



Physical, chemical, and rheological properties of flour from accessions of Frafra potato (*Solenostemon rotundifolius*)

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ABSTRACT

Frafra Potato (FP) is a climate-smart crop facing extinction in the tropical regions of Africa due to inadequate information about its properties. This study determined the physicochemical, functional, and rheological characteristics of flours from ten FP accessions to gauge their suitability for culinary purposes. The flour yield from FP tubers ranged from 59.3 % (E134) to 69.3 % (E111). While FP flours (FPF) exhibited consistent colour across accessions, variations in paste clarity were noted, ranging from 5.2 % (E145 and Maa-Lana) to 8.6 % (WAAPP). The least gelation concentration varied from 8 % (WAAPP) to 12 % (E 82, 111, 132, 134, 145). Released accessions showed higher protein and ash content than unreleased ones. Mineral composition differed significantly among accessions, including iron, calcium, zinc, and phosphorus, each with varying bioavailability percentages. Vitamin A content also varied across accessions. Proteins common in tuber crops, such as lipoxigenase, patatin, sporamin, tarin, and protease inhibitors (Bowman-Birk PIs), were identified in FPF. Amino acid analysis revealed nineteen amino acids, including seven essentials. FPF characteristics included a bulk density of 0.9 g/ml, oil and water binding capacities of 3 g/g and 1.3 g/g respectively, a pH of 6.4, and titratable acidity of 0.5. All FP flours displayed standard non-Newtonian behaviour, exhibiting pseudoplastic properties. They also showed a type II sigmoidal sorption curve, indicating increased equilibrium moisture content with higher water activity. Moisture sorption studies predicted a safe storage maximum allowable moisture content. These findings have practical implications for flour packaging and storage. The study underscores the culinary potential of Frafra potato and its role in addressing food and nutrition security in Ghana and Sub-Saharan Africa.

1. Introduction

Frafra potato (*Solenostemon rotundifolius*) is a resilient root tuber crop cultivated in tropical regions like Ghana, particularly in Northern Ghana, where it is known by common names such as Piesa or Piera [1,2]. It serves as a crucial food crop for domestic consumption, contributing approximately 20 % to household food supplies, typically during the period from October to December [1,3]. Frafra potato tubers are a valuable source of carbohydrates, vitamin A precursor (β -carotene), and essential minerals such as iron and calcium [3,4].

Despite its ability to withstand various environmental stress conditions, Frafra potato remains underutilized in Ghana and Sub-Saharan Africa. This underutilization is attributed to insufficient information

about its properties and the prevalence of readily available substitutes like yam (*Dioscorea* spp.) and sweet potato (*Ipomoea batatas*) [1,2]. Other contributing factors include high post-harvest losses of around 40 %, the absence of suitable preservation methods, smaller tuber sizes compared to more abundant crops, and limited strategies for promoting its utilization [1,4]. Properly harnessing Frafra potato has the potential to enhance local food and nutrition security [5,6]. Addressing challenges such as its short shelf life could involve processing the tubers into an intermediary staple product, such as flour, enabling versatile use in various food applications [3,4]. Several efforts are being made to combat the effects of climate change and achieve food security. Prominent among them is the recognition of the need to promote climate-resilient, lesser-known crops through extensive characterisation to further expand

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the portfolio of staple crops, especially in developing countries [7–10]. Modest efforts to expand the utilization of Frafra potato include studies by Osei Tutu et al. [11] and Tortoe et al. [12], who have explored the performance of flours obtained from the crop in composite flour pastry products. Several accessions of Frafra potato have been developed, with potential differences in cooking quality and physicochemical properties [5,13,14].

Explicating the physicochemical, functional and rheological properties of Frafra potato flour is of nutritional and commercial interest since this would inform the selection of appropriate packaging, storage, and handling conditions [11,15–17]. This would provide valuable information to determine their suitability for food and industrial applications and target specific accessions for integration into food systems. Therefore, the objective of this study was to determine the physicochemical and rheological characteristics of Frafra Potato flours.

2. Materials and methods

2.1. Source of raw materials

25 kg each of ten accessions of Frafra potato (FP) were obtained from the Council for Scientific and Industrial Research (CSIR), Savanna Agricultural Research Institute (SARI), Manga-Bawku in the Upper East Region of Ghana. The accessions obtained include WAAPP Piesa, Maa-Lana Piesa, Naachem-Tiir Piesa, Nutsugah Piesa, Manga Moya Piesa (released accessions from Ghana), E82, E111, E132, E134, E145 (unreleased accessions from Burkina Faso). The tubers were transported (about 8 h) to the food processing laboratory at Food Research Institute, Accra, packed in perforated paper cartons (aeration) for processing. Analytical grade reagents (AnalaR BDH Chemicals Ltd., Poole, England) were obtained from local chemical suppliers.

2.2. Frafra potato flour preparation

The methods of Tortoe et al. [12] was followed. Frafra potatoes were washed with potable water, weighed, hand-peeled, washed, weighed, and cut into thin slices (5 mm thick) using a mechanical slicer (SLP45HC, Foshan Sorumpor Electrical, Guangdong, China) into a basin containing a solution of 0.5 % sodium metabisulphite to control browning. The slices of tubers were removed after 10 min, and adhering water was allowed to drain before spreading thinly on trays. The sliced tubers were dried at 60 °C in a thermostat-controlled mechanical dryer (TM1006, NEUE HERBOLD, Sinsheim-Reihen, Germany) for 12 h. The dried slices were milled with a hammermill (Full Circle Pulverator, Jacobson Machine Works, Inc., Minneapolis, USA) to pass through a 500 µm sieve (American Standard Test Sieve Mesh No. 40) to obtain Frafra potato flours (FPF). The flours were packed into high-density polyethylene (HDPE) bags, sealed airtight with an impulse sealer ("Oalink, QNS-3200HI, Accra, Ghana") and kept for further tests.

2.3. Flour yield of Frafra potato

The yield of FPF and the proportion of peels and moisture removed during processing of the ten accessions of FP was determined as a percentage of the unpeeled FP weight.

2.4. Colour parameters of FPF

The method of Andrés-Bello et al. [18] was followed. The colour parameters of FPF were characterised by their paste clarity and colour. The Colour of FPF was measured using a Minolta Chromameter (CR-400 Chroma Meter, Konica Minolta, Tokyo, Japan). The instrument was calibrated against a standard white tile ($L^* = 98.93$, $a^* = 0.31$, and $b^* = 4.63$) before use. FPF samples were contained in a transparent Petri dish and covered with the same. FPF colour was also described using C^* (Chroma) and h^* (Hue angle) notations. Paste Clarity of FPF was

determined as follows. 5 ml of 1 % flour suspension in 15 ml screw-capped centrifuge tubes were incubated in a boiling water bath for 30 min, with continual shaking. The flour solutions were cooled to 25 ± 0.53 °C, and their transmittance (%) were determined against water blanks at 650 nm on a UV-VIS spectrophotometer (Shimadzu 1800, Tokyo, Japan).

2.5. Particle size distribution of FPF

The method of Aprianita et al. [19] was followed. The particle size distribution of FPF was determined using a Meinzer II mechanical shaker (Advantech Manufacturing, Inc., New Berlin, USA) fitted with 100 µm–500 µm screen sieves. 100 g of each flour was shaken for about 20 min, with each fitted sieve, at a frequency of 50 Hz. After 20 min, the particles kept by all the sieves were weighed. The weight obtained was calculated as a proportion of the total sample used to determine the particle sizes distribution of the flours.

