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CHARACTERISATION OF POTATO VARIETIES COMMONLY GROWN IN UGANDA FOR FOOD PROCESSING SUITABILITY

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ABSTRACT

Potato (*Solanum tuberosum* L.) is an important crop for food and income generation in Uganda. However, lack of data on the physico-chemical characteristics of the major potato varieties to support industrial-level processing is one of the major limitations. To bridge the existing information gap, nine major potato varieties grown in Uganda; namely: *Cruza, Kachpot1, Kimuli, Kinigi, Mbumbamagara, Rutuku, Rwashaki, Rwangume* and *Victoria* were characterised to generate information on physical, chemical and processing traits. The results indicated that *Kinigi* had the highest dry matter (27.2%); whereas *Rutuku* had the lowest (19.28 %). Most varieties had tubers of medium size (50-60 mm), round in shape with medium eye depth. *Kimuli* recorded the highest (0.55 g 100 g^{-1} FW) levels of reducing sugars; whereas *Kinigi* had the lowest (0.02 g 100 g^{-1} FW). Cluster analysis separated the varieties into three groups; group 1 included varieties *Cruza, Kimuli* and *Rwangume,* which were found unsuitable for processing French fries and crisps due to high levels of reducing sugars; but are excellent candidates for preparation of mashed potato and salads. The second group included *Kachpot1, Kinigi* and *Rwashaki* and was found suitable for processing French fries, crisps and starch due to high dry matter and low reducing sugars. Group 3 included *Mbumbamagara, Rutuku* and *Victoria* and was found only suitable for production of potato flour, mashed potato and salads due to low dry matter content and small tubers.The information generated by the study is important in guiding interventions aimed at improving the potato value chain in Uganda and its contribution to socio-economic development.

Key Words: French fries, reducing sugars, *Solanum tuberosum*

RÉSUMÉ

La pomme de terre (*Solanum tuberosum* L.) est une culture importante pour l'alimentation et la génération de revenus en Ouganda. Cependant, le manque de données sur les caractéristiques physico-chimiques des principales variétés de pommes de terre pour appuyer la transformation au niveau industriel est

l'une des principales contraintes. Pour combler ce manque d'information, neuf variétés de pommes de terre cultivées en Ouganda, à savoir : *Cruza, Kachpot1, Kimuli, Kinigi, Mbumbamagara, Rutuku, Rwashaki, Rwangume* et *Victoria* ont été caractérisées pour générer des informations sur les traits physiques, chimiques et de transformation. Les résultats ont indiqué que *Kinigi* avait la teneur en matière sèche la plus élevée (27,2%), tandis que *Rutuku* en avait la plus faible (19,28%). La plupart des variétés avaient des tubercules de taille moyenne (50-60 mm), de forme ronde avec une profondeur d'œil moyenne. *Kimuli* a enregistré la concentration la plus élevée (0,55 g 100 g^{-1} FW) de sucres réducteurs, tandis que *Kinigi* a enregistré la plus faible (0,02 g 100 g^{-1} FW). L'analyse typologique (Cluster) a synthétisé les variétés en trois groupes. Le groupe 1 comprenait les variétés *Cruza, Kimuli* e*t Rwangume*, qui se sont avérées inadaptées à la production des frites et des chips en raison de leurs niveaux élevés de sucres réducteurs, mais sont d'excellents candidats pour la préparation de purée de pommes de terre et de salades. Le deuxième groupe comprenait *Kachpot1, Kinigi* et *Rwashaki* et s'est avéré adapté à la préparation des frites, des chips et de l'amidon en raison de leur matière sèche élevée et de faibles concentrations en sucres réducteurs. Le groupe 3 comprenait *Mbumbamagara, Rutuku* et *Victoria* et n'était adapté qu'à la production de farine de pommes de terre, de purée de pommes de terre et de salades en raison de la faible teneur en matière sèche et des petits tubercules. Les informations générées par cette étude sont importantes pour guider les interventions visant à améliorer la chaîne de valeur de la pomme de terre en Ouganda et sa contribution au développement socio-économique.

Mots Clés : Chips, frites, transformation, *Solanum tuberosum*

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the major staple food world wide and in Uganda. The crop has been classified among the commodities with potential to make a significant contribution to increasing rural incomes and improving food and nutrition security (Mugisha *et al*., 2017). According to Woolfe (1987), 100 g of raw potato offers 80 kilo calories of energy and comprises 18.5 g carbohydrate, 2.1 g protein, 1.5 g dietary fibre, 17 mg vitamin C, 11 mg riboflavin, 1.2 mg niacin, and 13 mg calcium. Potato is also high in phytochemicals (251.12 mg g^{-1}) (Kipkoech Kirui *et al*., 2018), antioxidants (596 mg 100 g^{-1}), potassium (430 mg 100 g^{-1}), and low cholesterol (Storey, 2007), thus it is regarded as a health promoter (Ezekiel *et al.,* 2013).

In addition to its domestic use, a number of products namely; French fries, potato crisp, potato patties, dehydrated potato granules, potato flour and flakes are processed from potatoes on a commercial basis (Ugonna *et al*., 2013). However, processed products such as French fries and crisps are of significant importance as they have gained tremendous economic value in the food industry due to their ability to provide convenience food with enhanced nutritional value (Keijbets, 2008).

At larger scale processing, the quality of finished potato product is affected by the genotype which dictates on the physico-chemical and functional attributes of raw potato tubers (Abbasi *et al.*, 2019). In Uganda, despite the growing demand for potato processed products and the importance of potato, its potential has not been fully realised. Use of non-improved or uncertified genotypes is one of the major constraints affecting the potato processing and utilisation in Uganda (Mbowa and Mwesigye, 2016). Different potato varieties are being cultivated due to the suitable conditions in particular agro-ecological zones and farmers preferences. As a result, the nutritional and processing traits of the major potatoes varieties grown in Uganda were not well documented. The objective of this study was to assess the suitability of the potato varieties commonly grown in Uganda, for processing into viable commercial products.

METHODOLOGY

Sample collection. Nine potato varieties, mostly cultivated in Uganda namely; *Cruza, Kachpot1, Kimuli, Kinigi, Mbumbamagara, Rutuku, Rwashaki, Rwangume* and *Victoria,* were obtained from Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI), in Kabale, South-western Uganda. The potatoes were produced under standard agronomic practices, harvested at mature stage (four months) and transported to the laboratory at the School of Food Technology, Nutrition and Bio-Engineering, Makerere University, Kampala, Uganda for physico-chemical analysis.

