Nutrient composition and starch characteristics of eight European potato cultivars cultivated in South Africa

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Abstract

The nutrient composition and starch properties of eight potato cultivars (Electra, Fianna, Innovator, Mondial, Navigator, Panamera, Savanna and Sifra) was evaluated to determine value to human nutrition and inform decisions for culinary usage. Potatoes which had been cultivated under the same agronomic conditions were used in this study. The results showed that there were significant differences ($p<0.05$) in all the parameters measured. Fianna and Innovator had the highest dry mass content of 22 and 21%, respectively, while Electra had the lowest (16%). Innovator, together with Navigator, displayed the highest starch (17.9%) and amylose content (27.2%) denoting them as floury potatoes. However, Fianna and Panamera had the highest protein content, of 2.87 and 2.53%, respectively. Mineral element determination showed that Electra had the highest calcium (10.2 g 100 g^{-1}) and iron (2.91 g 100 g^{-1}) content, offering 3 and 32%, respectively, towards the estimated average dietary requirement. Mondial was affirmed as a waxy potato due to a low amylose content, high swelling power, oil absorption capacity and gelatinization enthalpy and a greater frequency of small-sized granules in its starch. The differences reported in this study will have substantial impacts on population health as potato consumption is increasing in South Africa.

Keywords potato quality, starch properties, nutrient elements, food quality, cultivar differences, amylose, nutrition, dietary aluminium

1. Introduction

Potato (*Solanum tuberosum*) is an important food crop and a staple in many countries. The crop is mostly sought-after for its caloric value, coming mainly from the carbohydrate content. It is a good source of potassium, copper, phosphorous, iron, zinc, magnesium and manganese (White et al., 2009; Lewu et al., 2010). This makes it a valuable candidate for alleviating mineral deficiencies associated with diet constraints. In South Africa, potato has grown in popularity and consumption is currently peaking at 38 kg per capita, which is only third in ranking after maize and wheat (75 and 49 kg per capita, respectively) of all crops produced in the country (Department of Agriculture, Forestry & Fisheries, 2016). While many potato cultivars are produced in South Africa, knowledge about the nutritional content is required to inform selection for consumers and the processing sector. Such nutritional composition information has only been ascertained on a few traditional cultivars and only one cultivar is recorded in the South African Food Composition Tables (Lewu et al., 2010; Womarans et al., 2010; van Niekerk et al., 2016). Genetic variation in the mineral content of potatoes is well documented in literature (White et al., 2009; Nassar et al., 2012), with lower concentrations sometimes being associated with high yield capacity. Although the final concentration of most minerals depends on whether the skin is present or not and on the method of processing, the potato is considered a nutritious food (Lewu et al., 2010; Subramanian et al., 2011; Ezekiel et al., 2013; Furrer et al., 2016; van Niekerk et al., 2016). The most popular methods for cooking the crop are boiling, frying and roasting. However, South African consumers particularly prefer using potatoes in stews and to make French fries (Badenhorst 2014). Knowing the composition of potatoes prior processing is important as this determines the structural changes that occur during processing and can be used to categorize potatoes to specific cooking methods.

On the other hand, a number of studies have reported the nutritional quality of potato cultivars grown in different regions (e.g. Murniece et al., 2011; Šimková et al., 2013; Chung et al., 2014). These studies indicate significant differences in the nutrient quality due to genetic influence, which are also affected by other factors such as agro-climatic, agronomic and storage conditions. With the major component of potato dry mass being starch, understanding the cultivar-specific characteristics of starch is necessary to add value to any study aiming to inform decisions for processing. Potato starch is of semi-crystalline structure composed of amylose and amylopectin occurring roughly in a 3:1 ratio (Alvani et al., 2011; Šimková et al., 2013). The amylopectin component accounts for the crystallinity, while amylose represents the amorphous component. Amylopectin is structurally branched and amylose is a linear polymer. The ratio of these components affects starch swelling capacity, water solubility, water absorption capacity, barrier and mechanical properties of starch, starch films and other microscopic properties (Alvani et al., 2011). Amylose is generally slower to digest compared to amylopectin, resulting in high amylose contents contributing to a lower glycaemic index in potatoes (BeHall and Howe, 1995; Ek et al, 2014). The polymer appears in much reduced concentrations in waxy potatoes and generally decreases with tuber development (Liu et al., 2003; Noda et al., 2004; Ezekiel and Rana, 2009; Šimková et al., 2013; Jansky and Fajardo, 2016). According to the description provided by Furrer et al. (2016), waxy potatoes are low in starch (16-18%) and have a high proportion of amylopectin; whereas, floury potatoes are higher in starch (20-22%) and have a high proportion of amylose. Amylose content has also been shown to be higher in cultivars with tolerance to cold-induced sweetening than in those which are susceptible (Jansky and Fajardo, 2014), making a high amylose content potato favourable to processors and diet conscious individuals. Generally, potato starch has a higher swelling power and solubility than corn, rice and wheat starch, while the granules are larger, smother and more regular (Singh et al., 2003; Chandra and Samsher, 2013). These properties are indicative of the interaction between the amorphous and crystalline components of its starch. Hence, quantifying the amylose content in potato cultivars grown in South Africa is required. This study aims to give a detailed account on the nutrient composition and properties of selected cultivars which are growing in popularity in the country.

2. Material and Methods

Eight potato cultivars (Electra, Fianna, Innovator, Mondial, Navigator, Panamera, Savanna and Sifra) were planted at Ukulinga Research Farm (at the University of KwaZulu-Natal, Pietermaritzburg, South Africa - 30°24′E, 29°40′S) under the same cultural growing conditions with irrigation. The cultivars were planted in a randomised complete block design with three replications. Potatoes were harvested 2-3 weeks after shoot die back, hand-washed with tap water, allowed to air-dry and stored in a dark room for two months at 8-12°C. A homogenised 100 g sample of fresh potato was weighed before and after oven-drying at 105°C to a constant weight to determine the dry mass content (Puri et al., 2015). Eight medium-sized (100-250 g) potatoes were then frozen (-20°C) until required for further processing within three months period. Five of these potatoes were retrieved, lyophilised (-56°C, 4.0 mbar) for 72 hours, milled with a Laboratory Mill 120 (Perten instruments, Germany) and the powder was stored in air-tight plastic bags at ambient temperature (±25°C) until required for different analyses.

2.1 Starch content

A 0.2 g powder sample, was moistened with a few drops of 80% ethanol and mixed with 5 ml of deionised water according to Raigond et al. (2015) using the modified method by McCready et al. (1950). Twenty five ml of 80% ethanol was added and the mixture was allowed to stand overnight and then centrifuged at 200×g (at 37°C) for 5 min. The supernatant was discarded and the residue was washed two more times with 30 ml of 80% ethanol, followed by centrifugation, to remove free sugars. Five ml of deionised water and 6.5 ml of 52% perchloric acid were added to the residue, then the mixture was continuously swirled for 20 min. Twenty ml of deionised water was added and the sample was centrifuged. The resulting supernatant was transferred to a 100 ml volumetric flask. The residue was treated with five ml of deionised water and 6.5 ml of 52% perchloric acid again, and allowed to solubilize as before for 30 min. The two mixtures were combined, made up to 100 ml with deionised water and filtered using Whatman no 1 filter paper. Then, a 0.5 ml sample was taken from this solution and made up to 50 ml. One hundred µl of the sample was diluted with 900 µl deionised water and then mixed with 2 ml of fresh anthronesulphuric acid reagent (200 mg anthrone in 100 ml chilled concentrated sulphuric acid). The sample was heated for 8 min in a water bath (100°C), then cooled to ambient temperature and absorbance was recorded at 620 nm. This experiment was repeated four times. The starch concentration was calculated using an equation from a glucose standard curve prepared by diluting a standard stock solution of glucose (1000 mg l^{-1}) with de-ionised water to achieve 0.1, 0.2, 0.3, 0.4 and 0.5 mg ml^{-1} and expressed on fresh mass basis (fmb) calculated using dry mass content data.