2.6. Least gelation concentration (LGC)

Samples suspension of 2–12 % (w/v) were prepared in 5 ml of distilled water. Test tubes containing the suspensions were heated for 1 h in boiling water (100 °C). They were cooled afterwards under running water and then followed by rapid cooling in a refrigerator (4 °C) overnight with tubes inverted. The least gelation concentration (LGC) was measured when the samples in the inverted test tubes slipped along the tubes' walls. The least gelation concentration of the flours was estimated following the method of Adebowale et al. [20].

2.7. Proximate composition of FPF

The proximate composition of the flours was characterised using AOAC methods [21]. Components such as moisture (method 925.40), fat (method 948.22), protein concentration (method 955.52), ash (method 935.52), and dietary fibre (method 985.29) were determined, and carbohydrate was estimated as the difference between the sum of the other components and 100 %. Energy was calculated using; $E = (4 \times \text{protein}) + (4 \times \text{carbohydrate}) + (9 \times \text{fat})$. Using the methods of Hernández et al. [22], minerals composition were determined using Atomic Absorption Spectrometer (Shimadzu AA-7000 Atomic Absorption Spectrophotometer, Tokyo, Japan), and Vitamin A composition was determined using the methods of Garai [23] using a High-Performance Liquid Chromatography (Shimadzu HPLC-2010 H T, Tokyo, Japan).

2.8. Bioavailability of minerals

Following the method of Skibniewska et al. [24] with modifications by Eshun [25], bioavailability was expressed as a proportion of the total reference mineral in the samples, using: $\text{Bioavailability} = X/Y \times 100 \%$. Where Y is the total content of the reference mineral and X is the reference mineral in the filtrate.

2.9. Protein profile of FPF

Protein profile was identified using sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE). The gel image was captured using an imager (Amersham Imager 600, Xuri, United Kingdom). The molecular weights, indicated by bands, were used to identify the proteins present.

2.10. Amino acids profile of FPF

An improved analytical method by Ozcan and Senyuva [26] that offers rapid, accurate determination and identification of amino acids in various foods was used to quantify amino acid concentration in FPF. Amino acids concentration in FPF was determined using Liquid

Chromatography/Mass Spectrometry (LC/MS) (Agilent 1100 Series, Waldbronn, Germany). Data was collected in SIM mode with the following interface parameters: 4 L/min drying gas flow, 55 psig nebulizer pressure, 320 °C drying gas temperature, 425 °C vaporizer temperature, 3 kV capillary voltage, 8 A corona current, 55 V fragmentor voltage, and 27 msec dwell time.

2.11. Bulk density

The flour bulk density was determined using the method of Oladele and Aina [14]. The bulk density was then calculated using:

$$\text{Bulk density} = \frac{\text{Weight of sample (g)}}{\text{Volume of sample (ml)}}$$

2.12. Water and oil absorption capacity

The water and oil absorption capacities of FPF was determined using the method by Klunklin and Savage [27] with modification. 10 g of each flour were mixed with 100 ml of distilled water/vegetable oil in a centrifuge tube and allowed to stand at room temperature (26 ± 1.3 °C) for 1 h. The mixture was centrifuged (Remi R23 Research Centrifuge, REMI Instruments, Mumbai, India) at 2500 rpm for 30 min. Water/oil was drained, and the paste was weighed. Water and oil absorption capacities were expressed as a gram of water/oil absorbed per gram of sample.

2.13. Swelling power and solubility (soluble matter)

The flour samples' swelling power and soluble matter were determined using the procedure described by Chinma et al. [28]. 1 g of each sample was weighed into a 50 ml graduated centrifuge tube. Distilled water was added to obtain a total volume of 40 ml. The suspension will then be stirred. The samples were heated at 85 °C in a thermostatically controlled bath (Grant OLS 200, Grant Equipment, England) for 30 min while shaking continuously. The tube was removed from the bath, wiped dry, cooled to room temperature (25 ± 0.53 °C), and centrifuged (Remi R23 Research Centrifuge, REMI Instruments, Mumbai, India) for 15 min at 2200 revolutions per minute. The supernatant was decanted and evaporated in a hot air oven. The dried residue was weighed to determine the solubility (soluble matter) using the formula:

$$\text{Solubility \%} = \frac{\text{Weight of dried sample in supernatant}}{\text{Weight of original sample}} \times 100$$

The pastes obtained from decanting the supernatant were weighed to determine the swelling power. The swelling power was calculated using the formula:

$$\text{Swelling power} = \frac{\text{weight of paste}}{\text{weight of dry flour}}$$

2.14. Foaming volume and stability

The foaming volume and stability of FPF were determined using the method by Chinma et al. [28]. 10 g of each sample were whipped with 100 ml distilled water for 5 min in a blender (to foam) and poured into a 250 ml graduated cylinder. Foam stability was determined at 0, 10, 20, 30, 40, 50 and 60 min after whipping. The foam volume at 30 s after whipping was expressed as the foam capacity and the foam volume after 60 min as the stability for the respective periods. Foaming capacity and Foam stability are given by the following:

$$\text{Foaming capacity (\%)} = \frac{\text{Volume after blending} - \text{Volume before blending}}{\text{Volume before blending}} \times 100$$

$$\text{Foam stability (\%)} = \frac{\text{Foam volume after time (t)}}{\text{Initial foam volume}} \times 100$$

2.15. pH of FPF samples

The pH of FPF was determined using the method described by Oladele and Aina [14]. 10 % suspension of each flour was prepared, and the pH of 10 ml of each solution was determined using a pH meter (Mettler Toledo S220-Kit, Benchtop pH/ISE Meter, USA).

2.16. Titratable acidity (TTA) of FPF

TTA of FPF was determined using the method described by Oladele and Aina [14]. The samples used for determining pH were also used to determine total titratable acidity. A few drops of phenolphthalein indicator were added to the solution. Titration was carried out by adding 0.1 M NaOH from a burette until a colour change to pink indicated the endpoint. The volume of NaOH added was read from the burette and multiplied by 0.09 to obtain the % titratable acidity as lactic acid (being the predominant acid).

2.17. Pasting properties of FPF

The pasting properties of FPF was determined by the method described by Klunklin and Savage [27]. FPF pasting characteristics were determined on a 12 % slurry, using a Brabender (Viscograph – E, Brabender GmbH & Co. KG. 803301, 803301E000-02, Germany). This was done to record the following indices quantitatively: peak viscosity, pasting temperature, hot paste viscosity (peak), cool paste viscosity (final), breakdown, and setback.

2.18. Flow behaviour of FPF slurry

Using the method of Klunklin and Savage [27], the viscosity of FPF gels [12 % flour heated at 95 °C for 30 min with continual shaking and cooled to room temperature (26 ± 1.3 °C)] was determined using a viscometer (Brookfield Engineering Labs Inc., Stoughton MA, USA) at different spindle speeds (5–30 rpm) using an RV spindle 2. Measurements were taken in a 250 ml beaker, 2 min after the spindle was immersed in FPF gels. Viscosity data was recorded at 2 min intervals. This was done to allow thermal equilibrium between the test sample and spindle and to eliminate the effect of immediate time dependence, as directed by the manufacturer of the viscometer. The flow behaviour (n) and apparent viscosity (k) were determined using the Herschel Buckley model.

