Research Article

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Expanding industrial uses of sweetpotato for food security and poverty alleviation

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Abstract: Sweetpotato breeding over the years solely depended on sensory evaluation for domestic uses, thereby downplaying the need for adjustment of breeding objectives and selection procedures to cater for industrial potential. This study was conducted to evaluate ten elite genotypes of sweetpotato for diversified utilization and commercialization. These genotypes had been selected over the years for high dry matter and starch content according to the preference of Ghanaian consumers. Analyses were carried out on key nutrient components, pasting properties, and starch granule morphology using near infrared reflectance spectroscopy, rapid viscosity analysis, and light microscopy, respectively. Sensory evaluation was carried out using a focus group approach. Based on functional diversity and unique combinations of quality traits identified, the genotypes were found to have several potential applications in the food industry. These include *fufu* flour, bread, pastries, French fries, gluten-free noodles, yogurt filler, baby food, juices, and raw material for brewery and other industries. These elite genotypes, when released as new varieties, can immensely contribute to a more diversified use of sweetpotato in Ghana and ultimately contribute to the enhancement of food and job security.

Keywords: elite genotypes, breeding objectives, utilization, industrial potential

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1 Introduction

Sweetpotato (*Ipomoea batatas* L.) is a versatile and nutritious root crop cultivated in more than 100 countries. It is rich in simple and complex carbohydrates and dietary fibers and also provides nutritionally significant quantities of ascorbic acid, riboflavin, pyridoxine, iron, calcium, and protein. Also, the orange-fleshed varieties are rich in beta-carotene, a nutrient that may be effective in preventing certain types of cancer (Prakash 1994), and has also been sustainably used in public health campaigns for the alleviation of vitamin A deficiency (van Jaarsveld et al. 2005). Among the food crops, sweetpotato has the highest recorded net protein utilization based on the percentage of food nitrogen retained in the body (Prakash 1994). The nutritional superiority of this crop also includes the presence of nutraceuticals (e.g., bioactive phenolic compounds and anthocyanins in the purple fleshed varieties) and a glycemic index much lower than that of the Irish potato (Kays 1992, 2005a). Its consumption is reported to help stabilize blood sugar levels and to decrease insulin resistance (Hung 2004; Zakir 2005; Allen et al. 2012). Sweetpotato has also been successfully used in a number of African countries to combat widespread vitamin A deficiency that results in blindness and even death of 250,000–500,000 children per year. This crop is very productive and has the potential to play a key role in national economies.

Regardless of the great potential of sweetpotato to alleviate food insecurity, malnutrition, and poverty, its level of utilization has remained low over the years (Kays 2005a; Shih et al. 2009; Adu-Kwarteng et al. 2017), despite the release of many improved varieties. Sweetpotato has been described as one of the most misunderstood crops among the major food crops (Scott and Maldonado 1998). Due to its wide genetic diversity coupled with inherent postharvest changes that occur (Zhang et al. 2002), it is often difficult for the user, whether domestic or commercial, to determine the most suitable characteristics for particular product. Enzymes in sweetpotato that have a direct bearing on its processing quality are alpha-amylase, beta-amylase, and polyphenol oxidase. These enzymes cause changes in taste and texture during cooking. Changes in texture (e.g. loss of firmness) occur due to enzymatic breakdown in starch content (Truong and Avula 2010), and the formation of additional sugar (maltose) by enzyme action during processing results in an increase in the overall sweetness of the final product (Kiribuchi and Kubota 1976).

Generating information on diversified utilization options for available sweetpotato germplasm and how to incorporate these into commercially viable processed forms would provide the missing link in the promotional drive of this important crop. Currently, it is uncommon to find sweetpotato being served in any Ghanaian restaurant, institution, or food service establishment. This study was conducted to evaluate ten elite genotypes of sweetpotato for diversified utilization and commercialization potential, with the ultimate goal of increasing consumption and demand levels to enhance production and trade volumes. Several commercial applications were linked with relevant traits identified in the genotypes studied, and this can hopefully serve as a guide to breeding programs, product developers, and other users when the genotypes are released as commercial varieties.

2 Materials and methods

The study was conducted at CSIR-Crops Research Institute and the International Potato Center Laboratories in Fumesua, Ghana, using ten elite genotypes developed for release as commercial varieties. Within 48 h after harvest, a batch of representatively sized roots (small, medium, and large) was sampled for each genotype and processed for analysis.