Physical potato tuber characteristics. The physical tuber characteristics, namely; shape, size, skin, flesh colour and eye depth were determined according to the methods described according to Abong (2008). The shape of 10 tubers per variety was determined using the objective description form (USDA, 2012). The shapes were recorded as compressed, round, oval, oblong or long.

The size (diameter) and eye depth of the tubers were determined using a Vernier Caliper (AARSON, India); and the depth gauge of the Vernier caliper, respectively. The diameter was taken transversally on the tuber; whereas eye depth was measured by inserting the depth gauge in the eye of the tuber until the strip of the Vernier caliper with graduations touched the potato. Size was categorised as small (<50 mm), medium (50-60 mm) or large (>60 mm). Eye depth was recorded as shallow (<0.20 mm), medium (0.20-0.50 mm) or deep (>0.50 mm).

For skin colour, five representative tubers were picked randomly from a bag containing approximately 10 kg of each variety and visually examined for colour, which was recorded as cream, red, white, pink or purple. Each tuber was then cut with a stainless steel knife longitudinally and flesh colour recorded as white, yellow or cream based on the objective description form by (USDA, 2012).

Specific gravity of the potato tubers was determined according to the weight under water method (Ludwig, 1972). About six kilogrammes of tuber material were meticulously washed in water to remove adhering soil. The tubers were then air-dried and weighed in open air using a hanging weighing scale (Salter, United Kingdom) to 5 kg. A single tuber was cut, whenever required, to adjust the total weight exactly to 5 kg. The 5 kg tubers were immersed in clean water and under water weight (UWW) was recorded. The specific gravity was then calculated using the following formula:

$$\text{Specific gravity} = \frac{\text{Weight in air (in grams)}}{\text{Weight in air} - \text{Under Water Weight}}$$

Dry matter content was determined using the dry air oven method (AOAC, 1990). Briefly, five whole tubers were randomly picked from a bag containing 10 kg of each variety and cut into small slices (1-2 mm) and mixed thoroughly. About 20 g samples were dried at 80 °C for 72 hours in an air forced oven. Dry matter content was calculated as follows;

$$\text{Dry matter content (\%)} = \frac{\text{Dried weight}}{\text{Intial weight}} \times 100$$

Chemicals and reagents. Physiological amino acid standards, A9906 10 ml, Ortho-Phthalaldehyde and 9-fluorenyl-methoxycarbonyl Chloride, were all HPLC grade and were purchased from Sigma Aldrich UK. Potassium Dihydrogen Phosphate (KH_2PO_4), glucose, fructose and sucrose standards were of chromatography grade and were purchased from Loba chemicals, India. All vitamin standards (Thiamine Hydrochloride, Nicotinic Acid, Pyridoxine Hydrochloride, Folic Acid and Riboflavin) were of chromatography grade and were purchased from Sigma Aldrich, UK. Analytical reagent-

grade acetonitrile was purchased from Carlo Erba, UK while Methanol, Hydrochloric Acid and, Potassium Hydroxide were obtained from Rankem, India. The water used for HPLC and sampling was prepared with a Millipore Simplicity instrument (Millipore, Molsheim, France).

Sample preparation. The potato tubers were washed and sliced into 10 mm thick transverse slices using a stainless steel knife. Subsequently, the potato slices were freeze-dried using a SCIENTZ-18ND equipment (Zhejiang, China). Parameters were set at: freezing temperature: (–56 ± 1°C) for 24 hr; drying process: (40 ± 1°C) at maximum vacuum (pressure: <10Pa) during 24 hr. The dried slices of potatoes were milled into powder using a mortar and pestle and stored in polyethylene bags at room temperature.

Amino acid profiling. For each sample, 100 mg of the lyophilised powder were placed in 16 -25 mm screw-cap tubes and hydrochloric acid (6 M, 10 ml) containing 50 mg crystals of phenol was added. The tubes were closed under nitrogen, placed in an electric oven at 110 °C for 36 hrs. The hydrolysate was cooled, and the acid evaporated in a vacuum oven. The slurry was reconstituted with 20 ml of 0.1M HCL and filtered through micro-filter 0.45 µm diameter 25 mm. One (1) ml of amino acid standards solution and sample hydrolysates (1000 µl) each were placed in a HPLC vial and dried in a vacuum oven for 40 min at 60 °C. Approximately 200 µl Methanol–ACN–H_2O (45:45:10) was used to reconstitute the samples and standards, which was followed by vortexing for 1 min for each. About 100 µl of borate buffer pH 8.0 was added to each vial containing standards and samples; followed by Ortho-Phthalaldehyde (OPA) (100 µl) for derivatisation of primary Amino Acids and 100 µl of 9-fluorenyl-methoxycarbonyl chloride (FMOC) for secondary amino acids. The vial was filled to 1ml, using the solvent Methanol–ACN–H_2O (45:45:10). HPLC were performed with a SHIMADZU NEXERA (Shimadzu, Japan). LC-20AD pump at 0.8ml/min, a 20-µl injection loop, and RF-20a fluorescence detector were used. Laboratory solution 5.97 software was used for data acquisition. Temperature was controlled at 40 ± 0.1 °C with a CTO-10AVP column heater. Amino acids were separated on a SUPELCO 25 cm×4.6 cm x 5 µm, ODS2 reversed-phase column. The amount of sample injected using SIL-20A auto-sampler was 20 µl. The mobile phase was a gradient prepared from two solutions, A and B. Solution A was 40 mM potassium di-hydrogen phosphate (pH adjusted to 6.4 with potassium hydroxide pellets). Solution B was acetonitrile/Methanol/water (45:45:10 (v/v)). The excitation wavelength was 250 nm and emission wave length was 395 nm.