2.19. Moisture sorption studies

The standard gravimetric method, as explained by Andrade et al. [29], with modifications by Eshun [25], was used for the equilibrium moisture studies. It consisted of moisture sorption measurements using six different concentrations of sulfuric acid (H₂SO₄) solution ranging through five, fifteen, thirty-five, forty-five, fifty-five and sixty-five per cent to produce water activities (a_w) ranging from 0.1 to 0.9. These saturated solutions were carefully poured into glass containers. The flours were placed in plastic containers, and a thread was used to support the samples and inserted into the containers to rest just above the acid solution and kept in an oven preset at 30 °C. The samples were removed and weighed every 24 h using an electronic weighing balance until consecutive readings were less than 0.05 % of the sample weight. The moisture sorption isotherms were obtained by plotting the equilibrium moisture content (EMC, expressed as a gram of water per gram of dry solids) against a_w. The EMC were calculated as averages of triplicates from which the moisture sorption isotherms were determined.

2.20. Statistical analysis

The data obtained were subjected to one-factor Analysis of Variance (ANOVA) using “R” statistical software for Windows pc version 4.1.1 (R Project, Bell Laboratories, USA) and Duncan Multiple Range Test (DMRT) was performed to identify varieties with significantly different ($p < 0.05$) means. Principal component analysis (PCA), in XLSTAT 2018 for windows pc, was used to cluster samples with close associations based on their physicochemical properties.

3. Results and discussion

3.1. Flour yield of Frafra potato (FPF)

The flour yield of the ten accessions of Frafra potato tubers are summarized in Fig. 1.

The flour Yield of the Frafra Potato tubers ranged from 59 to 69 % (Fig. 1). There was a significant difference ($p \leq 0.05$) between the flour yield and moisture among the FPF cultivars. However, there was no significant differences between peels (3.5 %–3.8 %). Moisture ranged from 27 % (E111) - 38 % (E134). The differences observed in the flour yield and moisture content can be attributed to varietal differences reported in other tuber crops flour studies [6,30]. However, the flour yield in these FPF cultivars is higher than flours from some potato varieties, ranging from 37 to 49 % [6], and some varieties of cassava, which ranged from 18 to 20 % [31]. The yield of FPF provides important information for the selection of indigenous tubers for flour production. It may also influence the advanced selection of accessions of interest for developing suitable cultivars for specific end-use.

3.2. Colour of FPF

The colour and optical properties of FPF are summarized in Table 1. Table 1 illustrates that the L^* values for the flours ranged from approximately 82 to 84, indicating that the flours from different cultivars were darker than the standard white ($L^* \sim 98$). With the exception of PC, the flours exhibited similar ($p \leq 0.05$) values for L^* , a^* , b^* , h^* , and C^* . PC varied between about 5 % to 9 %, with E145 and Maa-Lana having the lowest and WAAPP the highest PC content. The observed differences in PC properties among the FPF cultivars may be attributed to variations in carotenoid concentrations and varietal distinctions ([32]; Peroni et al., 2006).

PC is a crucial property for flour gels, particularly in culinary applications, and it varies among different botanical sources or cultivars [33]. The results indicate that the flours formed opaque gels, which may be undesirable in food systems requiring high transparency, such as jellies ([30]; Peroni et al., 2006). However, FPF could find utility in food systems not demanding transparency, such as pastry products, soups, and stews (Peroni et al., 2006).

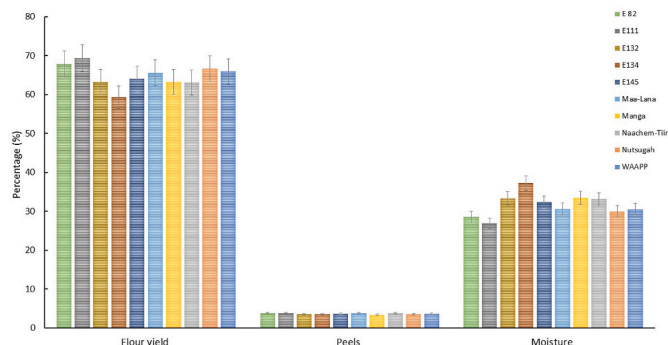


Fig. 1. Flour yield, moisture content and proportion of peels from FP.

Table 1
Colour parameters of FPF.

Cultivar	L^*	a^*	b^*	h^*	C^*	PC (%)
E 82	83.62 ± 0.06 ^a	1.10 ± 0.09 ^a	11.87 ± 0.12 ^a	84.71 ± 0.06 ^a	11.92 ± 0.11 ^a	6.27 ± 0.31 ^c
E111	83.82 ± 0.12 ^a	1.12 ± 0.02 ^a	12.05 ± 0.14 ^a	84.69 ± 0.17 ^a	11.99 ± 0.08 ^a	6.20 ± 0.26 ^c
E132	82.59 ± 0.09 ^a	1.10 ± 0.13 ^a	11.79 ± 0.10 ^a	84.67 ± 0.09 ^a	11.99 ± 0.15 ^a	5.43 ± 0.12 ^d
E134	81.90 ± 0.12 ^a	1.08 ± 0.11 ^a	11.95 ± 0.09 ^a	84.84 ± 0.13 ^a	11.99 ± 0.02 ^a	6.47 ± 0.06 ^c
E145	82.86 ± 0.11 ^a	1.12 ± 0.03 ^a	12.03 ± 0.14 ^a	84.68 ± 0.01 ^a	12.08 ± 0.16 ^a	5.20 ± 0.26 ^d
Maa-Lana	83.51 ± 0.05 ^a	1.13 ± 0.05 ^a	11.65 ± 0.11 ^a	84.46 ± 0.03 ^a	11.71 ± 0.05 ^a	5.20 ± 1.07 ^d
Manga	82.49 ± 0.07 ^a	1.11 ± 0.15 ^a	11.82 ± 0.07 ^a	84.64 ± 0.10 ^a	11.87 ± 0.17 ^a	7.73 ± 0.06 ^b
Naachem-Tiir	82.48 ± 0.10 ^a	1.12 ± 0.12 ^a	12.05 ± 0.12 ^a	84.69 ± 0.08 ^a	12.10 ± 0.05 ^a	8.43 ± 0.12 ^a
Nutsugah	83.54 ± 0.04 ^a	1.09 ± 0.06 ^a	11.91 ± 0.13 ^a	84.77 ± 0.12 ^a	11.96 ± 0.01 ^a	7.47 ± 0.06 ^b
WAAPP	83.53 ± 0.08 ^a	1.11 ± 0.10 ^a	12.09 ± 0.08 ^a	84.75 ± 0.05 ^a	12.14 ± 0.12 ^a	8.60 ± 1.40 ^a

L^* - lightness from dark, $a^*/-a^*$ = redness/greenness, $b^*/-b^*$ = yellowness/blueness, h^* = Hue angle (dominant colour), C^* = Chroma (colour intensity), PC = Paste clarity. Values are means of triplicates with standard deviation. Means in the same column with different superscript are significantly different ($p \leq 0.05$).

3.3. Particle size distribution of FPF

The particle size distribution of the flours from the ten (10) cultivars of Frafra potato is summarized in Fig. 2.