2.1 Near infrared reflectance spectroscopy (NIRS)

2.1.1 Sample preparation

Roots from each sample batch were washed, scrubbed, and air dried for 24 h. Each root from the sample was quartered, and the quarters pooled to form one sample. From this, 50 g portions were weighed in triplicate, placed in special sample bags, and kept in a deep freezer (−20°C) to freeze. The frozen samples were then freeze dried for 72 h (YK-118-50 Vacuum Freeze-dryer; True Ten Industrial Co. Ltd., Taiwan), milled using a Cyclotec 1093 sample mill (Rose Scientific, Ontario, Canada) to pass through a 60–80 mesh screen, and kept in airtight plastic bags at room temperature until analysis.

2.1.2 NIRS analysis

Nutrient components were analyzed using NIRS (Model XDS Near infra-red; XM-1100 series, Sweden). Data collected were dry matter, beta-carotene, sugar, starch, iron, and zinc content.

2.2 Flour pasting properties

2.2.1 Sample preparation

Fresh root samples were peeled, grated, and processed into flour by drying in an air oven at 60°C for 72 h and milling (using a Cyclotec 1093 sample mill) to pass through a 60–80 mesh screen. These flour samples were kept in airtight plastic bags at room temperature until analysis.

2.2.2 Rapid viscosity analysis (RVA)

Flour pasting properties were determined by the rapid viscosity analyzer (RVA model 4500; Perten Instruments, Australia) using 14% flour slurries (dry weight basis). Profiles were run in duplicate. The following parameters were measured:

- Pasting temperature in degree Celsius – the temperature at which starch gelatinization begins.
- Peak viscosity (PV) – the highest viscosity attained during the heating cycle.
- Setback ratio – C/PV, where C is the cold paste viscosity (final viscosity after cooling down from 95°C and holding at 50°C).

Estimates of amylase (starch-hydrolyzing) enzyme activities were derived using PVs from the RVA profiles in conjunction with the starch content data. These values were derived as follows:

$$\text{Estimated amylase activity index} = \frac{\text{Starch content (dry basis)}}{\text{RVA peak viscosity}} \times 10$$

Scoring was presented based on the scale in Table 1.

Table 1: Scale used to score the estimated amylase activity index of the sweetpotato genotypes

Activity index value	Activity description
0–0.5	Low or absent activity
>0.5–1.0	Moderate activity
>1.0–2.0	High activity
>2.0	Very high activity

2.3 Starch pasting properties

2.3.1 Sample preparation

Starch was extracted from fresh sweetpotato roots through maceration, filtration, and sedimentation. Starch sediments were air dried for 72 h to approximately 12% moisture levels.

2.3.2 RVA

RVA pasting properties of starch samples were determined as described for flour samples, but the slurry concentration used was 11.2% (dry weight basis).

2.3.3 Starch granule morphology

A small quantity of each starch sample (7–10 mg) was taken using the tip of a spatula and placed on a glass slide. The sample was mixed with 1–2 drops of 0.2% iodine solution, spread out, and observed under a light microscope (Novex, Holland) fitted with a calibrated eyepiece to calculate the size range of the granules. Micrographs were taken with a digital camera (Canon sx210 IS) at a magnification of 400×.

2.4 Sensory evaluation

Sensory evaluation was done using a focus group approach. The group was made up of ten experienced sweetpotato consumers with a wide age range (22–51 years) and diverse educational backgrounds. In each session, the group participants assessed and discussed the quality characteristics of one or two products prepared using the ten elite sweetpotato genotypes. The food products presented were bread, crispy chips, French fries, chunk-fried pieces, and boiled pieces. These were prepared at CSIR-Crops Research Institute Postharvest Test Kitchen. Each sweetpotato product was assessed based on its appearance, texture/mouthfeel, taste/flavor, and overall eating quality/acceptability.

3 Results

3.1 Key nutrient components

Dry matter content ranged from 32.39% to 47.03%, while starch content ranged from 70.41% to 79.49% of the dry matter (Table 2). On a dry weight basis, beta-carotene content was diverse, ranging from 2.38 mg/100 g to 28.46 mg/100 g. Sugar content ranged from 10.94% to 18.12%, while iron (Fe) and zinc (Zn) content ranged from 1.39 mg/100 g to 1.65 mg/100 g and 0.72 mg/100 g to 0.89 mg/100 g, respectively.