2.2 Total and reducing sugar content

A 2 g powder sample was mixed with boiling de-ionised water (1:4, w/v) and made up to 40 ml with deionised water at ambient temperature. The sample was placed in a refrigerator at 3°C until the time of analysis using an HPLC according to Morales-Fernández et al. (2015). Briefly, the sample was thawed back to ambient temperature overnight, filtered and made up to 100 ml with deionised water. Glucose, fructose and sucrose were separated using an isocratic HPLC system equipped with a refractive index detector on a Phenomenex® column (Rezex RCM–Monosaccharide) and ultra-pure water at a flow rate of 1 ml min^{-1}. A 20 µl sample was injected into the HPLC (Shimadzu, Japan) at ambient temperature and read three times. The concentration of individual sugars was determined using a sucrose standard curve prepared by diluting a standard stock solution of sucrose (1000 mg l^{-1}) with de-ionised water to achieve 0.5, 1, 1.5, 2.5, 5, 10 and 40 mg ml^{-1} and expressed on fmb. The sum concentration of all sugars was considered to reflect the total sugar concentration while that of fructose and glucose is reported as the reducing sugar content.

2.3 Crude protein content

A frozen sample was dried at 75°C overnight to prepare a 0.5 g dry ground sample according to a method by Bárta and Bártová (2008). This was used to determine the nitrogen content through the automated Dumas dry combustion method using LECO CNS 2000. Briefly, the sample was weighed into a ceramic crucible to which 0.5 g of vanadium pentoxide was added as a combustion catalyst and burned in a stream of oxygen at 1350°C in a horizontal furnace. Nitrogen was determined (as N_2) in a thermal conductivity cell. Crude protein content was calculated by multiplying total nitrogen by a conversion factor of 6.25 and expressed on fmb.

2.4 Mineral element content

A 0.5 g frozen sample was dried in the oven at 105°C for two hours, in a 100 ml pre-weighed beaker. The beaker containing material was weighed again after drying and ashed overnight in a furnace at 450°C. This was allowed to cool at ambient temperature, and the ash was moistened with a few drops of deionised water before adding 2 ml of concentrated HCI. The sample was placed in a water bath in a fumehood to dry through evaporation. Then, 25 ml of a freshly prepared 1:9 HCl solution was added. The sample was stirred and filtered. The filtrate was diluted with de-ionized water to a 1:5 ratio and analysed for phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe) and aluminium (Al) on the inductively coupled plasma optical emission spectrometer Vista-MPX 2004 (Varian, Germany). Mineral element concentration was expressed as mg 100 g^{-1} fresh mass.

2.5 Starch physiochemical properties

Starch was extracted by mixing potato powder with deionised water, sieving the mixture through a 150 µm mesh and oven-drying the sediment at 105°C for 24 hours following several washes of removing remaining impurities. Extracted potato starch was use for the following analyses:

Amylose content

Amylose content on the non-defatted starch was determined using the iodine binding method according to Puri et al. (2015). A 100 mg starch sample was mixed with 95% ethanol (1 ml) and 1N NaOH (9 ml). The sample was then heated in boiling water bath for 10 min for starch to gelatinise and allowed to cool to ambient temperature. The sample was raised to 100 ml with deionised water. A 2.5 ml aliquot of sample was mixed with 1 N acetic acid (0.5 ml) and an Iodine solution (1 ml; prepared and kept in the dark). The mixture was raised to 50 ml, allowed to stand for 20 min under dark incubation for colour development and then the absorbance was read at 620 nm. This experiment was repeated four times. The amylose content was calculated using an equation from a potato amylose standard curve prepared by diluting a standard stock solution (1000 mg l^{-1}) with de-ionised water to achieve 0, 0.02, 0.04, 0.06, 0.08, 0.10 and 0.12 mg ml^{-1} and expressed as a percentage on dmb.

Starch swelling power and solubility

A 350 mg starch sample which was put in a 15 ml centrifuge tube and reweighed (W1) for analysis according to Soison et al. (2015). The starch was mixed with 12.5 ml of water and the mixture heated at 55, 65, 75 and 85°C for 30 min in a water bath. The mixture was allowed to cool to ambient temperature and then centrifuged at 3000 rpm for 15 min. The supernatant was decanted carefully into a pre-weighed aluminium weighing boat and the weight of the residue, together with the water it retained and the centrifuge tube, was taken (W2). This experiment was done in triplicate. Swelling power was calculated by dividing the difference between the initial weight of the sample and the residue after the sample mixture with water was heated by the initial weight of starch (i.e. [W2 – W1]/Weight of starch). Starch solubility was determined by drying the supernatant at 105°C to a constant weight. The residue obtained after drying represented the amount of starch solubilised in water, which was expressed as a percentage on dmb.

Water and oil absorption capacity

A 0.5 g starch sample was weighed into a 15 ml conical centrifuge tube and 5 ml of deionised water/canola oil was added according to Shimelis et al. (2006). Water density was 1 g cm^{-3} and oil density was 0.89 g cm^{-3} at ambient temperature. The suspension was allowed to stand for 2 h and then centrifuged at 350×g for 30 min. The supernatant was decanted and the sample was re-weighed. This experiment was done in triplicate and absorption capacity was expressed as the percentage of water/oil absorbed on dmb.

Starch thermal characteristics

Starch thermal characteristics were determined through differential scanning calorimetry using the Simultaneous Thermal Analyser (STA 6000, Perkin-Elmer Inc., USA) according to Soison et al. (2015). Three milligrams of the starch sample was weighed into a differential scanning calorimetry pan. Deionised water was added to make a starch concentration of 30% on dry mass basis and the sample was left at ambient temperature for 1 h before heating in the STA. An empty pan was used as the reference. Sample was heated from 25°C at a heating rate of 10°C min^{-1} until mass loss had ceased. The following gelatinisation parameters were computed from the STA software: onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and enthalpy (ΔH). The gelatinisation temperature range (ΔT) was calculated from a difference between T_o and T_c (i.e. T_c-T_o). The peak height index was calculated as $\Delta H/(T_c-T_o)$. This analysis was done in duplicate.

Starch granule morphology

Granule morphology was determined using the scanning electron microscope (JEOL JSM-35, Japan). Starch samples were placed on double-sided silver tape attached to a brass disk. The sample was coated with gold using an ion sputter coater (Eiko IB-3, Japan). Micrographs of each starch sample were taken at 1500× magnification, using the acceleration potential of 10 kV. Granule length and width was measured through image analysis using the software AnalySIS for

Windows (Soft Imaging System GmbH, Germany) and these were plotted to show the frequency distribution between cultivars.

2.6 Statistical analysis

Data analysis was performed using GenStat for Windows (17th edition; VSN International, United Kingdom). Analysis of variance (ANOVA) was used to test for differences and the Bonferroni's multiple comparison test was performed to separate the means at the 95% probability level. Correlation between parameters was tested.

3. Results and discussion

3.1 Potato composition

3.1.1 Dry mass

There were significant differences in the percentage of dry mass between cultivars, with Electra displaying a significantly lower dry mass content (16%) when compared to the other cultivars (Figure 1A). Fianna had the highest dry mass content (22%) followed by Innovator (21%), while differences between the other cultivars were not significant. The dry mass of these cultivars was mainly comprised of starch (61-85%), protein (9-14%) and sugars (6-16%). The high dry mass in Fianna and Innovator is particularly favourable in the processing industry as dry matter is generally linked to the cooking quality and represents the nutritious content in potatoes. Cultivars high in dry matter are targeted for processing especially when frying as they result in high product yields, limiting oil absorption and ensuring textural consistency in products (de Freitas et al., 2012). For this reason, potatoes high in dry mass are selected for baking as they tend to be mealy while those low in dry mass tend to be waxy and are considered ideal for boiling.