Particle size is an important physical property of flour products. It is crucial because it influences the texture and feel of food ingredients, appearance, viscosity, and bulk density [19]. The particles retained by each sieve differed significantly ($p \leq 0.05$) (Fig. 2). The flours had most of their particles below 100 μm , where E134 had the highest distribution (60 %) and Manga had the least distribution (39 %). A similar particle size distribution was reported for regular wheat flour, with most of the particles below 100 μm , by Hareland [34]. There were fewer particles retained by sieve sizes 100–425 μm , respectively. In contrast, sieve size 500 μm retained weights that ranged from 3.7 to 5.7 %, with E134 having the least and E111 having the highest, respectively. The results indicate that the flours have smaller particle sizes than larger sizes. Smaller particle sizes suggest that more of the flours have very fine particle distribution, similar to typical wheat flour. Flour with very fine particle size distribution can fill a smaller volume [19,35]. This would be a great advantage in terms of packaging and transportation. Also, smaller particle sizes have implications for functional properties and rate of chemical reactions in food systems. Flours with smaller particles sizes absorb more water, have lower gelatinization temperature and

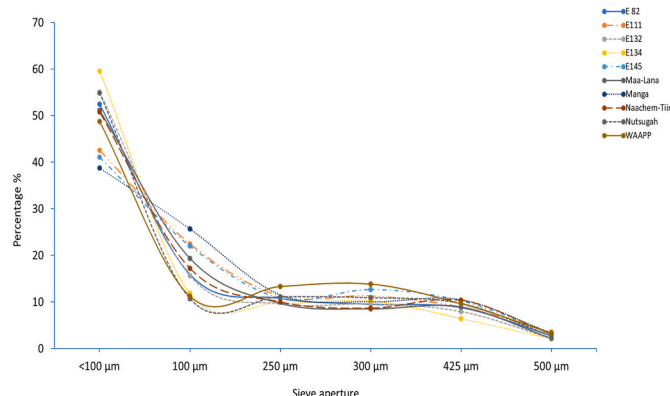


Fig. 2. Particle size distribution of FPF.

higher viscosity [35].

3.3.1. Least gelation of FPF

The least solids concentration of the flours from the ten (10) cultivars of Frafra potato required to form a stable gel is presented in Table 2.

The results in Table 2 indicate that the released FP cultivars had the least gelation concentration from 8 to 10 % w/v, with WAPP having the least concentration (value). The unreleased E-group cultivars required 12 % w/v to form a stable gel. In a predominantly starchy matrix such as FPF, Gelation properties are influenced by starch concentration, water absorption capacity, and particle size distribution [10,28]. Variations in the amino-acid concentration and particle size distribution of FPF could explain the slight differences in their gel formation capacity. Based on the results in Table 3, it can be suggested that the released cultivars had the least gelation concentration because they had a higher protein concentration. This will impact the use of these varieties in food systems where viscosity is desired.

3.4. Proximate composition of FPF

The proximate composition of the flours from the ten (10) cultivars of Frafra potato is summarized in Table 3.

Table 3 reveals significant differences ($p \leq 0.05$) in the moisture, protein, and ash composition of the flours, while no significant difference ($p \leq 0.05$) was observed in the fat, dietary fiber, carbohydrate, and energy content. Moisture content ranged from 6 % to 8 %, and ash content ranged from 5 % to 7 %. The released cultivars exhibited higher protein content, approximately 8 %–9 %, whereas the unreleased E-group cultivars had the least, ranging from 5 % to 7 %. This trend was similarly observed for ash content. The elevated protein content in released cultivars suggests their relatively better suitability for food applications like pastry [15,16,36]. Furthermore, variations in proximate composition have implications for functional flour properties such as pasting, least gelation concentration, and viscosity [6,19]. Flours with higher protein content could prove beneficial in baking applications [6–8].

3.5. Mineral and vitamin A composition

The minerals and vitamin A composition of the flours from the ten (10) cultivars of Frafra potato are summarized in Table 4.

The flours derived from the ten cultivars exhibited notable differences ($p \leq 0.05$) in vitamin A and mineral composition, as depicted in Table 4. The unreleased E-group cultivars displayed significantly higher vitamin A levels, ranging from approximately 3081 to 4118 μg , while the released cultivars had lower values, ranging from 737 to 1404 μg . Iron content was mostly similar across cultivars, except for Maa-Lana, which registered a significantly higher value of around 9 mg

Table 2
Least gelation concentration of FPF.

Cultivar	% w/v					
	2	4	6	8	10	12
E 82	-	-	-	-	-	+
E111	-	-	-	-	-	+
E132	-	-	-	-	-	+
E134	-	-	-	-	-	+
E145	-	-	-	-	-	+
Maa-Lana	-	-	-	-	+	+
Manga	-	-	-	-	+	+
Naachem-Tiir	-	-	-	-	+	+
Nutsugah	-	-	-	-	+	+
WAAPP	-	-	-	+	+	+

% w/v = percent solids, + = gel suspension did not slip along walls of inverted test tubes (for 24 h, at 4 °C), - = gel suspension slipped along walls of inverted test tubes (for 24 h, at 4 °C).

compared to the others. Calcium content ranged from 34 mg to 59 mg, with Maa-Lana and WAAPP displaying the highest values and E145 and Manga having the least. Phosphorus content also showed significant differences, ranging from 334 to 451 mg, with Naachem-Tiir and Nutsugah recording the least, and E 82, recording the highest values. As suggested by Nkansah [4] and Tortoe et al. [30], variations in mineral and vitamin A composition could be attributed to varietal differences.

3.6. Bioavailability of minerals

Micronutrient deficiencies, especially in vulnerable groups, such as children and women of reproductive age, are of great concern in developing countries [1]. This makes the determination of the bioavailability of minerals in foods essential. Bioavailability is a critical link between food ingredients and the nutritional effects of their proximate composition [24]. Per cent bioavailability of the minerals in the flours from the ten cultivars of Frafra potato is summarized in Table 5.

There were no significant differences ($p \leq 0.05$) between the per cent bioavailability of minerals in the ten FPF samples (Table 5). The bioavailability of iron was about 15 %, calcium was about 14 %, zinc and phosphorus were about 20 % and 21 %, respectively. Since these flours were made from a common tuber crop variety, it is practical for the flours to exhibit similar chemical characteristics [31], including the bioavailability of their minerals. The low bioavailability values for the minerals in FPF suggests that it cannot be the only source of minerals in food applications; other mineral-rich food ingredients should be added to ensure a greater likelihood of mineral bioavailability.

3.7. Protein profile of FPF

Protein profiling provides useful information on the types of proteins present in food ingredients and their implications for their functionality and food applications. SDS-PAGE was used for protein profiling of FPF. In SDS-PAGE, visible bands indicate different proteins of different sizes. Even though the data is qualitative, the intensities of the bands are indicative of the concentrations of the proteins present. The protein profile of FPF is presented in Fig. 3.

Five visible bands with varying intensities were observed for FPF (Fig. 3). The bands were similar in terms of their visibility and intensity, suggesting that all the FPF cultivars had similar proteins [36,37]. Based on the molecular weight of these proteins, the corresponding proteins were identified. The proteins are Lipoxygenase, Patatin, Sporamin, Bowman-Birk Inhibitors, and Tarin [36–40]. The bands for Sporamin were the deepest, and Patatin was the faintest. Amongst all the proteins, Sporamin was observed to be the most abundant for all the cultivars. It is reported that Lipoxygenase, Patatin, Sporamin and Tarin are globular proteins, hence are soluble in water and will influence certain functional properties such as water solubility index, foaming capacity, and gelation [15,36,37]. Lipoxygenase is a protein known to cause enzymatic browning in foods; this can significantly impact the colour of flour and other food products. Hence, there is the need to use browning prevention techniques or agents during the processing of tubers such as FP that contain lipoxygenase. It is, however, used in dough processing as an oxidative improving agent [37]. Recent advances in technology have enabled the isolation of Patatin in native form as a food ingredient at an industrial scale for use in flavour development in cheese ripening [40]. Sporamin has antioxidant and trypsin inhibitory activity; and the Bowman-Birk inhibitors (BBI) have been studied extensively to treat many diseases, especially in cancer prevention [38]. Tarin exhibits recognized biocide activities against viruses and has antitumoral properties [39].

