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Valorization options for small non-marketable potatoes (*Solanum tuberosum* L.) as a strategy to reduce postharvest losses and improve farmers' incomes

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Abstract

Potato (*Solanum tuberosum* L.) is an important food and cash crop grown by many farmers in Uganda, especially in the highland regions of western and eastern Uganda. However, post-harvest losses due to the high proportion of rejected small size potatoes are a major hindrance to profit maximization among farmers. The study assessed the potential of valorizing the small unmarketable potatoes into value added food products to reduce postharvest losses and improve farmers' incomes. Flour and soup powders processed from the small potatoes through boiling, steaming, drying, and milling were profiled for proximate composition, sensory and functional properties. The results revealed no significant differences ($p>0.05$) in the proximate composition between flour of small and large potatoes. Soup prepared using 100g of instant flour from small potatoes contributed 19.2, 26.7, 13.8, 9.16 and 10% of the recommended daily intakes for energy, carbohydrates, proteins, fat and fibre, respectively, for women of reproductive age (15-49 years). The soup formulations exhibited excellent reconstitution properties due to their high water solubility index (3.05 - 3.80%), swelling capacity (3.70 - 4.54%) and water absorption capacity (271.01 - 652.37%). Sensory evaluation results showed that soups prepared from the small potato powders received ratings between 7 (like

moderately) and 8 (like very much), comparable to the scores given to soup made from a commercial instant potato powder. The findings confirmed that the nutrient profile of small potatoes was similar to that of large potatoes. This implies that valorization of small potatoes into flour presents an opportunity for production of nutritious value added products that in turn can reduce postharvest losses and increase farmers' incomes.

Key words: Boiling, proximate composition, physiochemical properties, sensory evaluation, soup, steaming

Introduction

Potato (*Solanum tuberosum* L.) is an important crop in Uganda mainly produced in the highland areas of Kabale, Kisoro, Mbale, and Kapchorwa districts (Kyomugisha *et al.*, 2018). The major potato varieties grown include: *Rwangume*, *Victoria*, *Rwashaki*, *Mumba*, *Sutama*, *Kimuli*, *Rutuku*, *Cruza*, *Mitare*, *Kachpot*, and *Kinigi*. (Kesiime *et al.*, 2016). The crop is mainly grown by smallholder farmers with an average of 2 acres (UBOS, 2016). It is estimated that potato production covers 37,848 hectares of land with an estimates annual production of 244,071 tons (FAO, 2022). Potatoes are crucial in Uganda highland districts for food security, nutrition, income generation, employment, and as a raw material for industrial use (Mugisha *et al.*, 2017). Despite an increase in production of potatoes in Uganda, farmers face a problem of low returns on investment, partly due to failure to meet the quality specifications of the fresh market (Kyomugisha and Mugisha, 2017). This is attributed to a high proportion (21%) of small-sized potatoes, which are unsuitable for the fresh market (Namugga *et al.*, 2018). Such potatoes are either used as seed or disposed of, resulting into economic post-harvest losses. The income lost in the small sized potatoes causes demotivation among the farmers.

The poor utilization of the small sized potato tubers is mainly attributed to limited knowledge of their nutritional profile, and a belief that they are of poor quality and thus of no value. However, research reports show that small sized potatoes contain significant amounts of nutrients, and like large sized potatoes can be processed into various valued added products such as whole fry potato snacks, dehydrated flakes or powders, potato starch, potato flakes and bioethanol among others (Lal *et al.*, 2023). In Uganda, there has been limited research done to guide efforts to convert the small sized potatoes into high value products (valorization), as a strategy to reduce postharvest losses and increase farmers' incomes. Therefore, the objective of this study was to determine the nutrient content of small sized unmarketable potato tubers and their potential usage in formulation of instant soup powder.