3.1.2 Starch content

Navigator and Innovator had a significantly higher starch content (18.1 and 17.9%, respectively) than the other cultivars, while the differences in the starch content found in the other cultivars were non-significant and ranged from 13.7 to 15.4% (Figure 1B). With starch being the principal energy resource in potatoes, such cultivars should be targeted for high energy requirement diets. Additionally, the higher starch yielding capacity of these cultivars makes them favourable targets for industries that use potato starch. Although a correlation of the starch content to dry mass was expected (Ezekiel and Rana, 2009; Kaur and Aggarwal, 2014), the cultivars evaluated in this study showed a weak relationship in this regard (r=0.07). Electra had a substantially higher starch content (85%) on a dry mass basis than the other cultivars, and Fianna had the lowest (61%), while the other cultivars contained between 73 and 79% of starch. Although the starch content of Fianna and Mondial non-significantly differed in this study, van Niekerk et al. (2016) showed significant differences between these cultivars. In that study, the cultivars contained 18.8 and 14.7%, respectively, after production at the Eastern Free State Province of South Africa. The starch content for Fianna detected in this study is substantially lower than the one reported in that study, although that of Mondial and Sifra are comparable which may result from agro-climatic differences.

3.1.3 Total and reducing sugar content

Electra had the lowest total sugar content (1.0%), which was comparable to Mondial and Panamera in this study. Unexpectedly, Fianna contained the highest total sugar content (4.0%), followed by Innovator (2.8), while all other differences between the other cultivars were largely non-significant (Figure 1C). This was strongly correlated (r=0.98) to the reducing sugar content of 0.62% in Electra, 2.64% in Fianna and 1.65% in Innovator. Interestingly, the reducing sugar content of Electra was not statistically different from that of Mondial and Navigator when assessed on a dry mass basis (3.58, 3.97 and 4.21%, respectively). The differences between the reducing sugar content of Innovator and Savanna (6.71 and 7.44%, respectively), when assessed on a dry mass basis, were not significant as well. The cultivars in this study exhibited a high total and reducing sugar concentration. These values were higher than those reported for various other cultivars in the literature (e.g. Gumul et al., 2011; Murniece et al., 2011; Kaur and Aggarwal, 2014).

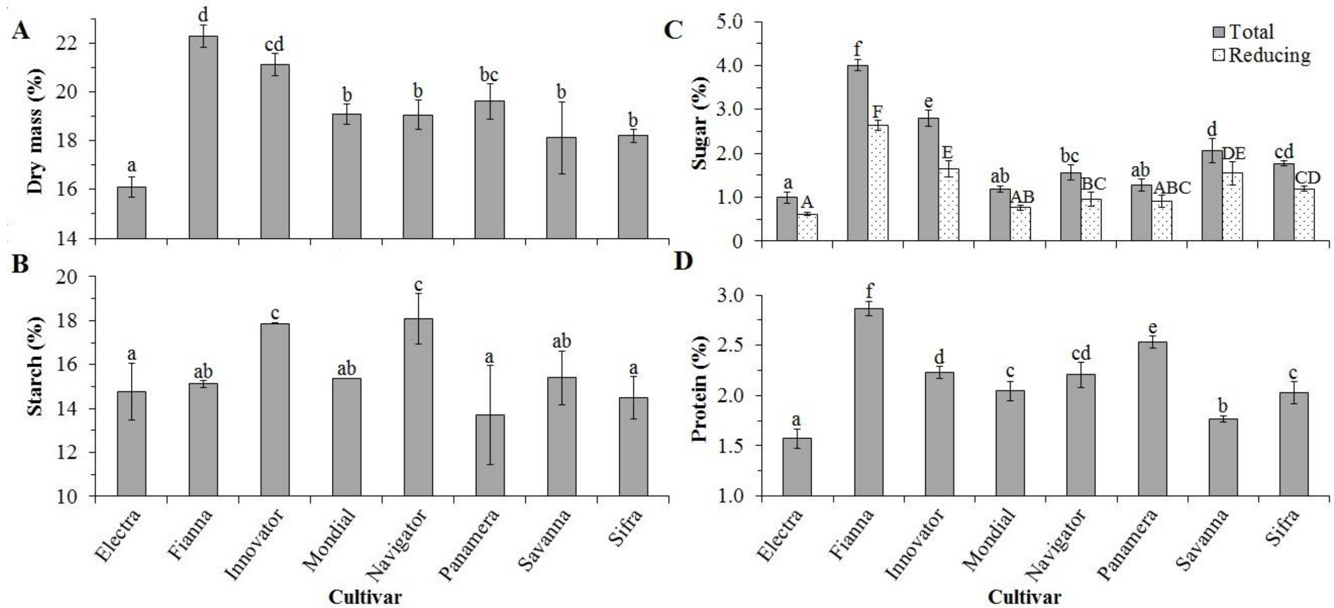

Figure 1 Potato composition on fmb. Graphs showing dry mass (A), starch (B), sugar (C) and crude protein content (D). Bars with the same letter differ non-significantly ($p>0.05$)

This is attributed to storage of the tubers before analysis, suggesting the occurrence of cold-induced sweetening. Although changes in sugar content have been suggested to be unlikely at the temperatures used in this study for some cultivars, the phenomenon is plausible on cultivars with short dormancies such as Fianna and Innovator (de Freitas et al., 2012; Morales-Fernández et al., 2015; Wang et al., 2015; European Cultivated Potato database, 2016). Moreover, hikes in reducing sugar contents due to the onset of cold-induced sweetening can also be associated with a reduction in amylose content (Jansky and Fajardo, 2014). Reducing sugar content has implications on processing quality and high levels have been shown to promote undesirable colour changes, particularly during frying (de Freitas et al., 2012; Pedreschi et al., 2014). The use of potatoes with low reducing sugars is favoured as it results in a product with a low acrylamide content after frying (Matthäus et al., 2004; Sanny et al., 2012). Acylamide has been identified as a probable human carcinogen which develops when potatoes are processed at high temperatures (Pedreschi et al., 2014).

3.1.4 Crude protein content

The broad differences observed in the chemical composition of cultivars were consistently apparent in the crude protein content, where Electra displayed the lowest (1.57%) and Fianna had the highest (2.87%) content than the other cultivars (Figure 1D). It was also noted that Panamera had a significantly higher protein content (2.53%), although this was lower than that found in Fianna. The protein contents reported in this study were within the range reported in the United States Department of Agriculture, New Zealand and Australian food database reports for white potatoes but differed from those reported by van Niekerk et al. (2016).

3.1.5 Mineral element content

The concentration of mineral elements varied between cultivars, with Fianna having the highest P, K, Mg, Na, Zn, Cu and Mn than the other cultivars. This was 56.90, 472.34, 20.60, 7.10, 0.48, 0.15 and 0.22 mg 100 g^{-1}, respectively (Table 1). All differences were significant ($p<0.05$) except for those found in the Na content ($p=0.824$). Electra had the highest Ca, Fe and Al content (10.23, 2.91 and 2.20 mg 100 g^{-1}, respectively). However, the cultivar had the lowest Mg and Zn content (14.36 and 0.29 mg 100 g^{-1}, respectively) than the other cultivars. Moreover, Innovator had the lowest Fe (1.65 mg 100 g^{-1}) and Al (1.06 mg 100 g^{-1}), Mondial had the lowest P (43.5 mg 100 g^{-1}), Navigator had the lowest Na (5.1 mg 100 g^{-1}), Panamera had the lowest Ca (5.2 mg 100 g^{-1}), Savanna had the lowest Cu (0.08 mg 100 g^{-1}) and Sifra had the lowest K (341.7 mg 100 g^{-1}) and Mn (0.14 mg 100 g^{-1}). The concentration of the nutrient elements evaluated in this study are discussed relative to the need and risk of deficiency in the African population below.