3.8. Amino acid profile of FPF

Amino acids concentration was determined to identify the amino acids profile of FPF. The amino acid profile of the flours from the ten

Table 3

Proximate composition of FPF (per 100 g).

Cultivar	Moisture	Fat	Protein	Ash	Carbohydrate	Dietary Fibre	Energy (kcal)
E 82	7.91 ± 0.12 ^a	1.69 ± 0.07 ^a	6.19 ± 0.43 ^b	5.62 ± 0.08 ^b	81.26 ± 0.26 ^a	3.24 ± 0.05 ^a	380.97 ± 0.09 ^a
E111	7.20 ± 0.09 ^a	1.46 ± 0.04 ^a	6.88 ± 0.08 ^b	5.82 ± 0.01 ^b	80.84 ± 0.33 ^a	3.07 ± 0.08 ^a	379.02 ± 0.23 ^a
E132	7.88 ± 0.22 ^a	1.40 ± 0.02 ^a	5.08 ± 0.12 ^c	5.11 ± 0.13 ^b	82.46 ± 0.15 ^a	3.95 ± 0.11 ^a	381.56 ± 0.03 ^a
E134	7.20 ± 0.09 ^a	1.36 ± 0.01 ^a	5.89 ± 0.11 ^c	5.12 ± 0.03 ^b	83.08 ± 0.21 ^a	2.55 ± 0.65 ^a	381.32 ± 0.12 ^a
E145	7.53 ± 0.19 ^a	1.57 ± 0.01 ^a	5.22 ± 0.23 ^c	5.23 ± 0.17 ^b	82.72 ± 0.09 ^a	3.26 ± 0.16 ^a	381.93 ± 0.22 ^a
Maa-Lana	5.53 ± 0.28 ^b	1.43 ± 0.02 ^a	8.72 ± 0.13 ^a	6.42 ± 0.29 ^a	79.38 ± 0.61 ^b	3.05 ± 0.05 ^a	376.47 ± 0.25 ^a
Manga	5.69 ± 0.28 ^b	1.42 ± 0.05 ^a	7.98 ± 0.13 ^a	6.42 ± 0.29 ^a	79.75 ± 0.61 ^b	3.43 ± 0.05 ^a	376.42 ± 0.32 ^a
Naachem-Tiir	5.48 ± 0.16 ^b	1.45 ± 0.03 ^a	8.53 ± 0.03 ^a	6.37 ± 0.09 ^a	80.23 ± 0.54 ^a	2.59 ± 0.78 ^a	374.17 ± 0.01 ^a
Nutsugah	5.61 ± 0.15 ^b	1.48 ± 0.09 ^a	8.41 ± 0.06 ^a	6.47 ± 0.34 ^a	79.15 ± 0.43 ^b	3.46 ± 0.05 ^a	376.52 ± 0.17 ^a
WAAPP	5.77 ± 0.36 ^b	1.44 ± 0.07 ^a	8.73 ± 0.11 ^a	6.41 ± 0.18 ^a	78.93 ± 0.52 ^b	3.49 ± 0.13 ^a	376.56 ± 0.14 ^a

Mean values (g/100 g) of triplicates with standard deviations. Values in the same column with different superscripts are significantly different ($p \leq 0.05$). The values were reported as % dry matter, except for moisture content values.

Table 4

Mineral and vitamin A composition of FPF (mg).

Cultivar	Iron	Calcium	Zinc	Phosphorus	Vitamin A (μg)
E 82	7.04 ± 0.12 ^b	45.36 ± 0.01 ^b	2.19 ± 0.03 ^b	451.90 ± 0.08 ^a	3080.80 ± 0.06 ^c
E111	6.50 ± 0.89 ^b	43.86 ± 0.01 ^b	1.73 ± 0.88 ^b	408.82 ± 0.01 ^c	3181.90 ± 0.03 ^c
E132	7.10 ± 0.09 ^b	48.70 ± 0.02 ^b	2.08 ± 0.02 ^b	393.11 ± 0.01 ^d	4948.43 ± 0.05 ^a
E134	7.20 ± 0.06 ^b	47.83 ± 0.04 ^b	4.89 ± 0.51 ^a	424.12 ± 0.01 ^b	3969.47 ± 0.01 ^b
E145	7.15 ± 0.04 ^b	34.41 ± 0.01 ^c	2.22 ± 0.13 ^b	424.23 ± 0.02 ^b	4117.90 ± 0.09 ^b
Maa-Lana	8.70 ± 0.10 ^a	58.84 ± 0.02 ^a	4.62 ± 0.13 ^a	413.42 ± 0.01 ^{bc}	1403.53 ± 0.01 ^d
Manga	7.05 ± 0.18 ^b	35.93 ± 0.01 ^c	2.94 ± 0.03 ^b	366.42 ± 0.71 ^d	808.63 ± 0.06 ^f
Naachem-Tiir	6.78 ± 0.16 ^b	46.66 ± 0.02 ^b	2.78 ± 0.03 ^b	334.37 ± 0.81 ^e	736.86 ± 0.04 ^g
Nutsugah	6.76 ± 0.15 ^b	48.39 ± 0.01 ^b	5.55 ± 0.06 ^a	334.47 ± 0.94 ^e	1100.77 ± 0.03 ^d
WAAPP	7.70 ± 0.19 ^b	56.94 ± 0.01 ^a	1.88 ± 0.71 ^b	401.50 ± 0.02 ^{cd}	895.13 ± 0.02 ^e

Values are means (mg or $\mu\text{g}/100\text{ g}$) and standard deviations of triplicates. Means in the same column with different superscripts are significantly different ($p \leq 0.05$).

Table 5

Percent bioavailability of minerals.

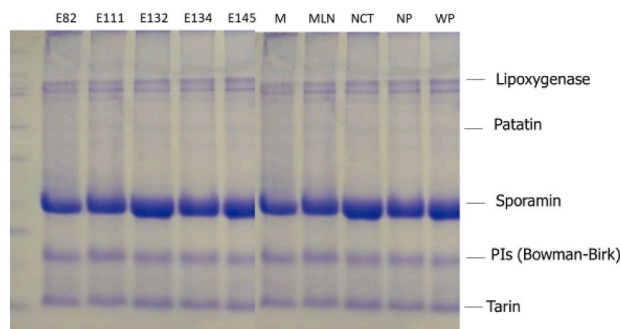
Cultivar	Fe	Ca	Zn	P
E 82	13.5 ± 1.03 ^a	13.1 ± 0.24 ^a	19.1 ± 0.35 ^a	20.6 ± 0.14 ^a
E111	13.6 ± 1.04 ^a	13.2 ± 0.05 ^a	19.2 ± 0.26 ^a	20.2 ± 0.09 ^a
E132	14.1 ± 0.05 ^a	13.1 ± 0.20 ^a	19.4 ± 0.17 ^a	20.1 ± 0.23 ^a
E134	14.3 ± 0.06 ^a	13.3 ± 0.17 ^a	19.3 ± 0.28 ^a	20.1 ± 0.18 ^a
E145	14.2 ± 0.07 ^a	13.1 ± 0.28 ^a	19.1 ± 0.19 ^a	20.4 ± 0.40 ^a
Maa-Lana	14.4 ± 0.08 ^a	13.7 ± 0.19 ^a	19.6 ± 0.30 ^a	20.2 ± 0.41 ^a
Manga	14.6 ± 0.09 ^a	13.4 ± 0.30 ^a	19.7 ± 0.21 ^a	20.3 ± 0.42 ^a
Naachem-Tiir	14.5 ± 0.32 ^a	13.7 ± 0.11 ^a	19.5 ± 0.32 ^a	20.6 ± 0.43 ^a
Nutsugah	14.6 ± 0.11 ^a	13.3 ± 0.22 ^a	19.8 ± 0.13 ^a	20.4 ± 0.44 ^a
WAAPP	14.2 ± 0.21 ^a	13.5 ± 0.33 ^a	19.9 ± 0.24 ^a	20.5 ± 0.45 ^a

Values are means and standard deviations of triplicates. Means in the same column with the same superscripts are not significantly different ($p \leq 0.05$).