Materials and methods

Materials used in the formulation of potato based soup powder

Potato tubers

Fully mature (100 days from planting date) potato tubers of *Victoria* variety were obtained from Kachwekano Zonal Research and Development Institute (KAZARDI), Kabale district in Uganda. The soils in KAZARDI are mainly volcanic, ferrallitic and peat, especially in the swampy areas (Djimbe and Hoekstra, 1987). *Victoria* is one of the major potato varieties grown in Uganda (Kajunju *et al.*, 2021). It has oval to round tubers with a smooth pink skin and light yellow flesh (Kajunju *et al.*, 2022). It is characterized by high dry matter, which makes it suitable for production of chips and crisps (Wayumba *et al.*, 2019). All potato tubers with a diameter less than 35mm were categorized as small and unmarketable (Nakibuule *et al.*, 2022). The potatoes were then stored at room temperature ($25 \pm 5^\circ\text{C}$) and away from direct sunlight until processing. The potato tubers were processed within 1 week after collection from the research station.

Other ingredients used in the formulation

The other ingredients used in the formulation of the product were: i) full cream milk powder (Nido, Nestlé), ii) bay leaves powder (Kooke Enterprises Ltd, Kampala), iii) parsley powder (Ubuy Uganda, Kampala), iv) corn starch (Ubuy Uganda, Kampala), v) table salt (Keshwala group, Kampala), vi) onion powder (Ubuy Uganda, Kampala), vii) garlic powder (Ubuy Uganda, Kampala) and viii) chicken bouillon (Ubuy Uganda, Kampala).

Production of instant powder from small sized potatoes

The potato tubers were processed into instant powder using the method described by Misra and Kulshrestha (2003). The potatoes were washed in clean running water to remove any soil and any foreign materials. They were then peeled using a mechanical peeler (Model: A302EP10A, Bordeaux, France), rinsed and sliced into thin pieces using a stainless-steel knife (Royal Kitchenware, India). The sliced potatoes were soaked in 1% citric acid for 20 minutes and later divided into six batches of 3.5kg each. The first three batches were placed in an open jacketed kettle (Model: M100BM, Bordeaux, France) containing hot water at 80°C and heated at intervals of 5, 10, and 15 minutes. The other three batches were placed on a netted stainless steel tray and covered with a stainless-steel plate. They were then placed over steam generated from boiling water in an open jacketed kettle for 5, 10 and 15 minutes. The heated and steamed potato slices were cooled, spread on perforated stainless-steel trays in a single uniform layer and dried in a forced air drier (Model: B. Master,

Camisano Vicentino, Italy) at 65°C for 8 hours. The dried potatoes were milled into a flour using a locally fabricated motorized hammer mill and sieved through a 250µm diameter mesh. The potato flours were separately packed in well labelled polyethylene bags and stored until further analysis.

Product formulation

The ingredients and the amounts used in the formulation of the product are indicated in Table 1. Nutrisurvey software (2017) was used to determine the optimum level of instant potato flour and full cream milk powder to cater for at least 15% of the daily recommended energy requirements of women of reproductive age (15-49 years). Product formulation was based on the six (6) batches of potato instant powder processed under the described pretreatments. For each batch, the same ingredients and in equal amounts were used resulting into six (6) formulations. The milk powder and corn starch were added to enhance the protein content and texture of the products, respectively. Salt, parsley, bay leaves, onion, garlic and chicken bouillon were added to enhance the taste and flavour of the products. The different dry ingredients were thoroughly mixed, packed in polyethylene bags, sealed in an air tight plastic container and stored at room temperature (25±5°C) until further use.

Table 1. Proportions (%) of ingredients used in the formulation of the instant potato soup powder

Ingredient	Amount (g/100 g)
Potato flour	60
Full cream milk powder	20
Cornstarch	10
Bay leaves (powder)	2
Parsley (powder)	2
Salt	2
Garlic powder	2
Onion powder	1
Chicken bouillon	1

Proximate analysis of fresh potatoes and instant potato powder

Fresh small and large sized potato tubers were analyzed for moisture, fiber, sugars, starch and protein content. The instant potato powders were also analyzed for ash, fiber, fat and carbohydrate content. All analyses were done in triplicates.