Global deficiencies associated with Ca, Zn and Fe are common globally, however Ca and Zn are the top nutrients elements with the highest risk of dietary deficiency within the African population (54 and 50%, respectively) and the greatest risk is found in the southern region of the continent (Joy et al., 2014). With the estimated average requirement (EAR) for Ca said to be at 636 mg $capita^{-1}$ day^{-1}, a 200 g sample (equivalent to a medium-sized raw potato) of Electra offers up to 3% towards this value (Joy et al., 2014). However, the nutrient reference value (NRV) provided by the South African Department of Health (2014) for individuals ≥37 months of age is two folds higher (1300 mg $capita^{-1}$ day^{-1}). This halves the offering made by Electra. With the number of studies reporting the nutrient content of potato cultivars in South Africa being limited, it is noteworthy that the Ca content of Electra reported in this study is substantially higher than that reported by van Niekerk et al. (2016) for the eleven cultivars tested in their study and that reported in the national Food Composition Tables (Wolmarans et al., 2010). However, a raw medium-sized potato of Panamera, which is the cultivar containing the lowest amount of Ca in this study, offers 1.6% of the EAR. Incorporation of such cultivars into the regular diet would contribute to the diversity of foods supplying Ca as over 50% of the dietary Ca consumed is sourced from animal products.

Table 1 Mineral element content (mg 100 g^{-1} fresh mass) of eight potato cultivars

Cultivar	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Cu**	**Mn**	**Fe**	**Al**
Electra	47.7a	347.5ab	10.2d	14.4a	6.7a	0.29a	0.11ab	0.19ab	2.91b	2.20c
Fianna	56.9b	472.3d	7.5c	20.6d	7.1a	0.48d	0.15b	0.22b	2.79b	1.61abc
Innovator	47.6a	360.4abc	6.2abc	18.2cd	6.3a	0.42bcd	0.12ab	0.17ab	1.65a	1.06a
Mondial	43.5a	366.2abc	6.8bc	17.3bc	5.3a	0.46cd	0.13ab	0.16a	2.23ab	1.81bc
Navigator	44.6a	379.8c	6.9bc	16.9abc	5.1a	0.39bc	0.10ab	0.17a	1.98a	1.16a
Panamera	47.6a	370.2bc	5.2a	17.1bc	6.2a	0.46cd	0.14b	0.15a	1.89a	1.20ab
Savanna	44.5a	367.0abc	6.8abc	15.3ab	6.4a	0.35ab	0.08a	0.16a	1.85a	1.20ab
Sifra	46.3a	341.7a	5.7ab	17.7bc	7.0a	0.37b	0.12ab	0.14a	1.71a	1.33ab
LSD	3.803	15.030	0.791	1.616	2.965	0.046	0.031	0.029	0.413	0.364
CV (%)	5.5	2.7	7.9	6.4	32.4	7.8	17.9	11.4	13.3	17.2

CV = Coefficient of variation; LSD = Least Significant Difference. Values with the same letter differ non-significantly ($p>0.05$)

The EAR and NRV for Zn is 10-10.5 mg $capita^{-1}$ day^{-1}, of which 56% is sourced from cereals (Joy et al., 2014). A raw medium-sized potato of Fianna can offer up to 9% towards these values. The same quantity of Electra, which contains the lowest amount of Zn in this study, offers 5.5%. This is a substantial contribution of one particular food, although the actual contribution of the potato when prepared as part of a meal would depend on the method used to process it. Subramanian et al. (2011) showed that these minerals exist in higher concentrations in potato skin rather than the flesh, but van Niekerk et al. (2016) reported a negligible reduction in Zn when the skin was removed. These reports are indicative of differences in mineral distribution being cultivar-specific, which has implications for processing in potatoes.

Although minerals such as Fe, Cu and Mg have a much lower estimated risk of deficiency within the African population (5, 1.1 and 0.7%, respectively), the cultivars evaluated in this study can offer ≥32, 27 and 18% towards the EAR, respectively (Joy et al., 2014). These are ≥25, 18 and 8% relative to the NRVs for South Africa, respectively (Department of Health, 2014). This indicates that the cultivars evaluated in this study contain appreciable amounts of these nutrients, with potential for use in alleviating the dietary deficiencies associated with them. Particularly, the Fe offering of Electra is higher than that of spinach (2.7 mg 100 g^{-1}) when compared on an equivalent fresh mass basis, while that of Mg resembles that found in banana (2.7 mg 100 g^{-1}; Wolmarans et al., 2010). However, the actual value of such minerals in diets would depend on the bioavailability after processing and ingestion.

Deficiencies for major elements like P, K and Na are uncommon as these minerals are abundant in foods commonly consumed such as cereals, meat and meat products, dairy and in fruits and vegetables. While P and K deficiencies usually occur in severe malnutrition, excess body Na results under these circumstances. The NRVs for these mineral elements in South Africa are 1250, ≥4700 and ≤2000 mg $capita^{-1}$ day^{-1}, respectively (Department of Health, 2014). The cultivars reported in this study offer 7-9, 15-20 and 0.5-0.7% relative to these values. Potatoes being a good source of K, the contribution offered by the cultivars reported in this study is within range to that reported for potatoes in the national Food Composition Tables (Wolmarans et al., 2010). However, the P contents reported in this study for Fianna, Innovator, Panamera and Sifra are higher than those in the national Food Composition Tables. This indicates a greater value in these cultivars. It is also noteworthy that the Na concentrations reported in this study are three folds higher than those reported in those tables. Efforts to reduce Na consumption are a global focus as high salt intake is a challenge and has negative implications for cardiovascular health. The average Na intake by South Africans is 7800-9500 mg $capita^{-1}$ day^{-1} and bread is the greatest contributor to this figure (Charlton et al., 2014). Increasing the consumption of low-Na potato cultivars in the diets of the population may help reduce overall Na consumption in the country.

Aluminium content was assessed in this study due to speculation about carcinogenicity and neurotoxicity in humans extrapolated from studies conducted in experimental animals. Although the European Food Safety Authority panel considers dietary doses unlikely to cause immediate harm, determining the footprint of various foods is important to monitor consumption trends (Aguilar et al., 2008). Currently, no regulatory measures are taken in South Africa and the use of aluminium anticaking additives in food products is permitted. However, since aluminium accumulates in the body following ingestion, other food safety authorities have set tolerable weekly exposure limits and these range from 1 to 2 mg kg^{-1} body weight $week^{-1}$ (Aguilar et al., 2008; Joint FAO/WHO expert Committee on Food Additives, 2011). This equates to a daily tolerable intake of ≤17 mg for an individual weighing 60 kg. Cereals and cereal products, vegetables and beverages are known to be the main contributors to dietary aluminium exposure. A raw medium-sized potato of any of the cultivars evaluated in this study can contribute 12-26% towards the daily tolerable intake for an individual weighing 60 kg and Innovator is at the lowest end of this scale (Table 1). Although this content is fair, caution should be practised when cooking the potatoes as the use of aluminium-containing cookware such as aluminium foil may leach additional aluminium and increase the dose ingested by consumers.

Innovator, when tested in five regions in Canada by Nassar et al. (2012), was reported to have substantially higher Ca, K, Mg, P, Na, Cu, Fe and Zn contents than those reported in this study even though the dry mass was comparable. In a later study, when tested in two of the regions used in the former study, Nassar et al. (2012) reported lower starch (68 and 72%, dmb) and higher starch amylose contents (33%) to those reported in this study (Chung et al., 2014). This confirms the regional differences in the quality of potatoes reported in literature resulting from differences in environmental conditions such as rainfall, temperature and soil type (Murniece et al., 2011; Šimková et al., 2013). In the case of South Africa, the nutrient composition of Fianna, Mondial and Sifra particularly differs from that reported by van Niekerk et al. (2016) from a study conducted in the Eastern Free State province in 2013, which assessed the nutrient composition of 11 cultivars that were popular in the country. Furthermore, while potato is known for its abundant K reserves, the contents found in this study were two folds higher than those reported by Lewu et al. (2010) in a study conducted in the Easterrn Cape province on peeled tubers. However, the other minerals were within the range of the values reported in that study. Furthermore, Tekalign and Hammes (2005), when working on four Ethiopian cultivars, reported nutrient contents within range of those reported in this study but also showed that potato berries/fruits are stronger mineral sinks compared to tubers in the crop.