Determination of sugars. Reducing sugars were extracted by the method described by Muttucumaru *et al*. (2013). Onegramme of the lyophilized powder of each variety was mixed with methanol/chloroform (75:25 v/v) and sonicated. After 15 min, the sample was placed in -20 °C environment and latter centrifuged at 15000 rpm 5 °C. The supernatant was collected and placed in 1.5 ml HPLC vial and the solvent dried in vacuum oven. The residue was reconstituted using mobile phase 1.5 ml ACN/H_2O (75/25). The sugar content was determined using HPLC equipment (Shimadzu, Japan) with RID-20A refraction index detector (equilibrated at 40 °C and well purged using the mobile phase) and a normal phase-amide column Supelco NH2 250 mm x 5 µm x 4.6 mm. Separation temperature for column oven CTO-10AVP was set at 40 °C. Automated injections of 20 µl were performed using SIL-20A auto sampler. LC-20AD running on isocratic mode of ACN/H_2O (75/25) was set at 1ml per minute The individual sugars (glucose, fructose and sucrose) were identified and quantified by external calibration using Shimadzu Lab Solutions software. Each extract was analysed

in triplicates, and the results expressed as grammes per kilogramme of fresh weight (FW).

Determination of starch content. The starch content of the potato tubers was determined using a spectrophotometer as described by Ross (1959). About 250 mg of powdered dry tuber samples were autoclaved for hydrolyzation in a solution of 10 ml of distilled water and 0.5 ml of concentrated HCl during 20 min at 120 °C. After cooling, the samples were neutralised with NaOH (50%) to pH=7.0. Then, 1 ml of the neutralised solution was added to 3 ml of distilled water and 0.5 ml of 2, 4-dinitrophenol solution (0.038 M). After vortexing, starch concentrations were estimated based on the glucose concentration measured at 600 nm.

Determination of B vitamins. Vitamin B group was extracted according to AOAC method (AOAC, 1990). Potato powder (2 g) was placed in Eppendorf tube 50 ml containing 30 ml deionised water. The contents were extracted using mechanical shaker for 1 hr; after which 50 mg of Taka diastase enzyme was added. The preparation was stored at 37 °C overnight. One milliter of the extract was then filtered through syringe micro-filter 0.45 µm 25 mm diameters. Quantification of vitamin B content was accomplished by comparison to vitamin B standards. Standard stock solutions with 100 mg l^{-1} for vitamins; thiamine, riboflavin, nicotinic acid, pyridoxine, and folic acid were prepared and dissolved in buffer pH 7.0 (potassium di-hydrogen phosphate). The stock solution was adjusted to pH 9.2 to completely dissolve the folic acid and riboflavin vitamins. Chromatographic separation was achieved on a reversed phase-(RP-) HPLC column (SUPELCO C18; 250×4.6 mm i.d., 5 µm) through the gradient elution (Mobile Phase A Methanol 100%) mobile phase B buffer (100 mM potassium di-hydrogen phosphate pH 7.0). The vitamins were detected using HPLC equipment (Shimadzu, Japan) with PDA M20A detector at 254 nm. CTO-10ASVP Column oven temperature was maintained at 40°C throughout the separation. Quantification of the vitamins against external standards was performed using Shimadzu Lab solutions 5.97 software.

Total phenolic compounds. Phenolic content of the potato tubers was determined according to the Folin-Ciocalteu spectrophotometric method (Singleton *et al*., 1999). Five grammes of the homogenised sample were extracted with 50 ml of ethanol water solution (80%) in a conical flask with a magnetic stirrer (magnet 4.0×0.5 cm) at 700 rpm for 1 h at room temperature (20±1 °C). The potato extracts were then filtered through a filter paper No 89. About 0.5 ml of the sample extract was added to 2.5 ml of Folin-Ciocalteu reagent (diluted 10 times with water) and, after 3 minutes 2 ml of sodium carbonate (Na_2CO_3) (75 g l^{-1}) were added. The sample was mixed and incubated for 30 minutes at room temperature. The absorbance was determined using a spectrophotometer at 765 nm. The same procedure was repeated for the standard solution of gallic acid and the calibration line was construed. Based on the measured absorbance, the concentration of phenolics was read from the calibration line; then the content of phenolics in extracts was expressed in terms of Gallic Acid Equivalent (mg of GAE100 g^{-1} of fresh potato).

Total flavonoid content. Total flavonoid content was estimated by aluminum chloride method (Quettier-deleu *et al.,* 2000). Potato extract samples (0.5 ml) were mixed with 2.5 ml of distilled water and 150 µl $NaNO_2$ solution (5%). The contents were vortexed for 10 seconds and left at room temperature for 5 min. Then, 300 µl $AlCl_3$ (10%) were added and contents vortexed and incubated at room temperature for 6 minutes. One (1) ml NaOH (1 M) and 550 µl of distilled water were added. The solution was mixed well and allowed to

stand for 15 min. The absorbance for each sample was measured at 510 nm. Total flavonoid content was expressed as quercetin equivalent in mg100 g^{-1} of fresh potato.

Total tannins. Tannins (tannic acid) in potato were estimated according to a method described by Saxena *et al.* (2013). Approximately 0.2 g of freeze-dried powdered potato was weighed into 250 ml conical flasks and 35 ml water added. The flask was heated gently and allowed to boil for 30 min. The resultant solution was transferred into 50 ml polypropylene tube and topped to 50 ml using deionised water and centrifuged at 1902 x g for 10 min. The supernatant was collected into separate vials. Into a 96 well microtiter plate, 50 µl of sample (supernatant), standards (tannic acid) and blank solution was added, followed by addition of 50 µl of Folin–Denis reagent and 100 µl of 7% sodium carbonate solution before mixing by priming using multichannel pipette. The absorbance reading was obtained at 700 nm after 30 min. A standard calibration curve of Tannic acid was used to calculate the concentration of total tannins in mg per 100 g of the fresh sample.

Statistical analysis. Data for physical characteristics and chemical properties were analysed using the GenStat software (14th Edition). Results were subjected to statistical analysis by considering the varieties as variation source, using one-way analysis of variance (ANOVA). The multiple comparison test of Tukey was used to separate the means at $P<0.05$. In order to group and select potatoes varieties with similar qualities, a cluster analysis was performed. Pearson Correlation Analysis was also performed to determine linear relationships where necessary.