Moisture content

The moisture content of the samples was determined by the oven drying method (AOAC, 2005a). This involved drying samples in an air oven at 100°C until there was no change in weight. The moisture content was calculated using equation 1.

$$\text{Moisture content (\%)} = \frac{\text{Weight of the wet sample} - \text{weight of the dry sample}}{\text{Weight of the wet sample}} \times 100 \dots (1)$$

Ash content

The ash extraction method (OAO, 2010) was used to determine the ash content of the samples. This involved igniting the samples in an electric muffle furnace at 550°C for 8 hours. The percentage ash content was determined using equation 2.

$$\% \text{ Ash (dry basis)} = \frac{\text{Weight of sample after ashing} - \text{weight of crucible}}{\text{Original weight of the sample}} \times 100 \dots (2)$$

Crude fat

The Soxhlet extraction method (AOAC, 2016) was used to determine the fat content. This involved drying the extracted fat samples in a forced air oven at 100°C for 1 hour. The crude fat content was calculated using equation 3.

$$\% \text{ Crude fat} = \frac{\text{Weight of fat extract} \times 100}{\text{Sample weight}} \dots (3)$$

Dietary fiber

Dietary fiber was determined following method described by AOAC (2016). The fibre was extracted using acid detergent fiber (ADF). The extracted fibre was dried in a forced air draft oven at 100°C for 1 hour. The total dietary fiber was calculated using equation 4.

$$\text{Dietary fiber} = \frac{\text{Weight of fibre}}{\text{Sample weight}} \times 100 \dots (4)$$

Protein content

Crude protein was determined following the Kjeldahl method (AOAC, 2005b). This involved digesting the samples using concentrated sulphuric acid. The extract was steam distilled to evolve ammonia trapped in boric acid. The resultant solution was titrated with standard HCl to a red endpoint. The crude protein content was then determined using equations 5 and 6.

$$\text{Kjeldahl nitrogen (\%)} = \frac{(Vs - Vb) \times M \times 14.01 \times 50}{W \times 10 \times 5} \dots (5)$$

$$\text{Crude protein (\%)} = \% \text{ Kjeldahl N} \times 6.25 \dots (6)$$

Where : V_s = volume (ml) of standardized acid used to titrate the digest, V_b = Volume (ml) of standardized acid used to titrate reagent blank. M = molarity of standard HCl; 14.01 = atomic weight of nitrogen (N); W = weight (g) of the original sample; 10 = factor to convert mg/g to percent, and $F = 6.25$ factor to convert N to protein.

Total sugars

The phenol–sulfuric method was used to determine total sugars (Nielsen, 2010). The total sugars were extracted with 80% ethanol solution. The absorbance of the solution was read using a spectrometer at 460nm. Concentration of total sugars was calculated using equation 7.

$$\text{Total Sugars (g/100g)} = \frac{(\text{Absorbance-Intercept on vertical axis}) \times D \times V_o \times V_i}{\text{Sample weight (g)} \times \text{Slope} \times V \times 10} \dots\dots\dots (7)$$

Where: D = Dilution factor ; 10 = a conversion factor from mg/100g to g/100g; V = volume of sample pipetted in ml; V_o = final volume of sample diluted up to 100 ml mark, V_i = Total volume.

Starch content

To determine the starch content, the sediment from the determination of total sugars was dissolved in 30ml of distilled water in a conical flask in which 1ml of lead carbonate and 1ml of concentrated sulfuric acid were added. The mixture was heated in a water bath at 80°C for 40 minutes to hydrolyze the sugars. Upon hydrolysis, phenol–sulfuric method for determining total sugars was used (Nielsen, 2010).