3.2 Starch physiochemical properties

3.2.1 Amylose content

Analysis of the starch component of the tubers revealed that the amylose content of Mondial was significantly lower (18.9%) than the other cultivars (Figure 2). The amylose content differences between the rest of the cultivars were not significant, ranging from 23.6 to 27.2%. Navigator had the highest amylose content. With the increase in the concern of potatoes being a high glycaemic index food and contributing to the risks of developing metabolic diseases if consumed excessively (Ek et al., 2014), a high amylose content cultivar such as Navigator may be of particular interest to consumers. This was closely followed by Electra (26.1%) and Sifra (26.0%). According to the definition provided by Furrer et al. (2016), Navigator, together with Innovator, shows characteristics of a floury potato due to its high amylose and starch content. Although Šimková et al. (2013) showed a negative correlation between the amylose content and P concentration in sixteen cultivars that were grown in the Czech Republic, such findings were not supported in this study (r=0.27).

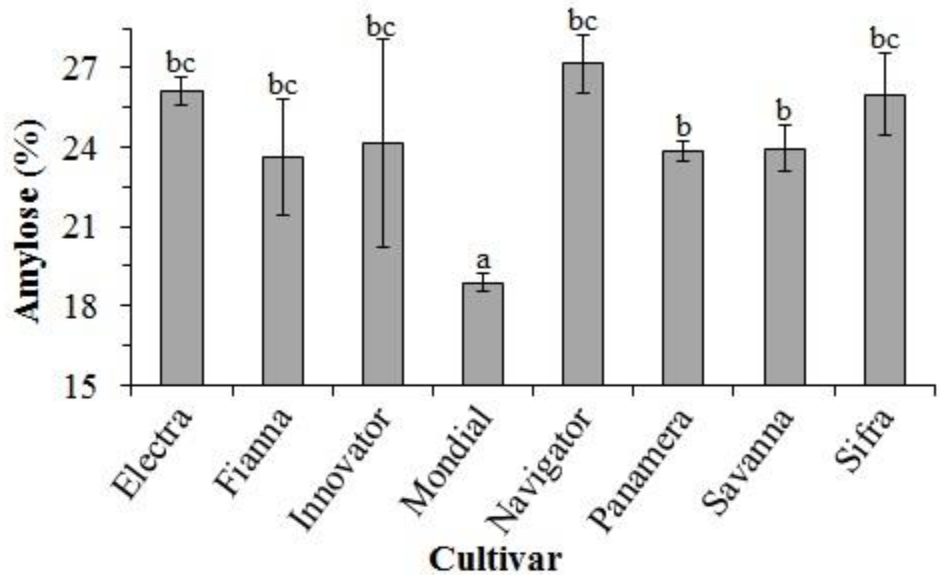

Figure 2 Starch amylose content of eight potato cultivars. Values with the same letter differ non-significantly (p>0.05)

3.2.2 Starch water and oil absorption capacity

The significantly low amylose content of Mondial was complemented by a significantly higher oil absorption capacity (85%; Figure 3B). The oil absorption capacity the starch of Innovator

(71%), Navigator (71%) and Panamera (70%) non-significantly differed, but were significantly higher than that of the starch of Sifra (64%). The oil absorption capacity the starch of Electra, Fianna and Savanna differed non-significantly to all other cultivars except for Mondial. Only Fianna and Navigator differed in water absorption capacity, with Fianna absorbing more water than the other cultivars evaluated (102%) and Navigator absorbing the least (89%; Figure 3A). The solubility and swelling power of the starch from all cultivars increased with an increase in temperature. However, Mondial showed a substantially higher swelling power at 75 and 85°C (Figure 3D). Starch from Savanna displayed a notably higher solubility at 75°C than the starch from the other cultivars in this study. This may be explained through further studies which would focus on determining the amylopectin content and analyse the interaction of amylose and amylopectin in the cultivars.

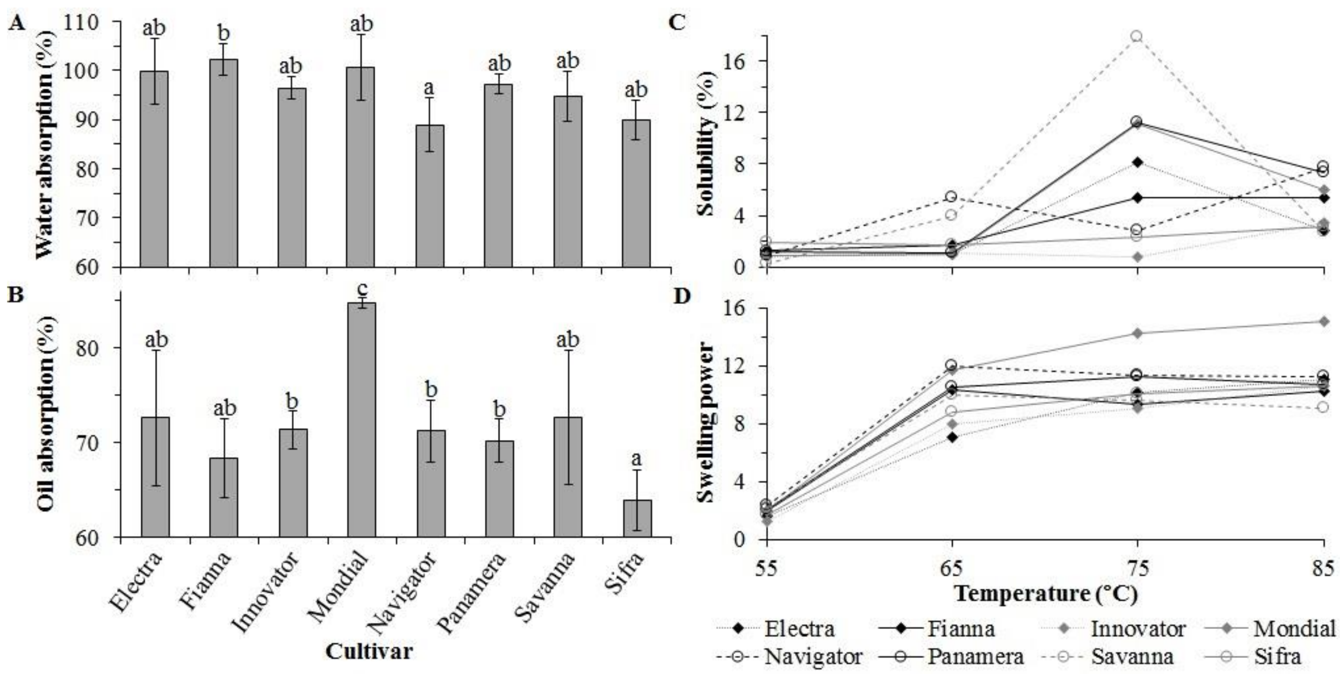

Figure 3 Physiochemical properties of potato starch. Graphs showing water absorption capacity (A), oil absorption capacity (B), solubility (C) and swelling power (D). Values with the same letter differ non-significantly (p>0.05)

3.2.3 Starch thermal characteristics

Results on the gelatinization properties revealed that the onset, peak and conclusion temperatures ranged from 45.8 to 77.8°C, 85.9 to 96.7°C and 135.5 to 138.1°C, respectively (Table 2).

Gelatinisation enthalpy ranged from 69.8 to 196.6 J g^{-1}. Although the gelatinization temperature ranges and enthalpies found in this study are much higher than those reported by Chung et al. (2014), for Innovator, and Alvani et al. (2011), for other cultivars, differences between cultivars were apparent. Mondial displayed a significantly lower gelatinization enthalpy and peak height index (1.2) than the other cultivars, indicating a higher interaction between water and the starch granules (Liu et al., 2007; Chung et al., 2014). The differences between the other cultivars were statistically non-significant. Furthermore, while the differences in the conclusion temperatures were not significant, it could be noted that Mondial had the highest gelatinization onset and the lowest peak temperatures (77.8 and 85.9°C, respectively).