(10) cultivars of Frafra potato is presented in Tables 6A and 6B.

Tables 6A and 6B shows that about 19 amino acids were detected in FPF. However, Histidine and Tyrosine were not detected in E82, and there were significant differences ($p \leq 0.05$) in the amino acid levels in FPF cultivars.

Seven (7) out of the nineteen (19) amino acids detected were essential amino acids. They are Histidine (with concentrations ranging from about 0 to 8 $\mu\text{g}/100\text{ g}$), Isoleucine (with concentrations ranging from about 1 to 2.2 $\mu\text{g}/100\text{ g}$), Lysine (with concentrations ranging from



PIs = Protease Inhibitors, M = Manga, MLN = Maa-Lana, NCT = Naachem-Tiir, NP = Nutsugah, WP = WAAPP

Fig. 3. Protein profile (SDS-PAGE) of FPF.

about 1 to 7 $\mu\text{g}/100\text{ g}$), Methionine (with concentrations ranging from about 1 to 6 $\mu\text{g}/100\text{ g}$), Threonine (about 1 $\mu\text{g}/100\text{ g}$), Tryptophan (with concentrations ranging from about 331 to 4012 $\mu\text{g}/100\text{ g}$), and Valine (with concentrations ranging from about 1 to 33 $\mu\text{g}/100\text{ g}$). Quantification of amino acids in foods such as FPF is vital for food applications because it plays a role in the nutritional value of foods and products for which it may be used. Variations in amino acid concentration might be due to differences in protein concentration and varietal differences. This is because protein composition and varietal differences can give rise to differences in the free amino acids in foods [26,36,37]. The released cultivars generally had higher amino acids concentration, hence may have better performance in pastry applications and other food systems that require high protein/amino acids concentrations [8] compared to the unreleased E-group cultivars. The profile of essential amino acids in FP is not typical of tuber proteins; hence, this makes FP unique with great potential as a non-conventional food ingredient in applications such as buttered and breaded foods.

3.9. Functional characteristics of FPF

The functional characteristics of FPF were characterised to understand how the flours would be suitable for and perform in food systems. The functional characteristics of FPF are summarized in Table 7.

Table 7 shows no significant differences ($p \leq 0.05$) between the bulk density, swelling power, water and oil binding capacities, pH, and total titratable acidity of all the FPF cultivars. However, significant differences ($p \leq 0.05$) existed between the released and unreleased cultivars for the solubility, foam volume and stability indices.

Solubility index is the per cent soluble solids, and it ranged from 6.7 to 8.5 % for all FPF cultivars (Table 7). According to Apea-Bah et al. [41], solubility is essential, especially in food systems, such as pastry, since flour with high solubility may give a soggy and less cohesive dough. It is observed (Table 7) that the unreleased E-group cultivars had a significantly higher solubility index compared to the released

Table 6AAmino acid profile of FPF ($\mu\text{g}/100\text{ g}$).

Cultivar	ala	asn	asp	cys	gln	gly	his	ile	lys	met
E 82	2.1 \pm 0.01 ^f	0.4 \pm 0.01 ^e	0.1 \pm 0.01 ^g	0.4 \pm 0.01 ^d	1.1 \pm 0.01 ^e	1.6 \pm 0.01 ^f	ND	1.0 \pm 0.02 ^a	1.0 \pm 0.01 ^d	0.5 \pm 0.01 ^e
E111	18.4 \pm 0.02 ^d	10.9 \pm 0.03 ^b	15.8 \pm 0.02 ^f	1.1 \pm 0.02 ^b	3.0 \pm 0.03 ^d	5.8 \pm 0.03 ^c	4.7 \pm 0.02 ^e	2.1 \pm 0.01 ^a	4.1 \pm 0.02 ^c	2.6 \pm 0.03 ^c
E132	19.7 \pm 0.03 ^d	9.5 \pm 0.01 ^c	18.4 \pm 0.01 ^d	2.1 \pm 0.03 ^a	4.7 \pm 0.01 ^c	3.0 \pm 0.02 ^d	6.7 \pm 0.01 ^c	1.8 \pm 0.02 ^a	4.8 \pm 0.03 ^c	6.1 \pm 0.02 ^a
E134	38.6 \pm 0.03 ^b	8.7 \pm 0.03 ^d	41.1 \pm 0.02 ^a	2.7 \pm 0.02 ^a	4.3 \pm 0.01 ^c	2.2 \pm 0.03 ^e	7.7 \pm 0.02 ^b	1.7 \pm 0.03 ^a	4.3 \pm 0.02 ^c	1.9 \pm 0.03 ^d
E145	14.1 \pm 0.02 ^e	10.3 \pm 0.03 ^b	36.7 \pm 0.02 ^b	0.9 \pm 0.01 ^c	4.5 \pm 0.02 ^c	1.7 \pm 0.01 ^f	3.6 \pm 0.02 ^f	1.2 \pm 0.03 ^b	4.0 \pm 0.01 ^c	2.1 \pm 0.03 ^c
Maa-Lana	28.1 \pm 0.03 ^c	12.3 \pm 0.01 ^a	20.5 \pm 0.03 ^c	1.4 \pm 0.03 ^b	6.8 \pm 0.01 ^a	5.5 \pm 0.02 ^c	6.7 \pm 0.03 ^c	1.4 \pm 0.01 ^b	6.6 \pm 0.03 ^a	3.4 \pm 0.02 ^b
Manga	34.0 \pm 0.01 ^b	12.4 \pm 0.02 ^a	16.0 \pm 0.03 ^e	0.5 \pm 0.02 ^d	4.9 \pm 0.01 ^c	10.3 \pm 0.03 ^a	4.7 \pm 0.01 ^e	1.7 \pm 0.02 ^a	4.8 \pm 0.01 ^c	2.6 \pm 0.03 ^c
Naachem-Tiir	33.1 \pm 0.02 ^b	8.2 \pm 0.02 ^d	15.5 \pm 0.03 ^f	1.1 \pm 0.03 ^b	5.1 \pm 0.02 ^b	3.6 \pm 0.02 ^d	7.0 \pm 0.03 ^b	1.8 \pm 0.01 ^a	4.9 \pm 0.03 ^c	3.3 \pm 0.01 ^b
Nutsugah	28.8 \pm 0.01 ^c	11.8 \pm 0.02 ^a	22.9 \pm 0.01 ^c	1.1 \pm 0.02 ^b	5.2 \pm 0.03 ^b	6.6 \pm 0.01 ^b	5.9 \pm 0.02 ^d	1.6 \pm 0.03 ^a	5.1 \pm 0.02 ^b	2.3 \pm 0.01 ^c
WAAPP	44.1 \pm 0.01 ^a	8.1 \pm 0.01	36.2 \pm 0.01 ^b	1.9 \pm 0.01 ^b	6.6 \pm 0.03 ^a	2.2 \pm 0.01 ^e	8.1 \pm 0.03 ^a	2.2 \pm 0.01 ^a	6.2 \pm 0.03 ^a	6.2 \pm 0.02 ^a

ala = DL-Alpha-Alanine, asn = Asparagine, asp = Aspartic acid, cys = Cysteine, gln = Glutamine, gly = Glycine, his = Histidine, ile = Isoleucine, lys = Lysine, met = Methionine, ND = Not detected. Essential amino acids detected = 7 (Histidine, Isoleucine, Lysine, Methionine, Threonine, Tryptophan, Valine). Values are means ($\mu\text{g}/100\text{ g}$) of triplicates with standard deviation. Means in the same column with different superscripts are significantly different ($p \leq 0.05$).