Physicochemical properties of the instant potato powder

Water absorption capacity (WAC)

The water absorption capacity of the instant potato powders was determined according to the method described by Bamidele *et al.* (2015) with slight modifications. A known amount (W_1) of the powders was mixed with excess distilled water and allowed to stand at room temperature for 30 minutes, and centrifuged at 4500rpm for 30 minutes. The supernatant was decanted and the excess moisture was removed by evaporation in a forced draft oven to constant weight (W_2). The water absorption capacity of the sample was calculated using equation 8.

$$\text{Water absorption capacity (g/100g)} = \frac{(W_2 - W_1)}{W_1} \times 100 \dots\dots\dots (8)$$

Swelling capacity and water solubility index

The method described by Oluwole *et al.* (2016) was used to determine the swelling capacity and solubility of the potato instant powders. This involved mixing the samples

in distilled water and heating the resultant slurry. The mixture was cooled at room temperature and centrifuged at 4500 rpm for 15 minutes. The starch sediment that remained after centrifuging was dried to constant weight. The residue obtained was taken to be the amount of starch solubilized in water. The swelling capacity and solubility of the sample was determined using equations 9 and 10.

$$\text{Swelling capacity (\%)} = \frac{\text{Weight of sediment paste(g)} \times 100}{\text{Weight of sample(g)}} \dots\dots\dots (9)$$

$$\text{Water solubility index (\%)} = \frac{\text{Weight of soluble starch(g)} \times 100}{\text{Weight of sample(g)}} \dots\dots\dots (10)$$

Estimating the nutrient contribution of the formulated powders to the nutrient requirements of women of reproductive age 15-49 years

The contribution of the formulated instant soup powder to the daily nutrient requirements of women of reproductive age (15-49 years) was estimated using equation (11). This category was chosen as a reference point because of their increased nutrient needs (Jennifer *et al.*, 2006).

$$(\% \text{ Contribution to RDA}) = \frac{\text{Nutrient content per 100g}}{\text{Recommended Daily Allowance (RDA)}} \dots\dots\dots (11)$$

Where: Nutrient content per serving per 100g: The amount of a specific nutrient in 100g of the instant powder; RDA (Recommended Daily Allowance) or Daily Requirement: The amount of the nutrient required per day for an individual, based on dietary guidelines. % Contribution: The percentage of the daily nutrient requirement met by consuming 100g of the instant potato powder

Sensory evaluation

The potato powders were prepared into soups by separately adding 100g of the instant flour in 200ml of cold water to make a paste. Hot water (800ml) was added to the paste and simmered for about 5 minutes while stirring. The soup was kept hot in coded thermo flasks (Always, TilyExpress). The sensory attributes of the soup were evaluated against soup prepared using a commercial instant potato powder by 30 untrained panelists consisting of both male and female students from the School of Food Technology, Nutrition and Bioengineering, Makerere University. Each panelist sat in an individual booth and was presented with the soup samples on plastic disposable plates marked with 3-digit codes corresponding with those on the flasks. The panelists were provided with drinking water to rinse the palate after each taste. The attributes of the soups which include general appearance, color, taste, mouth feel, flavor and general acceptability were evaluated on a 9-point hedonic scale (9= like extremely, 8= like very much, 7= like moderately, 6= like slightly, 5= neither like

nor dislike, 4= dislike slightly, 3= dislike moderately, 2= dislike very much, 1= dislike extremely) as described by Anita *et al.* (2016).

Statistical analysis

The data was summarized using Excel software (version 2016) and subjected to one-way analysis of variance (ANOVA) using SPSS software (version 23) to test for significant differences among the treatments at 5% ($p < 0.05$).

Results

Proximate composition of small and large sized potato tubers used as substrates

The results indicate that there was no significant difference ($p > 0.05$) in the proximate composition between small and large potatoes (Table 2). The overall mean moisture and starch content of the potatoes was 82.05 and 13.17g/100, respectively.

Table 2. Proximate composition of small sized and large sized potatoes (fresh weight basis)

Samples	Proximate composition (g/100g)					
	Dry matter	Crude protein	Crude fat	Crude fiber	Total sugars	Starch
Small potatoes	82.69±0.11 ^a	1.92±0.38 ^a	0.12±0.01 ^a	1.72±0.02 ^a	0.49±0.02 ^a	12.94±0.31 ^a
Large potatoes	81.64±0.62 ^a	1.73±0.07 ^a	0.10±0.02 ^a	1.68±0.01 ^a	0.47±0.03 ^a	13.53±0.11 ^a
Overall mean	82.05±0.47	1.86±0.10	0.13±0.019	1.69±0.024	0.48±0.02	13.17±0.31
LSD	1.054	0.2606	0.0453	0.0451	0.037	0.462

