcd}	28.33±3.33^{bc}
Clones	CIP399075.22	90.00±2.89^{a}	10.00±2.89^{bc}	0.00±00^{f}	0.00±0.00^{d}
	CIP392617.54	6.67±1.67 ^{b}	11.33±1.33^{abc}	35.33±2.60^{cde}	46.67±1.67^{a}
	CIP393251.64	13.33±1.67^{b}	19.33±2.33^{a}	45.67±2.33^{abc}	21.67±1.67^{c}
	CIP 399062.115	8.33±1.67^{b}	11.33±1.33^{abc}	44.00±2.08^{abc}	36.00±2.08^{ab}
	CV	23.16	24.60	9.76	13.55
	MSD	12.634	9.121	10.79	12.254

MSD: Minimum significant deference; Means followed by the same letter in the column do not differ by Tukey's test at 5%.

The colours of the skin were categorized as white, yellow, red, pink and purple. Similarly, most of flesh colours were yellow and white as shown in Table 2. The colour of potato has influence on consumer choice of fresh potatoes as some consumers prefer certain colours more than others. Potato colours were associated to phytochemicals (Ezekiel *et al.*, 2013). For processing purpose, white and yellow flesh potatoes can both be used for French fries and crisps, while white is more preferred for French fries and yellow for crisps. However, red or purple flesh potatoes are not suitable for French fries, crisps and other products due to the colour of final products which may be objectionable to some consumers.

The shapes of potatoes were classified as round, oblong and oval as presented in Table 2. Due to the shape of end products, round ones are preferred for crisps and oval ones are preferred for French fries (Kabira and Lemaga, 2003). It was further reported that round to oval are preferred for dehydrated products, oblong for French fries, round to oval for chips and canned potatoes (Marwaha *et al.*, 2010). Potato shape is of important consideration as it influences the shape of the final products.

Number of eyes and eye depth were also studied and they ranged from 6 for CIP399075.22, Kigega and Kinigi to 12 for Mabondo and the difference was statistically significant at ($P< 0.05$). Considering eye depth, the majority had shallow and medium eyes except Kinigi and CIP392617.54 which had deep eyes as shown in Table 2.Abong *et al.* (2010)classified eye depth as shallow (0.00-0.20 mm), medium (0.20- 0.50 mm) and deep (>0.50 mm). Many and deep eyes influence peeling losses of potatoes.

Phytochemical composition of potato tubers

Total phenols

Total phenols of potato cultivars in this study were statistically significantly different at ($P<0.05$). Orthogonal contrast showed asignificant difference between existing varieties and clones at ($P < 0.05$). On average existing varieties had higher total phenols than clones. Total phenols ranged from 17.80 to 21.52 mg/100g GAE as presented in Table 3.The highest total phenol was found in Gikungu and the lowest in Kirundo. These results align with phenolic compounds ranging from 5 to 30mg/100g (Lister and Munro, 2000). However, Lee *et al.* (2016) reported 168.44 to 423.92 mg/100g GAE in dried samples in white and colored potatoes. Phenolic contentis affected by genotype, agronomic factors, postharvest storage, cooking and processing (Ezekiel *et al.*, 2013).

Table 2. Morphological characteristics of potato tubers

	Cultivars	Skin color	Flesh color	Shape	Number of eyes	Eye characteristics
Varieties	Gikungu	Red	Yellow	Oval	6.33±0.33^{bc}	Shallow
	Kigega	Light yellow with pink eyes	White	Oblong	5.67±1.20^{c}	Shallow
	Kinigi	Purple	Light yellow	Round	6.33±0.33^{bc}	Deep
	Kirundo	White	White	Oblong	11.67±0.33^{a}	Medium
	Mabondo	Pink	Light yellow	Oblong to Oval	12.00±1.73^{a}	Medium
	Sangema	Light pink	Light yellow	Oblong	10.00±0.58^{ab}	Shallow
Clones	CIP399075.22	Light yellow	Yellow	Oblong to Oval	5.67±0.33^{c}	Shallow
	CIP392617.54	Pink and light yellow	White	Round	10.33±0.88^{ab}	Deep
	CIP393251.64	Red with pink eyes	Light yellow	Round	9.67±0.67^{abc}	Medium
	CIP 399062.115	Light yellow with pink eyes	Light yellow	Oblong	10.00±0.58^{ab}	Medium

Means followed by the same letter in the column do not differ by Tukey's test at 5%.