Table 2: Key nutrient content in the ten elite sweetpotato genotypes expressed on dry weight basis (d.b.)

Genotype	Dry matter (%)	Starch (% d.b.)	Beta-carotene (mg/100 g d.b.)	Total sugars (% d.b.)	Iron (mg/100 g d.b.)	Zinc (mg/100 g d.b.)
AGRA SP 04	38.49	79.49	2.51	11.10	1.60	0.76
AGRA SP 05	44.51	78.26	2.38	10.97	1.55	0.77
AGRA SP 06	47.03	76.55	7.25	10.94	1.65	0.89
AGRA SP 07	42.46	76.57	7.25	15.29	1.47	0.73
AGRA SP 09	38.25	77.01	2.85	14.47	1.40	0.85
AGRA SP 12	44.47	78.65	3.78	11.47	1.49	0.73
AGRA SP 13	41.62	74.62	11.38	16.56	1.39	0.72
AGRA SP 19	32.39	73.93	21.10	17.08	1.47	0.86
AGRA SP 20	34.78	70.41	28.46	18.12	1.65	0.89
AGRA SP 23	43.00	76.33	16.30	15.70	1.54	0.76
LSD (5%)	2.36	3.70	1.92	1.68	0.16	0.10

3.2 Flour pasting characteristics

The sweetpotato genotypes showed "A" type RVA pasting profiles, with sharp viscosity peaks followed by a steep drop in viscosity, which is due to a high degree of shear-thinning of the cooked paste (Figure 1); this feature is typical of most starchy root crops (Collado et al. 1999). However, there was diversity in cooked paste viscosities, showing clearly in the pasting profiles as relatively high viscosities (>2,000 centipoise) as seen in AGRA SP 04 and AGRA SP 09, moderate viscosities (>1,000 centipoise) and very depressed viscosities (<1,000 centipoise), and even as low as <100 centipoise as observed in genotypes AGRA SP 13 and AGRA SP 19 (Figure 1).

Flours from AGRA SP 06 and AGRA SP 09 were found to have the highest pasting temperatures of 88°C and 86°C, respectively, while genotype AGRA SP 12 had the lowest temperature of 82.82°C (Table 3).

3.3 Estimated amylase activity index

There was a wide range in the estimated index of amylase enzyme activity (Table 3). The values ranged from 0.35 for AGRA SP 04 to 3.55 for AGRA SP 19. Genotypes AGRA SP 05, AGRA SP 13, and AGRA SP 19 fell in the categories of high or very high activity, exhibiting the characteristics of high starch content (>70%) coupled with unexpectedly low cooked paste viscosities.

3.4 Starch RVA pasting properties

There was not much diversity in RVA pasting profiles of starch. Starches from AGRA SP 06 and AGRA SP 09 were found to have the highest pasting temperatures (84.85°C and 85°C, respectively) (Table 4). Setback ratios were relatively low (0.70–0.92) compared to that of starch from already-released Ghanaian varieties (1.25–1.61) as reported by Adu-Kwarteng et al. (2017).

3.5 Starch granule morphology

Starch granule morphologies were characteristic of sweetpotato starch, with a mixture of shapes represented in Figure 2. The average starch granule size ranged from 10 to 20 μm (Table 5).

3.6 Sensory evaluation

All the sweetpotato genotypes were found to have high acceptability when prepared in the form of bread, crispy chips, French fries, chunk-fried pieces, and boiled pieces.

4 Discussion

Dry matter in sweetpotato correlates well with starch content. High dry matter content is generally desirable in Ghanaian sweetpotato-based food products (Ellis et al. 2001; Adu-Kwarteng et al. 2003; CSIR-CRI 2012), and at above 35.0%, it is also desirable as a raw material in the starch processing industries (Mok et al. 1997). This means that apart from AGRA SP 19 and AGRA SP 20, which had dry matter content <35%, all the other eight genotypes would be potentially suitable for the starch processing industry. Despite the view in some circles that sweetpotato lacks potential in commercial starch exploitation due to relative advantages of other alternative starch sources (Wheatley and Loechl 2008), sweetpotato starch has performed creditably well in some Asian economies. For example, it has been used for the manufacture of starch noodles in China, Korea, and Japan for many years (Collado and Corke 1999).