*Values are mean ± standard deviation of the triplicate determination. Mean values in the same column with same superscripts are not significantly different ($p > 0.05$)

Proximate composition of the instant soup powder produced using small potatoes

The results show that there was no significant difference ($p > 0.05$) in all the parameters assessed namely; moisture, ash, fat, crude protein, fibre and carbohydrate content among all the six different formulations (Table 3). The instant potato powders had overall mean values of 4.36% for moisture content, 6.34% for crude protein, and 72.01% for carbohydrates. The average energy content of the flours was 365.71 kcal/100g.

Table 3. Proximate composition of the formulated instant potato soup powders

Product	% moisture	Ash (g/100g)	Fat (g/100g)	Crude protein (g/100g)	Fiber (g/100g)	Carbohydrates (g/100g)	Estimated energy (kcal/100)
Potatoes boiled for 5 min	4.48±0.05 ^a	7.60±0.03 ^a	5.69±0.20 ^a	6.31±0.04 ^a	2.72±0.16 ^a	72.51±0.34 ^a	366.49±12 ^a
Potatoes boiled for 10 min	4.21±0.03 ^a	7.41±0.20 ^a	5.97±0.05 ^a	6.29±0.03 ^a	2.52±0.01 ^a	71.89±0.40 ^a	366.45±24 ^a
Potatoes boiled for 15 min	4.33±0.01 ^a	7.61±0.03 ^a	5.64±0.08 ^a	6.44±0.02 ^a	2.56±0.02 ^a	71.96±0.16 ^a	364.36±14 ^a
Potatoes steamed for 5 min	4.38±0.04 ^a	7.68±0.60 ^a	5.60±0.50 ^a	6.32±0.07 ^a	2.35±0.29 ^a	72.66±0.35 ^a	366.32±16 ^a
Potatoes steamed for 10 min	4.39±0.06 ^a	7.51±0.01 ^a	6.02±0.30 ^a	6.37±0.02 ^a	2.71±0.13 ^a	71.79±0.28 ^a	366.82±21 ^a
Potatoes steamed for 15 min	4.41±0.07 ^a	7.56±0.36 ^a	5.69±0.10 ^a	6.35±0.01 ^a	2.54±0.04 ^a	71.80±0.90 ^a	363.81±15 ^a
Overall mean	4.36±0.09	7.49±0.21	5.68±0.02	6.34±0.03	2.58±0.13	72.01±1.36	365.71±2.2
F-value	1.014	1.22	0.75	2.29	2.67	3.01	3.09

*Values are mean ± standard deviation of the triplicates determined on fresh weight basis. Mean values in the same column with same superscripts are not significantly different ($p>0.05$). Critical value; $F_{0.05(5, 12)} = 3.11$

Contribution of soup prepared from instant potato powder to dietary intake for women 15-49 years

The results indicated that a daily consumption of soup prepared using 100g of instant potato powder would contribute 19.2, 26.7, 14, 8.9 and 10.8% of the recommended daily intakes of energy, carbohydrates, proteins, fat and fibre, respectively (Table 4).

Physiochemical properties of instant potato soup powder

The water solubility, swelling capacity, and water absorption index of all the instant potato-based soup powders increased with increase in time of heat exposure for both boiled and steamed potatoes (Table 5). The water solubility index (WSI) was lowest (3.05) in instant soup powders boiled for five minutes while the highest (3.80) was recorded in soup powders steamed for 15 minutes. A similar trend was observed for swelling capacity (SC), and water absorption capacity (WAC). The water absorption capacity (WAC) of the instant soup powders ranged from 271.01 to 652.37 g/100g with an overall mean of 479.38 g/100g. The results indicate that, for both processing methods, WAC increased with longer heat exposure durations. Additionally, the soup powders derived from steamed potatoes exhibited significantly higher ($p < 0.05$) water absorption capacity (WAC) compared to those made from boiled potatoes.