Table 6B

Amino acid profile of FPF.

Cultivar	DL- β -P	pro	trx4-hy-pro	ser	D-thr	L-thr	tyr	trp	val
E 82	0.5 \pm 0.01 ^c	0.9 \pm 0.01 ^c	1.1 \pm 0.01 ^c	1.1 \pm 0.01 ^f	0.9 \pm 0.01 ^c	0.6 \pm 0.01 ^a	ND	330.7 \pm 0.01 ^c	0.8 \pm 0.01 ^c
E111	464.3 \pm 0.02 ^b	1.7 \pm 0.03 ^b	112.1 \pm 0.01 ^b	6.1 \pm 0.03 ^d	4.2 \pm 0.02 ^b	1.0 \pm 0.01 ^a	18.0 \pm 0.03 ^e	3594.5 \pm 0.02 ^a	28.1 \pm 0.01 ^b
E132	467.5 \pm 0.01 ^b	2.5 \pm 0.02 ^a	148.8 \pm 0.03 ^a	6.5 \pm 0.01 ^d	4.5 \pm 0.01 ^b	1.0 \pm 0.03 ^a	303.7 \pm 0.02 ^b	4012.2 \pm 0.03 ^a	30.4 \pm 0.03 ^a
E134	458.7 \pm 0.01 ^b	1.7 \pm 0.02 ^b	110.7 \pm 0.01 ^b	8.5 \pm 0.02 ^c	4.8 \pm 0.01 ^b	0.9 \pm 0.01 ^a	16.7 \pm 0.03 ^e	3297.8 \pm 0.03 ^b	28.4 \pm 0.02 ^b
E145	464.4 \pm 0.03 ^b	1.8 \pm 0.01 ^b	111.8 \pm 0.02 ^b	5.3 \pm 0.02 ^e	5.6 \pm 0.03 ^a	0.8 \pm 0.01 ^a	273.7 \pm 0.01 ^c	3351.1 \pm 0.03 ^b	26.3 \pm 0.01 ^b
Maa-Lana	635.7 \pm 0.01 ^a	1.8 \pm 0.03 ^b	124.5 \pm 0.01 ^b	6.4 \pm 0.03 ^d	5.1 \pm 0.01 ^a	1.1 \pm 0.03 ^a	500.0 \pm 0.03 ^a	3860.2 \pm 0.02 ^a	32.4 \pm 0.03 ^a
Manga	484.2 \pm 0.02 ^b	1.7 \pm 0.02 ^b	115.1 \pm 0.03 ^b	10.3 \pm 0.02 ^a	5.0 \pm 0.01 ^a	0.9 \pm 0.03 ^a	17.6 \pm 0.02 ^e	3580.1 \pm 0.01 ^a	28.0 \pm 0.03 ^b
Naachem-Tiir	624.1 \pm 0.03 ^a	1.6 \pm 0.01 ^b	124.1 \pm 0.03 ^b	7.3 \pm 0.03 ^d	5.3 \pm 0.01 ^a	1.3 \pm 0.03 ^a	29.6 \pm 0.01 ^d	3762.4 \pm 0.02 ^a	32.6 \pm 0.03 ^a
Nutsugah	499.5 \pm 0.03 ^b	1.7 \pm 0.02 ^b	112.7 \pm 0.03 ^b	1.2 \pm 0.02 ^f	4.6 \pm 0.02 ^b	0.7 \pm 0.01 ^a	297.8 \pm 0.02 ^c	3649.5 \pm 0.01 ^a	26.1 \pm 0.02 ^b
WAAPP	496.7 \pm 0.03 ^b	2.3 \pm 0.01 ^a	151.1 \pm 0.02 ^a	9.0 \pm 0.03 ^b	5.4 \pm 0.03 ^a	0.8 \pm 0.02 ^a	20.3 \pm 0.01 ^d	4000.5 \pm 0.03 ^a	31.0 \pm 0.01 ^a

DL- β -P = DL- β -Phenylalanine, pro = D-Proline, trx4-hy-pro = Trans-4-Hydroxy-L-Proline, ser = Serine, D-thr = D-Threonine, L-thr = Threonine, tyr = Tyrosine, trp = Tryptophan, val = Valine, ND = Not detected. Essential amino acids detected = 7 (Histidine, Isoleucine, Lysine, Methionine, Threonine, Tryptophan, Valine). Values are means ($\mu\text{g}/100\text{ g}$) of triplicates with standard deviation. Means in the same column with different superscripts are significantly different ($p \leq 0.05$).

Table 7

Functional characteristics of FPF.

Cultivar	BD (g/ml)	SP (g/g)	SI (g/g)	WB (g/g)	OB (g/g)	FC (ml)	FS (ml)	pH	TTA (%)
E 82	0.9 \pm 0.1 ^a	19.2 \pm 1.3 ^a	8.7 \pm 0.4 ^a	2.8 \pm 1.8 ^a	1.2 \pm 0.6 ^a	9.4 \pm 1.4 ^c	4.7 \pm 1.2 ^c	6.4 \pm 0.1 ^a	0.5 \pm 0.6 ^a
E111	0.9 \pm 0.2 ^a	19.5 \pm 1.1 ^a	8.8 \pm 0.7 ^a	2.5 \pm 0.6 ^a	1.3 \pm 0.5 ^a	8.9 \pm 0.8 ^c	4.3 \pm 1.1 ^c	6.4 \pm 0.1 ^a	0.4 \pm 1.6 ^a
E132	0.9 \pm 0.2 ^a	19.3 \pm 1.6 ^a	8.6 \pm 0.4 ^a	2.6 \pm 1.3 ^a	1.4 \pm 1.4 ^a	8.7 \pm 0.8 ^c	4.3 \pm 1.3 ^c	6.3 \pm 0.1 ^a	0.4 \pm 0.6 ^a
E134	0.9 \pm 0.4 ^a	21.4 \pm 0.1 ^a	8.5 \pm 0.5 ^a	3.0 \pm 0.6 ^a	1.2 \pm 0.7 ^a	9.1 \pm 1.3 ^c	4.5 \pm 0.7 ^c	6.4 \pm 0.1 ^a	0.4 \pm 0.6 ^a
E145	0.9 \pm 0.2 ^a	21.0 \pm 0.1 ^a	8.7 \pm 0.1 ^a	3.0 \pm 1.9 ^a	1.1 \pm 1.8 ^a	9.2 \pm 1.4 ^c	4.6 \pm 1.5 ^c	6.4 \pm 0.1 ^a	0.5 \pm 0.5 ^a
Maa-Lana	0.9 \pm 0.1 ^a	22.2 \pm 0.1 ^a	6.5 \pm 0.1 ^b	2.5 \pm 1.4 ^a	1.4 \pm 0.3 ^a	15.7 \pm 1.6 ^{ab}	7.8 \pm 1.1 ^b	6.4 \pm 0.1 ^a	0.5 \pm 1.6 ^a
Manga	0.9 \pm 0.1 ^a	22.0 \pm 0.1 ^a	6.7 \pm 0.9 ^b	2.6 \pm 0.6 ^a	1.2 \pm 0.1 ^a	14.1 \pm 1.0 ^b	6.6 \pm 1.3 ^b	6.3 \pm 0.1 ^a	0.5 \pm 0.5 ^a
Naachem-Tiir	0.9 \pm 0.1 ^a	22.3 \pm 0.5 ^a	7.1 \pm 1.2 ^b	2.9 \pm 0.1 ^a	1.2 \pm 1.1 ^a	14.7 \pm 1.3 ^b	7.7 \pm 1.0 ^b	6.4 \pm 0.1 ^a	0.5 \pm 0.6 ^a
Nutsugah	0.9 \pm 0.9 ^a	22.0 \pm 0.1 ^a	7.0 \pm 0.3 ^b	3.0 \pm 1.3 ^a	1.3 \pm 0.6 ^a	14.5 \pm 1.3 ^b	7.5 \pm 1.4 ^b	6.4 \pm 0.1 ^a	0.5 \pm 1.6 ^a
WAAPP	0.8 \pm 0.2 ^a	22.8 \pm 0.1 ^a	7.3 \pm 0.6 ^b	3.0 \pm 0.6 ^a	1.2 \pm 0.4 ^a	16.7 \pm 1.2 ^a	10.1 \pm 1.1 ^a	6.4 \pm 0.1 ^a	0.5 \pm 0.6 ^a