The sugar content of sweetpotato is an important aspect of its flavor and eating quality (Kays 2005b). In Ghana, many communities have indicated the desire for nonsweet or low-sugar sweetpotatoes for adoption as a staple in their diets, as sweet taste is generally associated with luxury food, dessert, or snack and not with staple foods (Oduro 2013; Baafi 2014; Carey et al. 2019). The elite genotypes involved in this study, having relatively moderate sugar content (10.94–18.12%), may have an advantage in Ghana over some of the already released high-beta carotene varieties such as *Apomuden*, which has high sugar levels, reported as >30% (Adu-Kwarteng 2017). However, the sugar content in harvested sweetpotatoes is often not static but can undergo changes depending on harvest maturity and duration of storage (Adu-Kwarteng et al. 2014). The wide range in the beta-carotene content of the genotypes studied (2.38–28.46 mg/100 g dry weight) is directly linked with diversity in flesh color, thus making

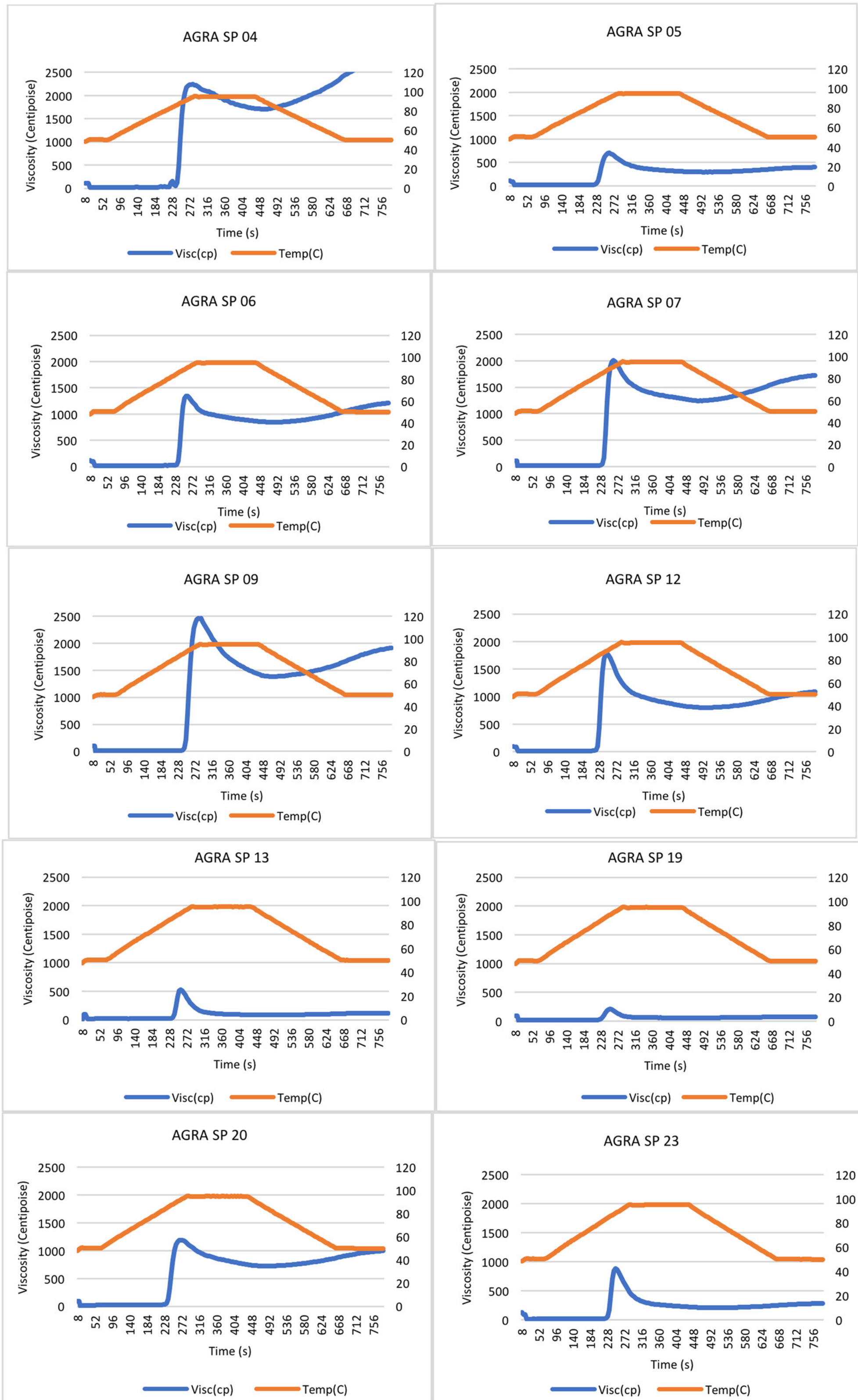

Figure 1: RVA pasting profiles of flour from ten elite sweetpotato genotypes.