Table 2 Gelatinisation properties of the starch from eight cultivars

Cultivars	**T_o (°C)**	**T_p (°C)**	**T_c (°C)**	**ΔH (J g^{-1})**	**ΔT (°C)**	**PHI**
Electra	52.0a	95.0b	137.7a	183.7b	85.7b	2.1b
Fianna	45.8a	94.2b	137.3a	196.6b	91.5b	2.2b
Innovator	49.2a	96.7b	138.1a	188.6b	89.0b	2.1b
Mondial	77.8b	85.9a	135.5a	69.8a	57.7a	1.2a
Navigator	50.8a	93.4b	140.2a	189.9b	89.4b	2.1b
Panamera	52.9a	91.4b	139.6a	189.6b	86.7b	2.2b
Savanna	52.1a	93.0b	137.6a	177.8b	85.5b	2.1b
Sifra	50.5a	91.8b	137.2a	177.2b	86.6b	2.1b
LSD	18.620	4.617	3.869	66.580	14.260	0.809
CV (%)	16.5	2.3	1.3	17.4	7.6	18.1

T_o = onset temperature; T_p = peak temperature; T_c = conclusion temperature; ΔH = enthalpy; ΔT = gelatinisation temperature range; PHI = peak height index. CV = Coefficient of variation; LSD = Least Significant Difference. Values with the same letter differ non-significantly ($p>0.05$)

3.2.4 Starch granule morphology

A microscopic analysis of the starch granules showed that the highest length and width was 84.3 and 66.6 µm among cultivars, respectively (data not shown). Innovator, Mondial and Savanna had a higher frequency (>50%) of granules with a width and length lower than 30 µm, which were considered small in this study, compared to the other cultivars (Figure 4). The starch granules of the cultivars evaluated in this study displayed the typical oval and ellipsoidal shape

(Alvani et al., 2011). The length of the granules ranged from 6-92 µm and the width ranged from 5-67 µm. The largest starch granules were found in Sifra, which also had a more balanced size distribution than the other cultivars. The granules of this cultivar had the average length and width of 46 and 34 µm, respectively. The smallest starch granules were found in Innovator and had the average length and width of 28 and 27 µm, respectively. The granules of Innovator, Mondial and Navigator were of a notably regular shape, while the granules of Electra, Fianna, Panamera and Savanna being more irregular (Figure 5).

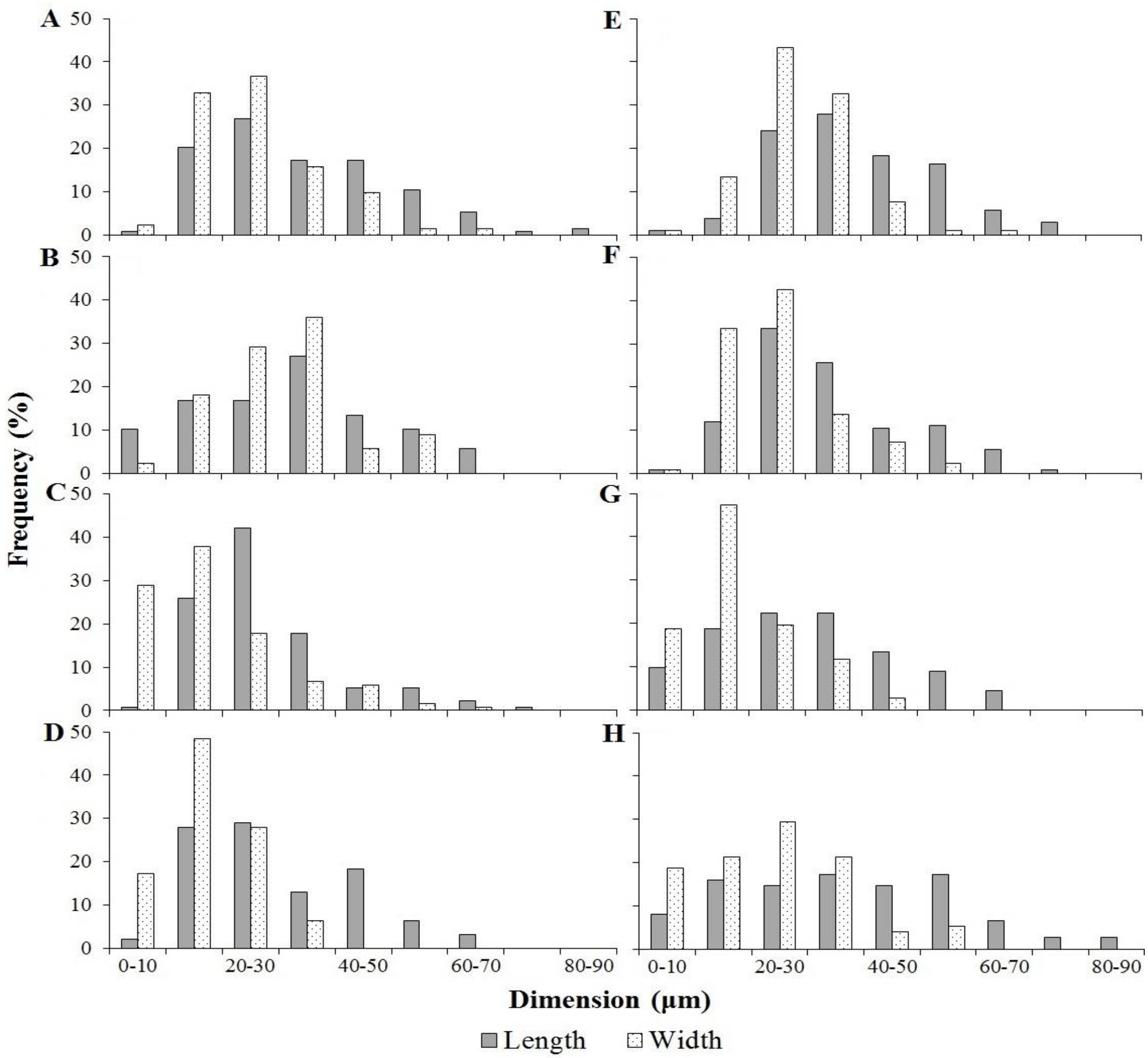

Figure 4 Starch granule size frequency distribution of Electra (A); Fianna (B); Innovator (C); Mondial (D); Navigator (E); Panamera (F); Savanna (G); and Sifra (H)