Table 4. Estimated contribution of the formulated potato soup powder to daily energy and nutrients for women 15-49 years

Component	Mean value ¹	Recommended value /day ²	% Contribution ³
Energy (kcal/100)	366.82	1900 kcal/day	19.2
Carbohydrates (g/100g)	72.66	270g/day	26.7
Protein (g/100g)	6.44	46g/day	14.0
Fat (g/100g)	5.60	63/day	8.9
Fiber (g/100g)	2.71	25g/day	10.8

¹Mean value for all the formulations (F1:F6); ²Source: Jennifer *et al.*, 2006;

³Authors' own calculation using average nutrients derived from 100g of the instant soup powder

Table 5. Physico-chemical properties of the instant potato soup powders

Product	Water solubility index (%)	Swelling capacity (%)	Water absorption capacity (g/100g)
Potatoes boiled for 5 min	3.05±0.11 ^a	3.70±0.10 ^a	271.01±56.28 ^a
Potatoes boiled for 10 min	3.18±0.09 ^a	3.88±0.04 ^a	334.12±59.84 ^a
Potatoes boiled for 15 min	3.31±0.05 ^a	3.92±0.03 ^a	423.00±70.63 ^b
Potatoes steamed for 5 min	3.61±0.04 ^b	4.23±0.14 ^b	472.87±37.33 ^b
Potatoes steamed for 10 min	3.76±0.11 ^b	4.31±0.07 ^b	518.45±95.07 ^c
Potatoes steamed for 15 min	3.80±0.22 ^b	4.54±0.18 ^b	652.37±27.68 ^d
Overall mean	3.44±0.29	4.1±0.3	479.38±128.53
F-value	15.95	14.75	75.24

*Values are mean ± standard deviation of the triplicates determined on fresh weight basis. Mean values in the same column with different superscripts are significantly different ($p < 0.05$). Critical value; $F_{0.05(5, 12)} = 3.11$

Sensory evaluation

The results indicate that all the presented soups were scored between 7 (like moderately) and 8 (like very much) (Table 6). The results indicate that there were no significant differences ($p > 0.05$) in the degree of liking between soups prepared using potato powders and the one from a commercial powder. In general, the soups prepared using instant potato powders from both processing methods received high sensory ratings, with overall acceptability scores ranging from 7.71 to 8.51, comparable to the score of 8.21 recorded for the soup made from commercial instant powder.

Table 6. Sensory scores of soup from instant potato powder and commercial instant powder

Attributes	Potatoes boiled for 5 min	Potatoes boiled for 10 min	Potatoes boiled for 15 min	Potatoes steamed for 5 min	Potatoes steamed for 10 min	Potatoes steamed for 15 min	Commercial instant powder	Overall mean	F-value
General appearance	7.47±1.06 ^a	7.78±1.81 ^a	7.81±1.80 ^a	8.03±1.88 ^a	8.47±1.53 ^a	8.87±1.61 ^a	8.52±1.82 ^a	8.2±1.43	1.86
Color	7.53±1.19 ^a	7.45±1.90 ^a	7.35±1.84 ^a	7.90±1.79 ^a	8.40±1.69 ^a	8.38±1.54 ^a	8.65±1.97 ^a	8.03±1.34	2.52
Aroma	8.40±1.11 ^a	8.51±1.24 ^a	8.52±1.34 ^a	8.70±1.32 ^a	8.47±1.48 ^a	8.63±1.51 ^a	8.08±1.81 ^a	8.48±1.06	2.42
Taste	7.76±1.84 ^a	8.12±1.63 ^a	8.50±1.68 ^a	8.24±1.68 ^a	8.34±1.61 ^a	8.72±1.83 ^a	7.57±1.95 ^a	8.11±1.21	2.57
Mouth feel	7.57±1.05 ^a	7.85±1.73 ^a	8.58±1.46 ^a	8.00±1.72 ^a	8.67±1.42 ^a	8.16±1.78 ^a	7.77±1.93 ^a	8.03±1.16	2.46
Flavor	8.07±1.68 ^a	7.87±1.86 ^a	7.87±1.68 ^a	7.97±1.94 ^a	8.40±1.54 ^a	8.13±1.73 ^a	7.53±1.92 ^a	7.98±0.95	2.18
Overall acceptability	7.71±1.57 ^a	7.81±1.84 ^a	8.13±1.78 ^a	8.21±1.72 ^a	8.13±1.46 ^a	8.51±1.65 ^a	8.21±2.02 ^a	8.11±1.14	2.44