Table 3: RVA pasting properties of flours and estimated amylase activity index of ten elite sweetpotato genotypes

Genotype	Pasting temperature (°C)	Peak viscosity (centipoise)	Setback ratio	Estimated amylase activity index
AGRA SP 04	83.12	2,268	1.24	0.35
AGRA SP 05	83.47	720	0.56	1.08
AGRA SP 06	88.00	1,368	0.86	0.55
AGRA SP 07	84.42	2,096	0.84	0.36
AGRA SP 09	86.00	2,175	0.81	0.35
AGRA SP 12	82.82	1,777	0.60	0.44
AGRA SP 13	84.82	460	0.23	1.62
AGRA SP 19	84.00	208	0.35	3.55
AGRA SP 20	83.00	1,193	0.84	0.59
AGRA SP 23	83.22	898	0.31	0.85

Table 4: RVA pasting properties of starches from ten elite sweetpotato genotypes

Genotype	Pasting temperature (°C)	Peak viscosity (centipoise)	Setback ratio
AGRA SP 04	83.50	4,340	0.79
AGRA SP 05	82.87	3,966	0.74
AGRA SP 06	84.85	3,887	0.79
AGRA SP 07	82.40	3,905	0.72
AGRA SP 09	85.00	4,486	0.70
AGRA SP 12	83.20	4,185	0.78
AGRA SP 13	83.60	3,793	0.79
AGRA SP 19	83.20	4,168	0.81
AGRA SP 20	83.70	3,974	0.92
AGRA SP 23	83.25	3,455	0.78

them versatile for a broad array of products. The nutritional advantage of the genotypes with higher beta-carotene content can be tapped successfully together with other traits relevant to the processing qualities of target products. Zinc and iron content in the genotypes studied were not very diverse, but the levels were found to be quite appreciable. In low-income areas, most infants are given cereal-based complementary foods prepared at home; these foods tend to be high in phytate, which limits the bioavailability of certain minerals including iron, calcium, and zinc, which are crucial to the development of infants. In a study on infant complementary foods, sweetpotato-based formulations were reported to have much lower phytate/mineral ratios for calcium, iron, and zinc compared to maize-based formulations, suggesting that absorption of these minerals could be better from the sweetpotato-based infant food (Amagloh et al. 2012). The recommended daily human requirement for iron and zinc are 8–15 mg and 3–12 mg, respectively.

For flour pasting characteristics, genotypes that had low PV (<1,000 cP) could be very suitable in baby food production (AGRA SP 05, AGRA SP 13, AGRA SP 19, and AGRA SP 23), while those with high viscosity (>2,000 cP) would be excellent candidates for pounded *fufu* as well as commercial *fufu* flour production (AGRA SP 04, AGRA SP 07, and AGRA SP 09). Low setback ratios obtained in the flour RVA profiles could also be an advantage in promoting these genotypes for bread and other baked goods, since low setback means minimal retrogradation, and this is a desirable trait for a better shelf life of such products.

Estimated amylase activity values were derived based on the inherent influence of amylase enzyme action on starch during cooking, as well as the well-known positive correlation between starch content and viscosity of cooked pastes. Genotypes AGRA SP 05, AGRA SP 13, and AGRA SP 19 fell in the categories of high or very high activity, exhibiting the characteristics of high starch content (>70%) coupled with unexpectedly low cooked paste viscosities. This could be due to the hydrolytic action of alpha- and beta-amylases on the native starch in the flour of these genotypes during the heating phase of the RVA profile. Sweetpotato amylase is known to be heat stable around and even above the gelatinization temperature of sweetpotato starch. Endogenous amylase enzymes or naturally occurring amylase enzymes in fresh sweetpotato roots are known to hydrolyze starch to form dextrin and maltose during cooking. High activity of these enzymes (alpha- and beta-amylases) in sweetpotato can be an advantage in the case of industrial processes such as brewing, alcohol production, and sugar syrup production where hydrolysis of starch into sugars is a required major step. Genotypic differences exist in the expression of both alpha- and beta-amylase enzyme activities. Some genotypes may exhibit more stability in the expression of this trait than others, and this must be studied further. Other factors (maturity at the time of harvest, postharvest storage duration, and ambient temperature) can influence the