Phenolic content were reported to be high in potatoes with purple skin and purple flesh, followed by red skin and red flesh and yellow skin with yellow flesh followed (Ezekiel *et al*., 2013). There was no red nor purple flesh potatoes in this study. Potatoes with red or purple skin had significantly higher total phenols at ($P < 0.0$) than potatoes with white or yellow skin. Flesh of studied potatoes were either yellow or white. Varieties had more total phenols than clones. However, potatoes with red and purple skin had more phenolic compounds than white or yellow potatoes. Therefore, phenolic compounds are associated with colour of potatoes. Phenolic compounds are important for human health due to their role in protection against oxidative diseases. Moreover, phenolic compounds have been reported to decrease risk of chronic diseases like cancer, heart diseases, and diabetes (Ezekiel *et al*., 2013; Lee *et al*., 2016). Further beneficial effect of phenolic compounds were reported to include bacteria and virus growth inhibition, antiglycemic, inhibition and destruction of cancer cells, anti-inflammatory and vasodilatory properties(Singh and Kaur, 2009; Akyol *et al*., 2016).Potatoes are good source of phenols and they protect the body against oxidative diseases.

Total Anthocyanins

Anthocyanins are plant pigments which are responsible for colours. Total anthocyanins in potato cultivars in this study were statistically significantly different at ($P < 0.05$). Orthogonal contrast showed a significant difference between anthocyanins in varieties and in the clones at ($P < 0.05$). On average, varieties had higher anthocyanins than the clones. Total anthocyanin content ranged from 0.24 to 1.46 mg/100gC3GEas presented in Table 3. CIP399075.22 had the lowest amount of anthocyanin, while Gikungu had the highest. Anthocyanin of potato was reported to range from 61.5 to 573.5 mg/kg C3GE FWB being higher in dark coloured potatoes (Hamouz *et al*., 2011). Anthocyanin for white colored potatoes was found to be 1.56 mg/100 g and for coloured potatoes 89.95 mg/100 g of dried samples (Lee *et al*., 2016). It was further reported that potatoes with red skin and white flesh have less than 1.5 mg/100g FW of anthocyanin content (Brown, 2008).

Table 3. Phytonutrients of potato in mg/100g of fresh weight

	Cultivars	Total Phenols	Total Anthocyanins	Total Carotenoids	Vitamin C
Varieties	Gikungu	21.52±0.22^{a}	1.46±0.06^{a}	0.13±0.03^{bc}	9.21±0.27^{d}
	Kigega	18.40±0.44^{b}	0.74±0.10^{c}	0.05±0.03^{e}	8.66±0.57^{d}
	Kinigi	20.07±0.34^{ab}	1.31±0.12^{ab}	0.07±0.00^{de}	15.33±0.41^{b}
	Kirundo	17.80±0.42^{b}	0.43±0.07^{d}	0.07±0.03^{de}	8.24 ±0.51^{d}
	Mabondo	19.48±0.32^{ab}	1.12±0.13^{b}	0.08±0.03^{de}	9.57±0.53^{cd}
	Sangema	19.43±0.10^{ab}	1.10±0.05^{b}	0.11±0.03^{c}	5.31±0.33^{d}
Clones	CIP399075.22	19.99±0.17^{ab}	0.24±0.08^{d}	0.19±0.04^{a}	26.60±0.48^{a}
	CIP392617.54	17.88±0.33^{b}	0.77±0.11^{c}	0.09±0.03^{d}	15.58±0.40^{b}
	CIP393251.64	21.11±0.40^{a}	1.21±0.102^{b}	0.07±0.03^{de}	7.58±0.29^{d}
	CIP 399062.115	18.54±0.33^{b}	0.38±0.03^{d}	0.14±0.03^{b}	14.70±0.32^{bc}
	CV	4.46	9.89	6.27	15.19
	LSD	2.5334	0.253	0.021	5.3719

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in the column do not differ by Tukey's test at 5%.

Anthocyanin of potatoes in this study was low and this might have been caused by cultivars which do not have a visible colouration in the flesh where all potatoes had yellow or white flesh colours. Potatoes with red and purple skin had higher anthocyanins than those with yellow or white colours. Apart from variety genotype, anthocyanin content is increased due to abiotic stress (Hamouz *et al*., 2011). Anthocyanin was reported to have antioxidant properties and potatoes with coloured flesh have more antioxidant than skin coloured alone (Lister and Munro, 2000; Brown, 2008). Antioxidant in purple potatoes was 5.03 times higher than white and yellow coloured flesh potato, while it was 4.34 higher in red fleshed potatoes than in white or yellow coloured flesh potatoes (Hamouz *et al*., 2011). On average total anthocyanins were higher in varieties than in clones. Coloured potatoes had more anthocyanins than non-coloured ones. Anthocyanins in potatoes play a role of customer attraction and antioxidant properties.