* Values are mean ± standard deviation of scores from 30 panelists. Means in the same row with the same superscripts are not significantly different (p>0.05). Critical value; $F_{0.05(6,14)} = 2.85$

Discussion

Proximate composition of potato flour, and the soup powders

Proteins, sugars and starch are the most important components of potatoes during processing (G³osek-Sobieraj *et al.*, 2022). When potatoes are fried, the reducing sugars such as glucose and fructose react with amino acids from the proteins present in the cells through a reaction termed as Maillard reaction (Singh and Kaur, 2016). This reaction leads to the formation of several compounds that contribute to colour and flavour of the fried chips (Mariotti *et al.*, 2015). Therefore, the proteins and sugars present in potatoes before processing play a key role in determining the final colour of the fried product (Kizito *et al.*, 2015). Starch plays a critical role in the texture and consistency of sauces, soups and porridges by acting as a thickener. Upon heating in the presence of a liquid, the starch granules absorb water, swell and eventually burst realizing starch chains into the liquid (Schirmer *et al.*, 2014). Upon release, the starch chains absorb more water, interact and entangle with each other to form a network of starch molecules that is responsible for the texture and consistency of soups, sauces, and porridges (Tako *et al.*, 2014).

The findings of this study showed that the proximate composition of small potatoes did not significantly differ from that of large ones. This implies that small sized potatoes which are not preferred by crisps processing industries, hotels and restaurants can be used in development of value added products without compromising the functional properties or nutritional quality of the final products. The findings suggest that conversion of small sized potatoes into instant flour presents a valorization pathway with potential for commercialization. The flour obtained can act as an ingredient in the formulation of several products such as sauces, gravies, soups and baked products. This approach, if commercialized has potential to contribute to reduction of postharvest losses and enhance economic viability of the potato value chain through offering income generating activities to all stakeholders.

The processing methods (boiling and steaming) used in this study did not result in significant differences in proximate composition of the instant soup powder. This suggests that both methods are suitable for processing potatoes into instant soup powders without compromising nutritional quality. In addition, the mean moisture content of the instant soup powders ranged between 4.33-4.48% which is far below the recommended threshold of 14% moisture content (Raihan and Saini, 2017). The low moisture content of the soup powders implies that they are less prone to fungal and insect infestation during storage (Gwinner *et al.*, 1996).

The results indicated that the potato-based instant soup powder can make a significant contribution to the RDA for energy, protein and dietary fibre for women of

reproductive age (Jennifer *et al.*, 2006). This highlights its potential as a nutritionally valuable supplementary food. Thus, the product can play a supportive role in improving the dietary intake of key macronutrients, particularly energy and carbohydrates, which are vital for meeting the increased physiological demands during the reproductive years. Moreover, its instant nature and ease of preparation offer significant time and energy savings, making it an especially practical option for women with limited time or access to cooking fuel. The product's shelf stability further enhances its convenience, allowing for safe storage and extended usability without refrigeration. These attributes position the soup powder as a promising intervention for maternal nutrition, particularly in settings where access to balanced, ready-to-use foods is limited.