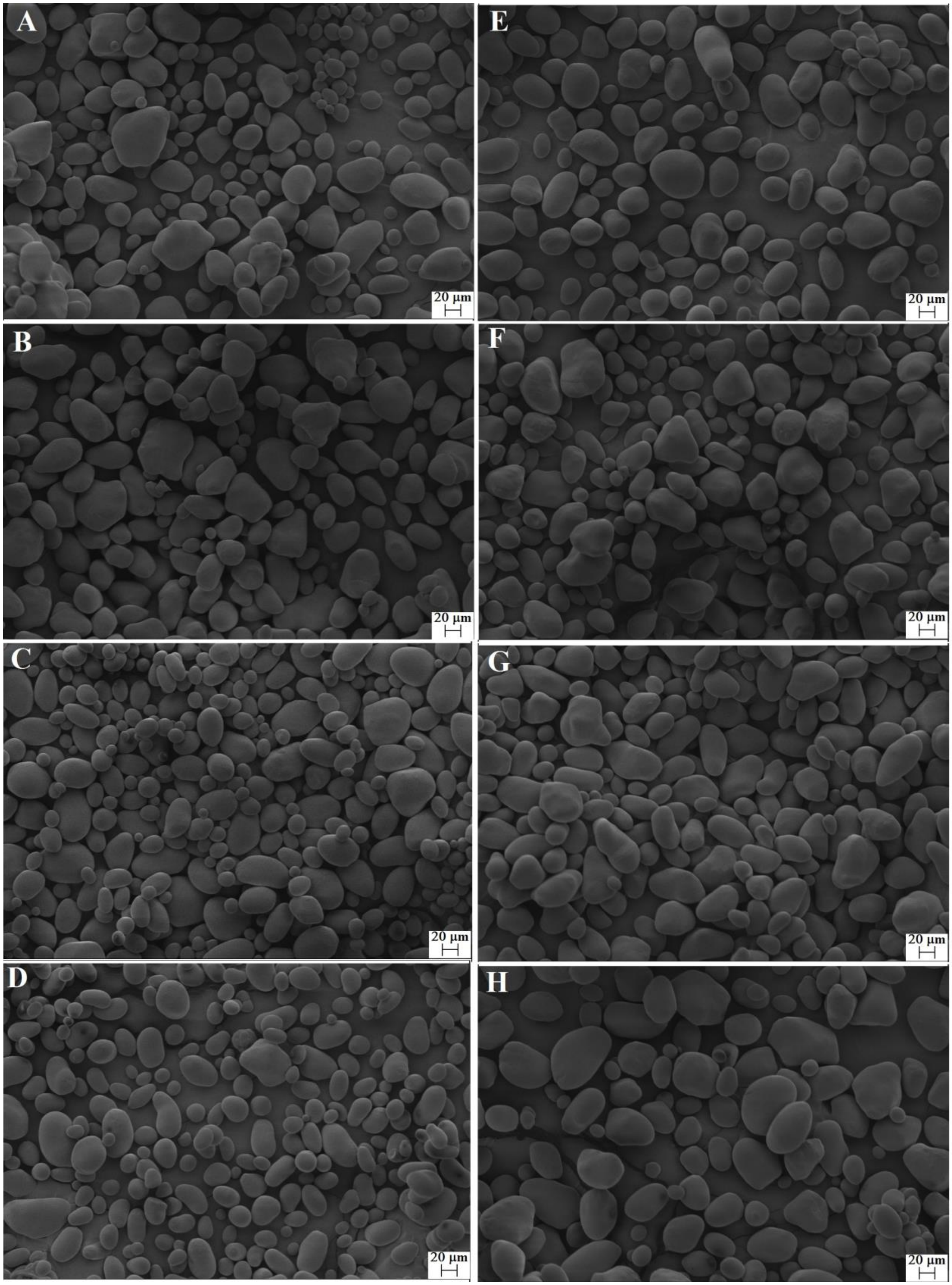

Figure 5 Starch granule morphology of Electra (A); Fianna (B); Innovator (C); Mondial (D); Navigator (E); Panamera (F); Savanna (G); and Sifra (H)

The high occurrence of small-sized granules explains the higher water holding capacity and lower gelatinization enthalpy of the starch of Mondial as a reduction in granule size increases the surface area available for water to bind to the granules. This is typical in waxy cultivars (Hoover, 2001). Cultivar differences in starch granule surface area have been reported by Jansky and Fajardo (2014) and the effect on the water holding capacity was also reported by Alvani et al. (2011). Alvani et al. (2011) also reported that high amylose contents lower the energy required to initialise gelatinisation. Interestingly, the starch of Sifra showed quite distinct characteristics to Mondial and this was not expected since the former is a descendent of latter. Nutritional composition differences between these cultivars were also reported in the study by van Niekerk et al. (2016), which reported similarities only in dry mass, starch and Zn contents.

4. Conclusions and Recommendations

Significant differences exist in the composition and nutrient quality of the cultivars tested in this study. Fianna showed good potential for processing due the high dry matter which was associated with moderate starch and a high protein content. Innovator and Navigator also showed potential in this regard, particularly because of their high starch and amylose content, which is typical in floury potatoes. However, while Innovator is a good candidate for processing because of the high dry mass, starch and better rheological properties, it is particularly a weaker source of Mg and Fe. Electra has the best Ca and Fe, even though it scored lowest for all dry mass components evaluated in this study. This cultivar may be used to correct dietary deficiencies associated with these minerals. Additionally, Fianna showed good nutritional value as it ranked highest in all other mineral elements evaluated in this study. Navigator showed potential as a lower glycaemic index cultivar in this study due to the highest amylose content coupled with a low water absorption capacity, but these findings need to be validated through investigation of the actual glycaemic index of the cultivars. Mondial showed characteristics of a waxy potato, evident from its significantly low amylose content, high starch swelling power and high oil absorption capacity. Further studies on the interaction of amylose with the amylopectin component are suggested to give more insight on the changes that may occur during processing. The information obtained from this study could be a useful guide in the selection of appropriate potato cultivars for specialized culinary needs for domestic and industrial applications, which will have substantial impacts on population health as potato is becoming a staple South Africa.

Author contribution

T Workneh supervised the study and edited the manuscript. N Ngobese conceived and conducted the experiments, analysed data and drafted the manuscript. B Alimi designed the experiments for assessments of the physicochemical properties of starch. S Tesfay supervised the sugar and starch quantification assessments.

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References

Aguilar, F., Autrup, H., Barlow, S., Castle, L., Crebelli, R., Dekant, W., Engel, K.-H., Gontard, N., Gott, D., Grilli, S., Gürtler, R., Larsen, J.-C., Leclercq, C., Leblanc, J.-C., Malcata, F.-X., Mennes, W., Milana, M.-R., Pratt, I., Rietjens, I., Tobback, P., Toldrá, F. (2008). Safety of aluminium from dietary intake [1]: Scientific opinion of the panel on food additives, flavourings, processing aids and food contact materials (AFC). *The European Food Safety Authority Journal*, 754, 1–34.

Alvani, K., Qi, X., Tester, R. F., Snape, C. E. (2011). Physico-chemical properties of potato starches. *Journal of Food Chemistry*, 125(3), 958–965.

Badenhorst, R. (2014). Potatoes SA 2014 consumer research study. *CHIPS Magazine*, 28(4), 20–29.

Bárta, J., Bártová, V. (2008). Patatin, the major protein of potato (*Solanum tuberosum* L.) tubers, and its occurrence as genotype effects: processing versus table potatoes. *Czech Journal of Food Sciences*, 26(5), 347–359.

BeHall, K., Howe, J. (1995). Effect of long-term consumption of amylose vs amylopectin starch on metabolic variables in human subjects. *The American Journal of Clinical Nutrition*, 61, 334–340.

Charlton, K., Webster, J., Kowal, P. (2014). To legislate or not to legislate? A comparison of the UK and South African approaches to the development and implementation of salt reduction programs. *Nutrition*, 6, 3672–3695.

Chandra, S., Samsher. (2013). Assessment of functional properties of different flours. *African Journal of Agricultural Research*, 8(38), 4849–4852.

Chung, H.-J., Li, X.-Q., Kalinga, D., Lim, S.-T., Yada, R., Liu, Q. (2014). Physicochemical properties of dry matter and isolated starch from potatoes grown in different locations in Canada. *Food Research International*, 57, 89–94.

de Freitas, S. T., Pereira, E. I. P., Gomez, A. C. S., Brackmann, A., Nicoloso, F., Bisognin, D. (2012). Processing quality of potato tubers produced durig autumn and spring and stored at different temperature. *Horticultura Brasileira*, 30, 91–98.

Department of Agriculture, Forestry & Fisheries (2016). Abstract of agricultural statistics. South Africa. Retrieved May 6, 2016 from: http://www.nda.agric.za/

Department of Health (2014). *Foodstuffs, Cosmetics and Disinfectant Act, 1972 (ACT No.54 of 1972) Regulations Relating to the Labelling and Advertising of Foods: Amendment (R429 of May 2014)*. Pretoria, South Africa: Government Gazette.