RESULTS

Physical characteristics of potato varieties. Physical tuber characteristics of the nine local potato varieties grown in Uganda are presented in Table 1. The morphology, external and internal colour of the potato varieties are indicated in Figure 1. The results indicate that seven varieties, namely; *Kachpot1, Kimuli, Kinigi, Mbumbamagara, Rwashaki, Rwangume* and *Victoria*, had round tubers. Only *Cruza* and *Rutuku* had oblong tubers. Varieties *Cruza, Kachpot1, Kinigi, Mbumbamagara, Rutuku, Rwangume* and *Victoria* had tubers with medium eye depths; whereas *Rwashaki* had deep eyes. Only *Kimuli* had tubers with shallow eyes.

Kachpot1, Rwangume and *Rwashaki* had red skin colour; whereas *Kinigi* had a red skin predominant colour with purple intense colour around eyes. On the other hand, *Victoria* and *Rutuku* had pink and light red skin colour, respectively; while *Kimuli* and

TABLE 1. Characteristics of nine potato varieties grown in Uganda

Variety/Cultivar	Skin colour	Flesh colour	Shape	Eye depth
Cruza	White	White with purple ring	Oblong	Medium
Kachpot1 (CIP 382171.4)	Red	Light yellow	Round	Medium
Kimuli	White cream	Cream	Round	Shallow
Kinigi	Red/purple	Cream	Round	Medium
Mbumbamagara	White cream	White	Round	Medium
Rutuku (CIP 720097)	Light red	Cream	Oblong	Medium
Rwangume (Naropot4)	Red	Light yellow	Round	Medium
Rwashaki	Red	Light yellow	Round	Deep
Victoria (CIP 381381.20)	Pink	Light yellow	Round	Medium

Variety Cruza | Variety Kachpot1 (CIP 382171.4) | Variety Kimuli

Variety Kinigi | Variety Mbumbamagara | Variety Rutuku (CIP 720097)

Variety Rwangume (Naropot4) | Variety Rwashaki (CIP 382171.4) | Variety Victoria (CIP 381381.20)

Figure 1. Morphology and colour of the major potato varieties grown in Uganda.

Mbumbamagara had white cream skin colour whereas that of *Cruza* was almost white.

Regarding flesh colour, light yellow was the dominant colour recorded in *Kachport1, Rwangume, Rwashaki* and *Victoria;* whereas cream colour was observed in *Kimuli, Kinigi* and *Rutuku.* The flesh of *Mbumbamagara* and *Cruza* was white in colour with a purple ring as a secondary colour.

Size, specific gravity and dry matter content. Data for size, specific gravity and dry matter content of the potato varieties used in the evaluation work are summarised in Table 2. *Cruza, Kachpot1, Kachpot2, Kinigi, Mitare, Rutuku, Rwashaki, Rwangume* and *Victoria* had tuber sizes of 50 mm and above in diameter; whereas *Mbumbamagara* and *Kimuli* had small tubers of 48.44 and 48.38 mm, respectively. *Kachpot1*, *Kinigi*, *Rwangume*, *Rwashaki* and *Victoria* had the largest tuber sizes of 59 mm and above. The specific gravity of varieties varied from 1.055 in *Rutuku* to 1.104 in *Kinigi*. All the varieties, with the exception of *Rutuku* and *Kimuli,* had specific gravity of more than 1.070. Dry matter content ranged from 19.28% in *Rutuku* to 27.62% in *Kinigi*. *Kinigi* and *Rwashaki* recorded the highest dry matter content of 27.62 and 25.67%, respectively. *Kinigi* and *Rwashaki* also recorded higher specific gravity indicating a linear relationship between specific gravity and dry matter content (r=0.61).

Chemical composition of raw potato tubers

Starch and reducing sugars. Table 3 shows the starch content and reducing sugar levels at harvest in the 9 potato varieties commonly grown in Uganda. Significant differences ($P<0.05$) in starch content were observed between *Cruza-Mbumbamagara* (12%), *Kimuli-Victoria* (14%), *Kachpot1-Mbumbamagara-Rwangume* (19%) and *Kinigi-Rwashaki* (22%). There was a positive relationship between dry matter content and

TABLE 2. Size, specific gravity and dry matter content of the potato varieties grown in Uganda

Variety/Variety	Size (diameter in mm)	Specific gravity	Dry matter (%)
Cruza	51.44 ±4.45^{ab}	1.076 ±0.004^{bc}	22.13 ±0.69^{ab}
Kachpot1 (CIP 382171.4)	59.86 ±3.97^{c}	1.089 ±0.002^{cde}	22.02 ±1.93^{ab}
Kimuli	48.38 ±5.77^{a}	1.065 ±0.003^{ab}	22.51 ±0.67^{b}
Kinigi	59.67 ±3.84^{c}	1.104 ±0.003^{e}	27.62 ±0.88^{d}
Mbumbamagara	48.44 ±3.23^{a}	1.085 ±0.003^{cd}	23.78 ±0.32^{bc}
Rutuku (CIP 720097)	53.05 ±3.79^{abc}	1.055 ±0.006^{a}	19.28 ±0.13^{a}
Rwangume (Naropot4)	59.70 ±5.82^{c}	1.093 ±0.006^{de}	21.00 ±1.44^{ab}
Rwashaki	57.93 ±7.88^{bc}	1.085 ±0.009^{cd}	25.67 ±0.43^{cd}
Victoria (CIP 381381.20)	59.31 ±6.47^{c}	1.094 ±0.008^{de}	21.87 ±1.37^{ab}

Values are means ± SD. Values in a column with the same superscript are not significantly different (P > 0.05). Number of replicates (n) =3

starch content. High dry matter content was associated with high starch content (r=0.61). The results further indicated that reducing sugar content also varied significantly (P<0.05) among the major potato varieties grown in Uganda (Table 3). *Rwashaki* (0.54 g 100 g^{-1} FW) and *Kimuli* (0.55 g 100 g^{-1} FW) recorded significantly higher (P<0.05) sugar levels than *Kinigi* (0.02 g 100 g^{-1} FW). Significant differences (P<0.05) between sucrose, fructose and glucose content of different potato varieties grown in Uganda were also observed. Glucose was the most abundant sugar in most of the potato varieties (0.0096 to 0.5387 g 100 g^{-1} FW). However, sucrose was exceptionally predominant than others sugars in *Kinigi* (0.4623 g 100 g^{-1} FW). The fructose content of the potato varieties ranged from 0.0034 g 100 g^{-1} FW in *Rutuku* to 0.0251 g 100 g^{-1} FW in *Kimuli*.