Physiochemical properties of instant potato soup powder

The water solubility index (WSI), swelling capacity (SC), and water absorption index (WAI) of instant powders are interrelated and collectively determine the powder's performance during reconstitution. The balance among these properties is critical in ensuring that instant powders meet specific textural, sensory, and rehydration requirements. The findings indicated that WSI increased with increase in holding time for both boiling and steaming. The higher WSI is an indicator that the flour became more soluble in water, which is associated with the physical and functional changes that took place within the product upon exposure to heat. One major change that takes place in pre-heated food items is the degradation of starch. When starch is heated in excess water, the crystalline structure is disrupted due to breakage of hydrogen bonds that hold the granule together (Alcázar-Alay and Meireles, 2015). This exposes hydrophilic groups, making the starch particles more water-accessible when dissolved in water. The increase in WSI with increased time of heat exposure is desirable in instant food powders where quick and complete dissolution is a key quality attribute. Rapid solubility of powders pre-treated at higher temperatures ensures convenience for consumers due to better dispersion of active compounds and nutrients. The increased WSI also implies that the powders are able to thicken or bind more quickly in hot water, which helps in quicker formation of thick and smooth soups. Whereas high temperature and time exposure is beneficial, overly high temperatures should be avoided as they may lead to break down of starch into smaller sugars; which led to negative effects on the thickening properties of the soup.

Swelling capacity is a measure of the ability of starch in the powder to imbibe water and increase in volume (Ojo *et al.*, 2017). The results in this study indicated that the swelling capacity increased with period of heat exposure for both boiled and steamed potatoes. High swelling capacity is valuable for instant powders because it aids quick interaction of the powder and water. This aids quick thickening and improves texture consistency. When starch is heated in water at low temperature, the starch molecules remain intact because the outer layer of the granules tends to maintain the integrity of

the granular structure. However, as the heating temperature increases, the starch structure is degraded and water penetrates the interior of the starch granule resulting into hydration of amylopectin and swelling of the granules (Alcázar-Alay *et al.*, 2015). The observed swelling capacity is lower than the 5.05-5.38% reported in the instant amaranth-based vegetable soup of Ssepuuya *et al.*, (2018). The differences in the swelling capacity could be attributed to the milk powder used in formulation of the potato-based instant soup powders. According to Tharise *et al.* (2014), a higher protein content in flour may cause the starch granules to be embedded within a stiff protein matrix that shields the granules from water, thereby limiting the swelling.

The study findings further revealed that water absorption (WAC) increased with longer heat exposure times during potato processing. Increased WAC is attributed to the loss of the starch crystalline structure (Yosuf *et al.*, 2017). This is very important for soup powders since it influences the consistency, mouth feel and ability of the powders to associate with water during the soup making process (Akinyede and Amoo, 2009). The high WAC of soup powders derived from steamed potatoes may be advantageous in formulations requiring high viscosity soups, whereas the lower WAC of powders from boiled potatoes makes them more suitable for preparing lighter soups (Chandra and Kumari, 2015).

Sensory evaluation

The sensory evaluation results indicated that in general, all the soups obtained from the instant powders were acceptable and compared very well with soup made using a commercial powder. This implies that all the soups met consumer expectations for all the parameters tested. The comparable score for powders from steamed and cooked potatoes suggest that it is possible to obtain good quality instant powders using less energy. This observation is very important for small scale processors that might not have resources to invest in technologies for steaming. The adoption of low temperature pre-processing treatments has a number of benefits which include, reduced energy costs, low production costs, and better retention of sensitive nutrients and flavours. In addition, the low temperature processes are more sustainable and environmentally friendly. This facilitates faster adoption in rural areas and ensures and production of potentially higher quality product.

Conclusion

The study demonstrated that small-sized potato tubers have a nutrient composition comparable to large-sized potatoes, making them a viable raw material for production of shelf-stable value added products. Boiling or steaming the small potatoes for 5–15 minutes did not significantly change the proximate composition of the resulting instant soup powders. Nevertheless, increased heat exposure enhanced key

functional properties such as water solubility index, swelling capacity, and water absorption capacity. Samples steamed for 15 minutes exhibited the most desirable characteristics for soup formulation. The soups made from the instant flours offer a nutrient-dense and convenient meal option for women with higher energy and macronutrient requirements especially those in settings where time and cooking fuel are limited. Furthermore, the soups received consumer acceptability scores comparable to a commercial alternative, confirming their market potential and supporting the feasibility of valorizing small potatoes into nutrient dense and convenient products. Further research is recommended to assess the feasibility of large-scale processing of small, hitherto unmarketable potatoes, and to evaluate the associated economic benefits for both farmers and processors.

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Conflict of interest

Authors declare no conflict of interest.

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