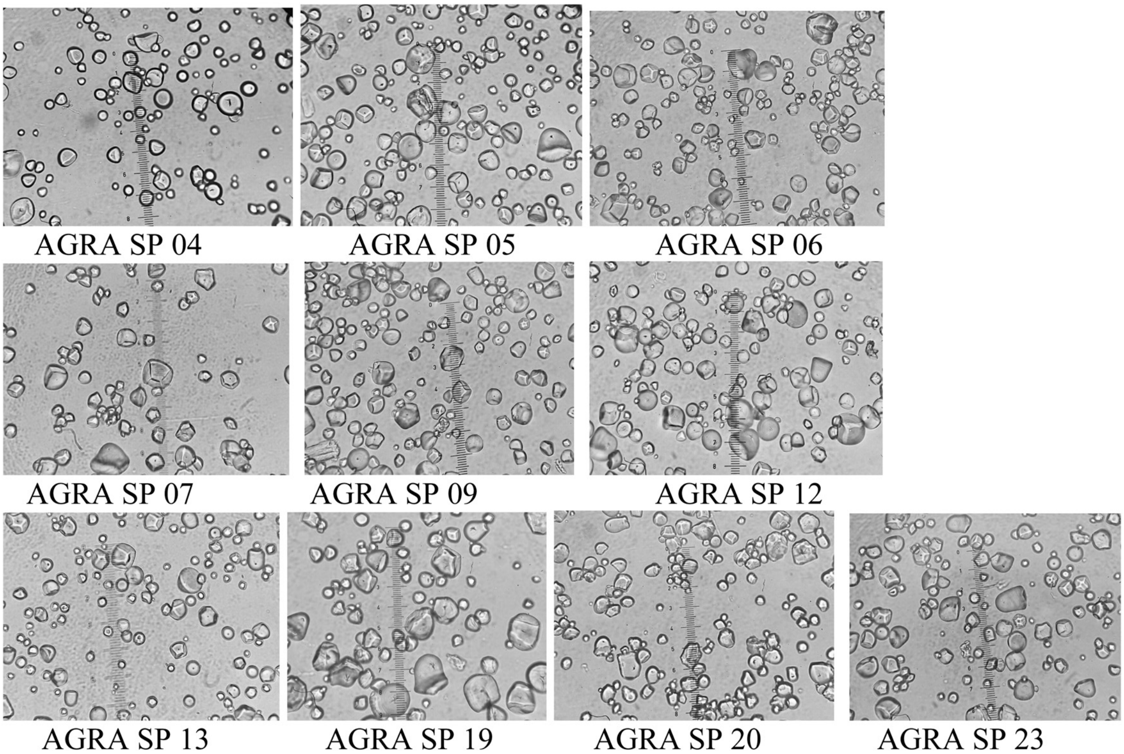

Figure 2: Photomicrographs of native starch granules from ten elite sweetpotato genotypes (major markings on each grid on the embedded scale = 25 µm).

Table 5: Starch granule morphology of ten elite sweetpotato genotypes

Genotype	Granule size distribution range (µm)	Description of granule shapes (predominant)
AGRA SP 04	5–28	Spherical, truncated oval
AGRA SP 05	3–40	Polygonal, truncated oval, spherical
AGRA SP 06	3–37	Polygonal, truncated oval
AGRA SP 07	5–35	Polygonal, semi-spherical
AGRA SP 09	5–28	Polygonal
AGRA SP 12	4–35	Spherical, truncated oval
AGRA SP 13	5–25	Polygonal, spherical, truncated oval
AGRA SP 19	4–45	Polygonal, truncated oval, spherical
AGRA SP 20	5–28	Amorphous, polygonal, spherical
AGRA SP 23	5–35	Polygonal, truncated oval

amylase activity (Adu-Kwarteng et al. 2014), resulting in either increase or decrease.