Beta-carotene, total phenolic compounds, tannins and flavonoids. Data for beta-carotene, total phenolic compound (TPC), tannins and flavonoids contents in raw potato tubers are shown in Table 4. The results indicated variation in total phenolic compounds, tannins and flavonoids content among the different potato varieties. Beta carotene ranged from 1.14 mg 100 g^{-1} in *Kinigi* to 1.77 mg 100 g^{-1} in *Kimuli*. Significant differences (P<0.05) in beta-carotene content were observed between varieties. A higher beta-carotene content was recorded in *Kachpot1* (1.60 mg 100 g^{-1}) and *Kimuli* (1.77 g 100 g^{-1}) than the rest of the varieties. *Rutuku* had the highest content of total phenolic compounds (2329.72 mg GAE100 g^{-1}); followed by *Victoria* (2146.71 mg GAE100 g^{-1}) and *Mbumbamagara* (2007.77 mg GAE100 g^{-1}); whereas *Rwangume* and *Cruza* recorded the lowest TPC contents (130.00 and 73.13 mg GAE100 g^{-1}, respectively).

B vitamins. The B vitamins in raw potato tubers are shown in Table 5. Most of the potato varieties had similar contents of B vitamins. In the majority of varieties, thiamin content varied from 52 to 71 µg 100 g^{-1}; whereas folic acid concentration varied from 118 to 151 µg 100 g^{-1} with *Mbumbamagara* recorded the highest thiamin content (172.78 µg 100 g^{-1}). A significant difference (P<0.05) was observed between *Kimuli* (7.22 µg 100 g^{-1}) and the other varieties (6.56-6.73 µg 100 g^{-1}) in terms of vitamin B2 content.

Amino acid profiles. The results of amino acid profiles show that aspartic acid was the dominant free amino acid in most of the varieties, followed by glutamic acid, cysteine, and methionine (Table 6). In general, a

TABLE 3. Starch and reducing sugars content of potato varieties grown in Uganda

Variety/Variety	Starch (%)	Reducing sugars	Fructose	Glucose	Sucrose
Cruza	12.73 ±1.19^{a}	0.49 ±0.03^{bcd}	0.0072 ±0.0018^{a}	0.49 ±0.03^{bcd}	0.34 ±0.21^{ab}
Kachpot1 (CIP 382171.4)	19.94 ±0.03^{c}	0.47 ±0.01^{bcd}	0.0052 ±0.0004^{a}	0.47 ±0.01^{bcd}	0.27 ±0.08^{ab}
Kimuli	14.82 ±0.09^{b}	0.55 ±0.16^{d}	0.0251 ±0.0035^{b}	0.52 ±0.12^{d}	0.20 ±0.10^{ab}
Kinigi	22.72 ±0.02^{d}	0.02 ±0.00^{a}	0.0036 ±0.0005^{a}	0.01 ±0.00^{a}	0.46 ±0.17^{b}
Mbumbamagara	20.24 ±0.33^{c}	0.52 ±0.04^{cd}	0.0058 ±0.0016^{a}	0.51 ±0.04^{cd}	0.30 ±0.20^{ab}
Rutuku (CIP 720097)	12.40 ±0.08^{a}	0.41 ±0.00^{b}	0.0034 ±0.0007^{a}	0.41 ±0.00^{b}	0.19 ±0.02^{a}
Rwangume (Naropot4)	20.05 ±0.10^{c}	0.44 ±0.01^{bc}	0.0041 ±0.0006^{a}	0.44 ±0.01^{bc}	0.18 ±0.09^{a}
Rwashaki	23.67 ±0.19^{d}	0.54 ±0.01^{d}	0.0058 ±0.0009^{a}	0.54 ±0.00^{d}	0.24 ±0.06^{ab}
Victoria (CIP 381381.20)	15.10 ±0.11^{b}	0.47 ±0.01^{bcd}	0.0046 ±0.0008^{a}	0.46 ±0.01^{bcd}	0.18 ±0.04^{a}

Values are means ± SD. Values in a column with the same superscript are not significantly different (P > 0.05). Number of replicates (n) =3

TABLE 4. Beta-carotene, total phenolic compound, tannins and flavonoids of 9 local potato varieties grown in Uganda

Variety/Variety	Beta-carotene (in mg100 g^{-1})	Total phenolic compound in mg GAE100 g^{-1}	Tannins in mg100 g^{-1}	Flavonoids in mg100g^{-1}
Cruza	1.42 ±0.08^{bc}	73.13 ±2.44^{a}	0.13 ±0.01^{b}	3.48 ±0.57^{a}
Kachpot1 (CIP 382171.4)	1.60 ±0.07^{d}	613.46 ±68.48^{c}	0.16 ±0.01^{bc}	19.82 ±0.12^{e}
Kimuli	1.77 ±0.04^{e}	232.38 ±9.85^{b}	0.23 ±0.01^{d}	13.65 ±0.05^{cd}
Kinigi	1.14 ±0.02^{a}	1014.85 ±14.89^{d}	0.34 ±0.02^{e}	4.43 ±0.21^{a}
Mbumbamagara	1.37 ±0.04^{bc}	2007.77 ±43.69^{e}	0.49 ±0.04^{f}	7.23 ±0.43^{b}
Rutuku (CIP 720097)	1.43 ±0.02^{bc}	2329.72 ±50.37^{f}	0.18 ±0.02^{c}	11.62 ±0.56^{c}
Rwangume (Naropot4)	1.36 ±0.11^{b}	130.00 ±1.40^{ab}	0.08 ±0.01^{a}	13.76 ±1.84^{d}
Rwashaki	1.53 ±0.05^{cd}	503.77 ±8.56^{c}	0.24 ±0.01^{d}	27.06 ±0.45^{f}
Victoria (CIP 381381.20)	1.54 ±0.03^{cd}	2146.71 ±115.43^{e}	0.31 ±0.00^{e}	4.98 ±0.70^{a}

Values are means ± SD. Values in a column with the same superscript are not significantly different (P> 0.05). Number of replicates (n) =3

TABLE 5. B vitamins content (µg 100 g^{-1} DW) in commonly grown potato varieties in Uganda