Total carotenoids

Carotenoids are plant pigments governing colours like red, yellow and orange in many fruits and vegetables. Total carotenoid of potato cultivars in this study were statistically significantly different at ($P < 0.05$). Orthogonal contrast revealed that there was a significant difference between varieties and clones. On average, clones had higher total carotenoids than varieties. They varied from 0.05 to 0.19mg/100g. The highest amount of total carotenoids was for CIP399075.22, while the lowest was for Kigega as shown in Table 3. Carotenoids from organically grown potato was reported to range from 0.089 to 0.385mg/100g FWB and 0.068 to 0.371 mg/100g FWB for conventionally grown potatoes (Murniece *et al*., 2014) which align with the results of this study. Total carotenoids in potato is very low comparing to sweet potato which can have 0.1 to 7.5 mg/100 FWB and dark varieties can have up to 20 mg/100g(Lister and Munro, 2000). Yellow fleshed potatoes had more carotenoids than white fleshed ones. Carotenoids are involved in protection against different diseases due to their ability to scavenge singlet oxygen generated during light induced lipid oxidation (Ezekiel *et al*., 2013;Lee *et al*., 2016). The carotenoids in potatoes are identical to those in the human retina and are involved in nutritional therapies for macular degeneration and cataracts (Brown, 2008). Total carotenoids were higher in clones than varieties on average. Consumption of carotenoid rich potatoes helps to protect the body against diseases related to oxidative stress.

Vitamin C content in potato

Vitamin C of potato cultivars in this study was statistically significantly different at ($P < 0.05$). Orthogonal contrast showed that there was a significant difference between vitamin C of clones and varieties at ($P < 0.05$). Clones had higher vitamin C than varieties. Vitamin C varied from 5.31 to 26.60 mg/100g as presented in Table 3. CIP399075.22 had the highest, while Sangema had the lowest of vitamin C content. The results in this study align with the ones reported by (Lister and Munro, 2000) which ranged from 1 to 54 mg/100g on FWB where majority were between 10 to 25 mg/100g. Vitamin C is essential for avoidance of scurvy with antioxidant properties. It is also an excellent antioxidant and it helps in prevention of oxidative stress (Lee *et al*., 2016). Clones had higher vitamin C content than varieties on average and this might have been influenced by varieties used for breeding. Regular consumption of potato can help to meet requirements of vitamin C for the body thereby protecting it against different diseases which are associated to oxidation.

CONCLUSION

The tubers morphological quality like color, shape, size, number of eyes and depth of eyes, as well as phytonutrients like ascorbic acid, total phenols, total anthocyanins and total carotenoids were investigated in this study. Morphological characteristics of studied cultivars are suitable for production of different potatoes products. CIP399075.22 was dominated by small tubers and it is favorable for canning and starch production. Kinigi and CIP392617.54 had deep eyes which can increase peeling losses. Varieties had high total phenols and total anthocyanins, while clones had higher total carotenoids and Vitamin C. Skin coloured potatoes had higher total phenols and total anthocyanins, while yellow flesh coloured potatoes had higher total carotenoids. Potatoes in this study can be used source of phytonutrients for protection against different oxidative diseasesand are suitable for various potato products.

ACKNOWLEDGEMENTS

The authors are grateful for NUFFIC, NICHE 185/RWA and Q- point for funding this research, the University of Rwanda (UR) for providing study leave for post graduate studies, farm and laboratory facilities. Egerton University for admitting the student and providing laboratory facilities. Rwanda Agriculture Board (RAB) for providing planting materials and Hollanda Fair Food (Winnaz) for processing facilities.

REFERENCES

[1] Abong, G. O., Okoth, M. W., Imungi, J. K.and Kabira, J. N. (2010). Evaluation of selected Kenyan potato cultivars for processing into potato crisps. Agric. Biol. J. N. Am., **1**(15):886–893. https://doi.org/10.5251/abjna.2010.1.5.886.893

[2] Akyol, H., Riciputi, Y., Capanoglu, E., Caboni, M. F.and Verardo, V. (2016). Phenolic compounds in the potato and its byproducts: An overview. Int. J. Mol.Sci., **17**(6): 1–9. https://doi.org/10.3390/ijms17060835

[3] Brown, C. R. (2008). Breeding for phytonutrient enhancement of potato. Am. J. Pot. Res., **85:** 298–307. https://doi.org/10.1007/s12230-008-9028-0

[4] Brown, C. R., Durst, R. W., Wrolstad, R.and Jong, W. De. (2008). Variability of phytonutrient content of potato in relation to growing location and cooking method. Potato Res., **51**:259–270. https://doi.org/10.1007/s11540-008-9115-0

[5] Burke, J. J. (2016). Growing the potato crop. Vita, Equity House, Upper Ormond Quay, Dublin 7, Ireland: 19-230.