Starch granule shapes and size distributions varied for the genotypes studied. Sweetpotato starch is generally known to have a granule size of about 4–40 µm. Starch granules from different sources exhibit a broad range of size in nature, and granule size and shape are among the most important morphologically distinguishing factors of starches from different origins. The granule size range has a significant bearing on the eating quality and acceptability of various starchy products. A small size range of starch granules coupled with high RVA peak viscosity indicates good prospects for sweetpotato in the production of gluten-free noodles for the ever-increasing gluten-free market (Adu-Kwarteng 2017). Two of the genotypes (AGRA SP 04 and AGRA SP 09) were found to have this combination of traits. In another study, varieties with relatively larger-sized starch granules, high PV, and low setback ratio of their starch were reported to have higher overall acceptability scores in sensory evaluation of fried crispy chips (Adu-Kwarteng 2017). In this study, starch from all the genotypes had relatively low setback ratios.

Table 6: Potential application of the sweetpotato genotypes in industry

Target application	Identified trait(s)	Genotypes
Bread, pastries	• Low setback ratio (minimal retrogradation i.e. less staling of bread, etc.)	AGRA 07, AGRA SP 13, AGRA SP 19, AGRA SP 20
French fries	• Low setback ratio (products retain acceptable texture after cooling) • High scores for good taste and appearance in sensory evaluations	AGRA 05, AGRA SP 09, AGRA SP 12, AGRA SP 13, AGRA SP 19, AGRA SP 20, AGRA SP 23
Fufu flour	• High RVA peak viscosity (>2,000 cP) for required stiff consistency • Low sugar content • Low amylase enzyme activity to prevent loss of consistency	AGRA SP 04, AGRA SP 07, AGRA SP 09
Gluten-free noodles	• Small size range of starch granules • High RVA peak viscosity (>2,000 cP)	AGRA SP 04, AGRA SP 09
Yogurt	• Small size range of starch granules (for smooth and creamy mouthfeel)	AGRA 04, AGRA SP 09, AGRA SP 13, AGRA SP 20
Baby foods	• Low RVA peak viscosity (<1,000 cP, for less bulk, higher energy density) • High beta-carotene content • Appreciable content of iron and zinc	AGRA 13, AGRA SP 19, AGRA SP 23
Juice mixes	• High beta-carotene content (imparts attractive color similar to fruit juice)	AGRA 13, AGRA SP 19, AGRA SP 20, AGRA SP 23
Enzyme source for breweries, ethanol, and glucose/maltose syrup production	• High or very high estimated index of amylase activity	AGRA 05, AGRA SP 13, AGRA SP 19
Fried crispy chips	• Low setback ratio and large starch granule size range	AGRA SP 12, AGRA SP 19

Therefore, genotypes AGRA SP 12 and AGRA SP 19, with PV above 4,000 centipoise and large starch granule size range, could be targeted for the commercial production of fried crispy chips. Small granule size in general is also linked with smooth and creamy mouthfeel, and this is relevant in the use of starch for various applications such as fillers or stabilizers in the production of ice cream and yogurt.

From the focus group discussions, AGRA SP 09 was found to exhibit a taste and texture similar to Ghana's premium yam (*Dioscorea* sp.) variety "Pona," and this could be an advantage in the promotion of the genotype if approved for release as a commercial variety in Ghana. Focus groups are widely used in market research and sensory analysis to assess consumer attitudes and preferences and can be used to develop a fair projection of consumers' behavior, preferences, and perceptions, based on which various decisions can be made (Lee and Lee 2007; Boquin et al. 2014; Barlagne et al. 2017). It is a cost-effective approach, especially at the early stages of product development and is often used before full-scale consumer tests. Focus groups are also a useful tool for clarifying a potential research area, which facilitates the contextualization of a perceived problem (Chung et al. 2011; Boquin et al. 2014). Sensory evaluation by the focus group showed that the ten sweetpotato genotypes were all suitable for the preparation of the products assessed. For each product, however, some particular genotypes were found to stand out in terms of product quality and acceptability, and this could be attributed to differences in the composition of nutrients and other attributes.

Based on various identified trait combinations (RVA data, estimated amylase enzyme activity estimation, starch granule size range, etc.), the ten sweetpotato genotypes were grouped or associated with several potential applications in the food industry (Table 6).

5 Conclusion

All the sweetpotato genotypes were found to have potential diversified applications in the food industry as well as for domestic use. Determination of unique trait combinations and the linking of these traits with possible target applications can serve as a useful tool that can aid breeding programs to meet their far-reaching objectives. It can also offer broader processing options to potential entrepreneurs for commercialization. The ten elite genotypes when released as commercial varieties can immensely contribute to the diversified use of sweetpotato in Ghana and the subregion, thereby enhancing the livelihoods of sweetpotato farmers and their families.

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Data availability statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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