Variety/Variety	Thiamin (vitamin B1)	Riboflavin (B2)	Niacin (B3)	Pyridoxine (B6)	Folic acid (B9)
Cruza	73.21^{a}	6.73^{ab}	289.25^{ab}	ND	150.56^{b}
Kachpot1 (CIP 382171.4)	59.03^{a}	6.59^{a}	216.85^{a}	92.73^{cd}	132.14^{b}
Kimuli	65.76^{a}	7.22^{b}	229.52^{ab}	92.43^{cd}	124.86^{b}
Kinigi	59.81^{a}	6.73^{a}	226.80^{ab}	58.63^{b}	143.35^{b}
Mbumbamagara	172.78^{b}	6.59^{a}	221.31^{ab}	100.08^{d}	ND
Rutuku (CIP 720097)	55.78^{a}	6.58^{a}	261.14^{ab}	81.69^{bcd}	151.98^{b}
Rwangume (Naropot4)	52.60^{a}	6.59^{a}	257.45^{ab}	92.72^{cd}	118.53^{b}
Rwashaki	71.00^{a}	6.56^{a}	202.19^{a}	71.52^{bc}	128.11^{b}
Victoria (CIP 381381.20)	63.20^{a}	6.71^{a}	307.38^{b}	111.57^{d}	136.46^{b}

Values are means in µg 100 g^{-1}. Figures in a column with the same superscript are not significantly different (P > 0.05). ND = Not detected

relatively high variation in the amino acid data was observed in all the potato varieties. There was a significant difference (P<0.05) in amino acids composition between the different varieties. *Cruza* (49.90 mg 100 g^{-1}) and *Rutuku* (7.47 mg 100 g^{-1}) recorded the highest and lowest amount of aspartic acid, respectively. *Kimuli* (96.36 mg 100 g^{-1}) recorded the highest content of glutamic acid. *Kinigi* and *Victoria* recorded the lowest mean content of most of the amino acids.

Cluster analysis. Cluster analysis grouped the varieties into three clusters (Fig. 2), in terms of morphological and chemical traits. Group 1 included three varieties namely; *Cruza, Kimuli* and *Rwangume*; while Group 2 comprised varieties *Kachpot1, Kinigi* and *Rwashaki.* On the other hand, Group 3 had varieties *Mbumbamagara, Rutuku* and *Victoria.* Group 1 was characterised by tubers of medium and small size having high reducing sugars content, high beta-carotene concentration, and high aspartic and glutamic acid. The group also displayed low starch content, low total phenolic compounds and low vitamin B6 content compared to the others. Group 2 was characterised by large tubers with high dry matter, starch and folic acid content; but low beta-carotene, reducing sugars and vitamin B1 concentration. Group 3 was characterised by tubers of small size with low dry matter, fructose, folic acid, aspartic and glutamic acid content; but high in total phenolic compounds and vitamin B1.

DISCUSSION

Physical and chemical characteristics of raw potatoes are key determinant of quality and acceptability of end potato processed products. Processors normally consider morphological traits such tuber size, shape, skin and flesh colour; and chemical composition including high dry matter, reducing sugar content, amino acid profile or phytochemicals content to decide which variety to use to process a given potato based

TABLE 6. Amino acid composition (mg 100 g^{-1}) of potato varieties commonly grown in Uganda

Amino acids	*Cruza*	*Kachpot1*	*Kimuli*	*Kinigi*	*Mbam.**	*Rutuku*	*Rwangume*	*Rwashaki*	*Victoria*
Alanine	0.16	0.14	0.11	0.02	0.12	0.14	0.07	0.08	0.13
Aspartic Acid	49.90	34.27	25.10	14.45	25.32	7.47	18.45	32.63	16.70
Cysteine	6.30	5.23	5.68	3.62	5.11	4.58	3.74	4.22	2.71
Glutamic acid	9.88	50.86	96.36	0.42	ND	68.13	90.00	34.34	4.22
Glycine	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Histidine	0.05	0.02	0.01	ND	0.01	0.02	0.08	0.01	0.01
Isoleucine	0.14	2.14	2.64	0.05	ND	0.65	1.21	3.45	0.12
Leucine	0.08	0.10	0.09	0.02	0.05	0.03	0.01	0.04	0.10
Lysine	0.01	0.10	0.06	0.43	ND	0.24	0.04	0.02	0.24
Methionine	2.26	1.30	1.70	1.07	1.70	0.42	0.84	0.95	0.79
Phenylalanine	0.10	0.01	0.11	0.07	0.10	ND	0.12	0.14	0.08
Proline	0.01	0.07	0.19	0.01	ND	0.03	ND	0.10	ND
Serine	1.43	0.14	1.66	1.14	1.64	1.38	1.11	0.32	1.47
Threonine	2.21	ND	1.75	0.03	3.18	ND	0.02	ND	ND
Tyrosine	0.02	0.02	0.01	ND	0.02	0.01	0.01	0.02	0.01
Valine	0.07	0.06	0.04	0.07	0.10	0.06	0.10	0.03	0.04
Tryptophan	0.44	0.14	0.48	0.44	0.58	0.36	0.27	0.26	0.16