Joint FAO/WHO Expert Committee on Food Additives (2011). Evaluation of certain food additives and contaminants. WHO Technical Reports Series 966:7–17. Retrieved May 6, 2016 from: http://apps.who.int/iris/bitstream/10665/44788/1/WHO_TRS_966_eng.pdf

Joy, E. M. J., Ander, E. L., Young, S. D., Black, C. R., Watts, M. J., Chilimba, A. D. C., Chilima B., Siyame, E. W., Kalimbira, A. A., Hurst, R., Fairweather-Tait, S. J., Stein, A. J., Gibson, R. S., White, P. J., Broadley, M. R. (2014). Dietary mineral supplies in Africa. *Physiologia Plantarum*, 151, 208–229.

Ek, K. I., Wang, S., Copeland, L., Brand-Miller, J. C. (2014). Discovery of a low-glycaemic index potato and relationship with starch digestion *in vitro*. *British Journal of Nutrition*, 111, 699–705.

Ezekiel, R., Rana, G. (2009). Physicochemical properties of potato starch in relation to cultivar, growing location, season and crop maturity. *Advances in Horticultural Science*, 23(2), 94–100.

Ezekiel, R., Singh, N., Sharma, S., Kaur, A. (2013). Beneficial phytochemicals in potato – a review. *Food Research International*, 50, 487–496.

European Cultivated Potato database (2016). Variety index. Retrieved April 4, 2016 from: http://www.europotato.org/varietyindex.php

Furrer, A. N., Chegeni, M., Ferruzzi, M. G. (2016). Impact of potato processing on nutrients, phytochemicals and human health. *Critical Reviews in Food Science and Nutrition*, Doi: 10.1080/10408398.2016.1139542

Gumul, D., Ziobro, R., Noga, M., Sabat, R. (2011). Characterisation of five potato cultivars according to their nutritional and pro-health componens. *Acta Scientiarum Polonorum, Technologia Alimentaria*, 10, 73–81.

Hoover, R. (2001). Composition, molecular structure, and physicochemical properties of tuber and root starches: a review. *Carbohydrate Polymers*, 45, 253–267.

Jansky, S. H., Fajardo, D. A. (2014). Tuber starch amylose content is associated with cold-induced sweetening in potato. *Food Science & Nutrition*, 2(6), 628–633.

Jansky, S., Fajardo, D. (2016). Amylose content decreases during tuber development in potato. Journal of the Science of Food and Agriculture, Doi: 10.1002/jsfa.7673

Kaur, S., Aggarwal, P. (2014). Studies on Indian potato genotypes for their processing and nutritional quality attributes. *International Journal of Current Microbiology and Applied Sciences*, 3(8), 172–177.

Lewu, M. N., Adebola, P. O., Afolayan, A.J. (2010). Comparative assessment of the nutritional value of commercially available cocoyam and potato tubers in South Africa. *Journal of Food Quality*, 33, 461–476.

Liu, Q., Weber, E., Currie, V., Yada, R. (2003). Physicochemical properties of starches during potato growth. *Carbohydrate Polymers*, 51(2), 213–221.

Liu, Q., Tarn, R., Lynch, D., Skjodt, N. M. (2007). Physicochemical properties of dry matter and starch from potatoes grown in Canada. *Food Chemistry*, 105, 897–907.

Matthäus, B., Haase, N. U., Vosmann, K. (2004). Factors affecting the concentration of acrylamide during deep-fat frying of potatoes. *European Journal of Lipid Science and Technology*, 106, 793–801.

Mccready, R. M., Guggolz. J., Silviera, V., Owens, H. S. (1950). Determination of starch and amylose in vegetables. *Analytical Chemistry*, 22, 1156.

Morales-Fernández, S. D., Mora-Aguilar, R., Salinas-Moreno, Y., RodríguezPérez, J. E., Colinas-León, M. T., & Lozoya-Saldaña, M. T. (2015). Growth, yield and sugar content of potato tubers at different physiological ages. *Revista Chapingo Serie Horticultura*, 21(2), 129–146. Doi: 10.5154/r.rchsh.2014.06.031

Murniece, I., Karklina, D., Galoburda, R., Santare, D., Skrabule, I., Costa, H. S. (2011). Nutritional composition of freshly harvested and stored Latvian potato (*Solanum tuberosum* L.) varieties depending on traditional cooking methods. *Journal of Food Composition and Analysis*, 24:699–710.

Nassar, A. M. K., Sabally, K., Kubow, S., Leclerc, Y. N., Donnelly, D. J. (2012). Some Canadian-grown potato cultivars contribute to a substantial content of essential dietary minerals. *Journal of Agricultural and Food Chemistry*, 60, 4688−4696.

Noda, T., Tsuda, S., Mori, M., Takigawa, S., Matsuura-Endo, C., Saito, K., Mangalika, W. H. A., Hanaoka, A., Suzuki, Y., Yamauchi, H. (2004). The effect of harvest dates on the starch properties of various potato cultivars. *Food Chemistry*, 86, 119–125.

Pedreschi, F., Mariotti, M. S., Granby, K. (2014). Current issues in dietary acrylamide: formation, mitigation and risk assessment. *Journal of the Science of Food and Agriculture*, 94, 9–20.

Puri, S., Dhillon, B., Sodhi, N. S. (2015). A study on the effects of degree of milling (DOM) on color and physicochemical properties of different rice cultivars grown in Punjab. *International Journal of Advanced Biotechnology and Research*, 6(3), 310–319.

Raigond, P., Singh, B., Kuandal, B. (2015). Changes in the starch and fiber fractions of French fries: response of freezing. *Potato Journal*, 42, 8–17.

Sanny, M., Jinap, S., Bakker, E. J., van Boekel, M. A. J. S., Luning, P. A. (2012). Is lowering reducing sugars concentration in French fries an effective measure to reduce acrylamide concentration in food service establishments? *Food Chemistry*, 135, 2012–2020.

Shimelis, E., Meaza, M., Rakshit, S. (2006). Physico-chemical properties, pasting behavior and functional characteristics of flours and starches from improved bean (*Phaseolus vulgaris* L.) varieties grown in East Africa. *Agricultural Engineering International: the CIGR E journal*, 8, 1–19.

Singh, N., Singh, J., Kaur, L., Sodhi, N. S., Gill, B. S. (2003). Morphological, thermal and rheological properties of starched from different botanical sources. *Food Chemistry*, 81, 219–231.

Šimková, D., Lachman, J., Hamouz, K., Vokál, B. (2013). Effect of cultivar, location and year on total starch, amylose, phosphorus content and starch grain size of high starch potato cultivars for food and industrial processing. *Food Chemistry*, 141, 3872–3880.

Soison, B., Jangchud, K., Jangchud, A., Harnsilawat, T., Piyachomkwan, K. (2015). Characterization of starch in relation to flesh colors of sweet potato varieties. *International Food Research Journal*, 22(6), 2302–2308.

Subramanian, N. K., White, P. J., Broadley, M. R., Ramsay, G. (2011). The three-dimensional distribution of minerals in potato tubers. *Annals of Botany*, 107, 681–691.

Tekalign, T., Hammes, P. S. (2005). Growth and productivity of potato as influenced by cultivar and reproductive growth: II. Growth analysis, tuber yield and quality. *Scientia Horticulturae*, 105, 29–44.

van Niekerk, C., Schönfeldt, H., Hall, N., Pretorius, B. (2016). The role of biodiversity in food security and nutrition: a potato cultivar case study. *Food and Nutrition Sciences*, 7, 371–382.

Wang, X., Sun, H., Sun, J., Zhu, X., Zhang, K., Shen, J., Cai, X. (2015). Effects of different storage temperatures on nutritional quality of potato cultivar Kevin no.1. *Agricultural Science and Technology*, 16(4), 810–814.

White, P. J., Bradshaw, J. E., Dale, M. F. B., Ramsay, G. (2009). Relationship between yield and mineral concentrations in potato tubers. *Horticultural Science*, 44, 6–11.

Wolmarans, P., Danster, N., Dalton, A., Rossouw, K., Schönfeldt, H. (2010). *Condensed Food Composition Tables for South Africa*. Parow Valley, Cape Town, South Africa: Medical Research Council.