[6] Climate-Data.Org. (2016). https://en.climate-data.org/location/323937/. viewed on July16th, 2016.

[7] Donnelly, D. and Kubow, S. (2011). Role of potato in human health. *CRAAQ-Colloque Sur La Pomme de Terre*, 1–6.

[8] Ezekiel, R., Singh, N., Sharma, S. and Kaur, A. (2013). Beneficial phytochemicals in potato — a review. Food Res Int., 50:487–496. https://doi.org/10.1016/j.foodres.2011.04.025

[9] FAO. (2008). New light on a hidden treasure. International year of poto 2008.FAO, Rome, Italy: 51p. *http://www. potato2008.org/en/index.html (Accessed on 20/10/2017).*

[10] Grudzińska, M., Czerko, Z., Zarzyńska, K. and Borowska-Komenda, M. (2016). Bioactive compounds in potato tubers : effects of farming system , cooking method , and flesh color. PLoS ONE, **11**(5): 1–13. https://doi.org/10.1371/journal.pone.0153980

[11] Hamouz, K., Lachman, J., Pazderů, K., Tomášek, J., Hejtmánková, K. and Pivec, V. (2011). Differences in anthocyanin content and antioxidant activity of

potato tubers with different flesh colour. Plant Soil Environ., **57**(10): 478–485.

[12] Iqbal, K., Khan, A., Ali, M. M., and Khattak, K. (2004). Biological significance of ascorbic acid (vitamin C) in human health – a review. Pakistan J.Nutr., ***3***(1): 5–13.

[13] Kabira, J. N. and Lemaga, B. (2003). Potato processing. Quality evaluation procedures for research and food industry applications in East and Central Africa. Kenya Agricultural research Publication, Nairobi, Kenya: 1-19.

[14] Lee, S. H., Oh, S. H., Hwang, I. G., Kim, H. Y., Woo, K. S., Woo, S. H., … Jeong, H. S. (2016). Antioxidant contents and antioxidant activities of white and colored potatoes (Solanum tuberosum L.). Prev.Nutr. Food Sci., **21**(2): 110–116. https://doi.org/10.3746/pnf.2016.21.2.110

[15] Lister, C. E. and Munro, J. (2000). Nutrition and health qualities of potatoes - a future focus. Crop & Food Research Confidential Report. New Zealand Institute of Crop and food Research Limited. Private Bag 4704, Christchurch, New Zealand **143**: 1–47.

[16] Liu, R. H. (2013). Health-promoting components of fruits and vegetables in the diet. ASN, **4**(3): 384–392. https://doi.org/10.3945/an.112.003517.convenient

[17] Marwaha, R. S., Pandey, S. K., Dinesh, K., Singh, S. V. and Parveen, K. (2010). Potato processing scenario in India : Industrial constraints , future projections , challenges ahead and remedies – A review. J. Food Sci. Technol., **47**(2): 137–156. https://doi.org/10.1007/s13197-010-0026-0

[18] Murniece, I., Tomsone, L., Skrabule, I., and Vaivode, A. (2014). Carotenoids and total phenolic compounds in potatoes with different flesh colour. In *Foodbalt2014*: 206–211.

[19] Robles-Ramírez, M. del C., Monterrubio-lópez, R., Mora-escobedo, R. and Beltrán-orozco, maria del C. (2016). Evaluation of extracts from potato and tomato wastes as natural antioxidant additives. Archivos Latinoamericanos de Nutrición,**66**(1): 66–73.

[20] SAS institute Inc.(2008). *SAS/STAT® 9.2 User's Guide. USA: Cary*, NC: SAS Institute Inc.

[21] Singh, J. and Kaur, L. (2009). Advances in potato chemistry and technology (1st edit). New York, USA.: Elsevier Inc: 1-458.

[22] Sun, C., Wu, Z., Wang, Z. and Zhang, H. (2015). Effect of ethanol / water solvents on phenolic profiles and antioxidant properties of Beijing propolis extracts. Evid. based Complent. Altern. Med.2015, 595393.

[23] Tokusoglu, O. and Yildirim, Z. (2012). Effects of cooking methods on the anthocyanin levels and antioxidant activity of local Turkish sweet potato [Ipomoea batatas (L .) LAM] cultivar Hatay kirmizi: boiling, steaming and frying effects. Turk. J Field Crops,**17**(1), 87–90.