ND = Not Detected. *Mbumbamagara

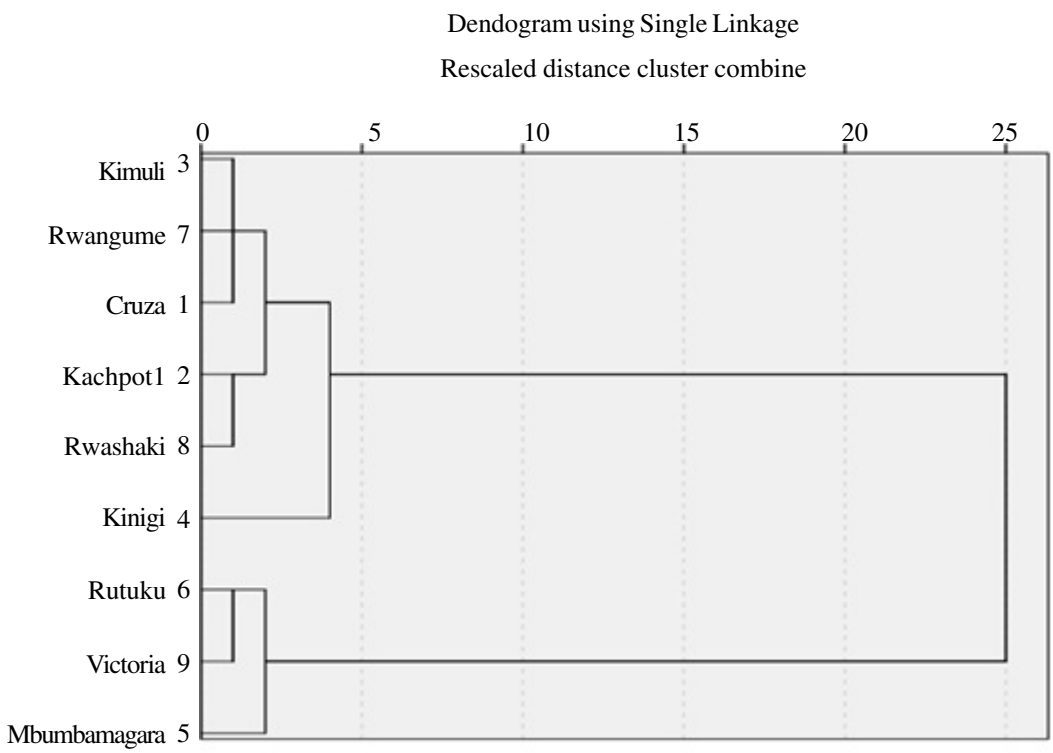

Figure 2. Classification of potato varieties grown in Uganda based on their physical and chemical characteristics.

product. This study assessed nine major potato varieties grown in Uganda for those processing traits. The assessed varieties varied significantly for the physical and chemical characteristics, suggesting that there is genetic variability among the varieties that were used in the present assessment. This is significant and crucial since it justifies the importance for improving varieties in breeding programmes. These variations among varieties for their morphological and chemical characteristics provide also tremendous opportunity for researchers to select the varieties for improvement, production and promotion that suit the consumers and processing demand.

Physical tuber characteristics. From this study, all the varieties, except *Kimuli* and *Mbumbamagara,* can be qualified French fries and crisps, based on their size. However, if other morphological characteristics such as tuber shape and eye depth are included, only *Cruza, Kachpot1, Kinigi, Rutuku, Rwangume,* and *Victoria* could be selected by the crisps and French fries processors. The suitability of the tubers from these six varieties was justified by their round shape with medium eye depth and relatively large size (Tables 1 and 2). These morphological traits are more of genotypic influence as well as cultural practices. Potato shape and size affect mainly the peeling and slicing losses or recovery; whereas eye depth influences the duration and the cost of the peeling process (Singh and Kaur, 2016). Generally, high losses are recorded for potato having small size tubers and not uniform and regular in shape. Among the 9 potato varieties studied, only *Rwashaki* had deep eye depths that can lead to adverse losses during peeling and trimming. Nevertheless, potato processed products (including potato starch and flour) not involving peeling and/or

trimming or implying processing operations such milling are not much affected by the size and shape of the potato tubers; suggesting that based on their morphology all the nine varieties are potential candidate for the potato starch industry.

Most varieties had light white/cream or pink/red skins, with the exception of *Kinigi* that had red-purple skin (Table 1). Light yellow/ cream colour was most abundant in the flesh of tubers. This is in agreement with the findings of Pino and Vergara (2021) who noticed that tuber flesh colour generally varied from white to dark yellow in cultivated potato in the world. This variation can be attributed to the genotype since skin and flesh colour are also genetic dependent (Calliope *et al.*, 2018). Flesh colour is one of the major quality attributes considered by processors and consumers when selecting potato tubers (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 (Kajunju *et al*., 2021); whereas tubers with white flesh colour are best for processing potato starch and flour (Soison *et al*., 2015). As such, variety *Mbumbamagara* could be good candidate for processing potato flour and starch.

Majority of the potato varieties recorded a dry matter content (mean 22.88%; Table 2) similar to that reported in other varieties such as *Roslin Tana, Desiree, Roslin Eburu, Nyayo, Tigoni Long* and *Kihoro* grown in Kenya (Abong' *et al.*, 2010). However, there were genotype-based variations in dry matter content among the nine potato varieties grown in Uganda. Similar results were obtained by Wayumba *et al.* (2019) when different potato varieties were grown in the same location under standard agronomic practices. The dry matter content of the raw tubers affects both the processing efficiency and the quality of the finished product. Tubers with low dry matter content (< 20%) require more energy to evaporate water during processing (frying or drying) and result into too soft and too wet French fries or provide low yield in starch and flour; whereas a high dry matter concentration results in a lower fat content in French fries which is better for the health of consumers (Keijbets, 2008; Teruel *et al*., 2015); but also a high conversion rate when processed into starch or flour. Based on their dry matter content, all the nine varieties were good material for processing both fried and dried potato products.

Chemical composition of tubers. A significant difference was noticed in the starch content of potato tubers under this study (Table 3). Since all the varieties were grown under the same standard agronomic practices and environmental conditions, the differences observed in starch content among the varieties were attributed to the genetic constitution of each variety. One of the major components of dry matter is starch which contributes to the texture as well as the oil uptake of French fries or to the final yield in starch and flour processing. The texture of French fries is positively correlated with starch content of raw tubers (Johnston *et al.,* 1970). Starch content is also positively correlated with starch and flour yield when processing potato dried products. In French fries and crisps industries, tubers with higher starch content also produce chips of lower oil (Bouchon and Pyle, 2004). The starch content of the potato varieties ranged from 12.40 - 29.94%. According to Mareèek *et al*. (2013), normal starch content in potato tubers after harvest ranges from 14-17% and represents 60 - 70% of the dry matter. The starch content of potato tubers is affected by variety, location, climatic conditions and fertilisation (Solaiman *et al*., 2015).

The lowest reducing sugar concentration was recorded in *Kinigi* variety (0.02 g 100 g^{-1}); whereas the highest was in *Kimuli* (0.55 g 100 g^{-1}). The reducing sugar content (mainly fructose and glucose) of the raw potato affects the colour formation of the fried and dried products. Presence of excessive amounts of

reducing sugars in potato tubers has been shown to result into unacceptable 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 to humans (Muttucumaru *et al*., 2014). In order to avoid such risks and inconvenience, the maximum amount of reducing sugars allowed in potatoes aimed for French fries has been set at 0.5 g 100 g^{-1} of fresh potato.

Studies have also reported that genotype can affect membrane permeability, enzyme activity, and starch content which in turn influences the accumulation of sugars (Weller and Iritani, 1980). However, other factors such as environmental conditions and cultural practices have a strong influence on initial reducing sugar levels in potato tubers (Muttucumaru e*t al*., 2017). Based on the present study, varieties with low reducing sugars content (< 0.50 g 100 g^{-1}) such as *Kinigi, Rutuku, Rwangume* and *Victoria* are qualified for processing fried and baked products; while those with high reducing sugars such as *Kimuli, Mbumbamagara* and *Rwashaki* are suited for domestic preparation of salads or processing of potato flour.

There were significant varietal differences in potato tuber phytochemicals contents (Table 4) perhaps resulting from differences in genotype response to the environmental conditions and their ability to overcome them (Grudziñska *et al.*, 2016). Potatoes are good sources of natural antioxidants, such as vitamins, carotenoids, flavonoids and phenolic compounds (Yang *et al.*, 2016). These compounds are also known as phytochemicals and are highly desirable in diet because of their beneficial effects on human health (Ezekiel *et al*., 2013). Most of these phytochemicals are known for their anti-oxidative properties and include polyphenols, vitamin C and carotenoids (Storey, 2007). Phytochemicals such phenolic compounds, carotenoids, flavonoids and tannins in potatoes play an important role in determining their organoleptic properties (Murniece *et al*., 2014). However, some of them especially phenolic acids have been widely studied because of their toxicity to humans and plant protection against phytopathogens (Kipkoech Kirui *et al*., 2018). Thus, quantification of these compounds in potato is key in obtaining potato products with desirable health benefits. Nevertheless, even though phytochemicals are beneficial for human diet, their higher content can be also an issue for processors since they indicate the immaturity of potatoes or inadequate storage conditions. Generally, concentration of phytochemicals in potatoes decreases as the tubers mature and potatoes stored for long and/or in the light accumulate more phytochemicals than those stored for a short period of time in dark conditions (Furrer *et al*., 2018). Consequently, varieties with high content of phytochemicals such as *Mbumbamagara, Rutuku* and *Victoria* may be rejected by processors and would need more investigations from breeders to determine whether their phytochemical content is genotypic-dependent or is related to storage conditions.

The provitamin A of potato varieties ranged from 1.14 - 1.77 mg 100 g^{-1}, with *Kimuli* having the highest and *Kinigi* having the lowest value. This corroborates the findings of other studies which stated that β-Carotene in potato is present only in trace amounts (Storey, 2007). β-Carotene, also known as provitamin A, is a very important nutrient since vitamin A deficiency remains a major public health concern affecting billions of people around the world. This implies that varieties with high beta-carotene content such *Kimuli* would be recommended for minimal processing or home preparation of salads to minimise vitamins losses that occur during processing operations including deep frying or prolonged boiling.

The content of B vitamins in the potato varieties ranged from 6.56 to 7.22 µg 100 g^{-1}, 52 to 172.78 µg 100 g^{-1}, 0.00 to 111.57 µg 100 g^{-1}, 0.00 to 151 µg 100 g^{-1}, and 202.19 to

307.38 µg 100 g^{-1} for vitamin B2, B1, B6, B9, and B3, respectively. The results from this study are in agreement with other studies that demonstrated that potatoes tubers contain low concentration of vitamin B2 and B9, modest levels of vitamin B1, B3 and B5; and high amounts of vitamin B6 and B7 (Navarre and Pavek, 2014). According to Navarre and Pavek (2014), genetic variation accounted for about 50% of the B vitamins variation observed in potato grown even under different environmental conditions. This study attributes the B vitamins variations to the genetic make-up of the varieties since all have been grown under the same environment and standard agronomic practices. However, breeders and producers can take advantage of these variations to improve the vitamin content of potatoes either by breeding them or by establishing agronomic practices and environment that promote formation of these vitamins.

Among the seventeen amino acids tested in this study, aspartic acid and glutamate were the most abundant in all varieties but their levels varied within the varieties. Based on their amino acids profile, varieties such as *Kinigi*, *Victoria*, *Mbumbamagara* are most suited for processing French fries due to their low levels of aspartic acid and glutamate and subsequently low risk of acrylamide formation during frying. Amino acid composition is strongly related to genotype (Markakis and Kaldy, 1972) and can be used to understand and to predict the behavior of food stuff during postharvest handling and processing. In potato industry, amino acids are used to predict the formation of acrylamide in fried and boiled potato; since they are considered as precursors of acrylamide in fried foods (Michalak *et al*., 2011; Yang *et al*., 2016; Muttucumaru *et al*., 2017).

Cluster analysis was used to group similar varieties into a number of clusters based on the observed values of several processing traits analysed for each variety. Three clusters emerged from the analysis (Fig. 2) based on both morphological and chemical traits. The traits exhibited by Group 1 with varieties *Cruza, Kimuli* and *Rwangume* show that these varieties are not suitable for processing French fries and crisps due their high levels of reducing sugars (greater than 0.50 g 100 g^{-1}) but could be excellent candidates for domestic preparation of mashed potato and salads, especially because their content in vitamins and the colour of the tubers. Members of Group 2 with varieties *Kachpot1, Kinigi* and *Rwashaki* are suitable for processing French fries and crisps due to their high dry matter and low content of reducing sugars but their large tubers. They can also be acceptable in the starch industry. Varieties *Mbumbamagara, Rutuku* and *Victoria* in Group 3 are suitable for production of potato flour, mashed potato and salads.

CONCLUSION

The results of this study have revealed that majority of potato varieties commonly grown in Uganda have high dry matter content (>20%), with tubers that are medium in size (50-60 mm), round in shape with medium eye depth. The study also established that the potato varieties cultivated in Uganda have fairly good processing quality traits with varieties *Kachpot1*, *Kinigi* and *Rwashaki* being the most suitable for processing French fries due to high starch content (>20%), low reducing sugar concentration (less than 0.50 g100 g^{-1} FW), big and round tubers with medium eye depth. The other potato varieties such *Cruza, Kimuli*, *Rwangume, Mbumbamagara, Rutuku* and *Victoria* are appropriate for domestic preparation of potato flour, mashed potato and salads.

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