BD = Bulk density, SP = Swelling power, SI = Solubility index, WB = Water binding capacity, OB = Oil binding capacity, FC = Foaming capacity, FS = Foam stability, TTA = Total titratable acidity. Values are means of triplicates with standard deviation. Means in the same column with different superscripts are significantly different ($p \leq 0.05$).

cultivars. This implies that in baking applications such as bread making, the flours from the unreleased E-group cultivars are more likely to perform poorly during the dough making stage. Variations in some of the functional properties could be associated with the proximate composition of FPF. WB capacities ranged from 2.5 to 3 g/g; while OB capacities ranged from 1.1 to 1.4 g/g for all FPF cultivars. Water and oil binding capacities are essential in food products' textural and flavour characteristics [8,18,41]. Hence flours with high W/OB could be a good ingredient in baking applications, such as bread, since higher water absorption enables bakers to add water to the dough, thus improving the handling characteristics and maintaining freshness in bread [8,18,41]. Also, flours with high WB capacities are considered critical in viscous foods such as porridge, soups, and gravies [28,42]. Hence, FPF may be useful as a functional ingredient in porridges, soups, gravies, and pastry products. FC and FS are dependent on the protein and carbohydrate content in the flour [20,42]. This could be the reason why the released

cultivars recorded higher values (14.1–16.7 %) relative to that of the unreleased E-group cultivars (8.7–9.4 %) ($p \leq 0.05$). Functional characteristics of flours are influenced by different resistant starch, amylose/amylopectin ratio and protein concentrations, their degree of interaction with water and their conformational characteristics [19,28,41]. Hence the differences ($p \leq 0.05$) in the functional properties of FPF could be due to their different resistant starch and protein concentrations. Based on the results (Table 7), FPF may be helpful in pastry applications, and a thickener in liquid and semi-liquid foods since the flours can absorb water and swell for improved consistency in these foods.

3.10. Pasting properties of FPF

The pasting characteristics of Frafra potato flours were determined to record the indices presented in Table 8 quantitatively.

Table 8
Pasting characteristics of FPF.

Cultivar	P _{Time} (min)	P _{Temp} (°C)	PV (BU)	BD (BU)	SB (BU)	FV (BU)
E 82	20.40 ± 0.10 ^a	78.30 ± 0.10 ^a	93.20 ± 0.20 ^a	6.01 ± 0.01 ^a	19.10 ± 0.01 ^b	92.13 ± 0.08 ^a
E111	19.55 ± 0.21 ^{ab}	78.90 ± 0.14 ^a	89.50 ± 0.03 ^{ab}	5.40 ± 0.91 ^b	21.59 ± 0.05 ^a	98.40 ± 0.45 ^a
E132	18.40 ± 0.03 ^c	76.80 ± 0.02 ^a	79.10 ± 0.01 ^c	3.10 ± 0.06 ^d	16.33 ± 0.06 ^e	84.20 ± 0.24 ^b
E134	19.20 ± 0.50 ^b	78.10 ± 0.40 ^a	82.20 ± 0.05 ^b	5.20 ± 0.12 ^b	17.14 ± 0.91 ^d	89.60 ± 0.07 ^b
E145	18.50 ± 0.41 ^{bc}	77.10 ± 0.08 ^a	77.60 ± 0.91 ^c	4.10 ± 0.04 ^c	18.23 ± 0.23 ^c	84.50 ± 0.16 ^b
Maa-Lana	17.55 ± 1.12 ^d	75.60 ± 0.05 ^a	85.20 ± 3.51 ^b	2.70 ± 0.13 ^e	18.62 ± 3.10 ^c	94.70 ± 1.85 ^a
Manga	20.35 ± 0.91 ^a	79.90 ± 0.23 ^a	68.10 ± 0.04 ^d	2.03 ± 0.01 ^e	18.20 ± 0.32 ^c	95.03 ± 0.14 ^a
Naachem-Tiir	20.15 ± 0.27 ^a	79.10 ± 0.02 ^a	84.30 ± 0.01 ^b	3.10 ± 0.09 ^d	15.14 ± 0.09 ^f	93.21 ± 0.06 ^a
Nutsugah	18.20 ± 1.01 ^c	75.90 ± 0.09 ^a	85.40 ± 3.19 ^b	3.40 ± 2.25 ^d	17.83 ± 2.94 ^d	84.90 ± 1.91 ^b
WAAPP	19.10 ± 0.10 ^b	77.40 ± 0.21 ^a	78.10 ± 0.03 ^c	3.10 ± 0.06 ^d	22.13 ± 0.71 ^a	85.05 ± 0.02 ^b

P_{Temp}. = Pasting temperature; P_{Time} = Pasting time (min); PV = Peak Viscosity; FV = Final Viscosity; BD = Break Down; SB = Set Back. Values are means of triplicates with standard deviation. Means in the same column with different superscript are significantly different (p ≤ 0.05).

From Tables 8 and it is observed that there were significant differences (p ≤ 0.05) in all the pasting property indices recorded, except for the pasting temperature of the FPF cultivars. Differences in pasting indices are influenced by the amylose/amylopectin ratio and chemical composition of the flours [18,41]. Variations in most of the indices could be associated with the proximate composition of FPF [10,28]. All the FPF cultivars had higher paste stability relative to close alternative tuber crops such as cassava and sweet potato [10,30]. The released cultivars and E132 had a relatively lower breakdown. The released cultivars formed more stable gels than the unreleased E-group cultivars (Table 2); this could explain why they have a somewhat lower breakdown. Higher setback values show a higher tendency to retrograde and vice versa [19,28,42]. The tendency of flour pastes to retrograde was highest in WAAPP, followed by E111. Therefore, pastry, such as bread, made from these cultivars is likely to stale faster than bread made from the other cultivars such as Naachem-Tiir and E132.

3.11. Flow behaviour of cooked FPF slurry

The flow behaviour of FPF was determined to understand how cooked slurries from flour made using the different cultivars differed. Fig. 4 and Table 9 summarize the flow behaviour and the apparent viscosity of FPF slurries.

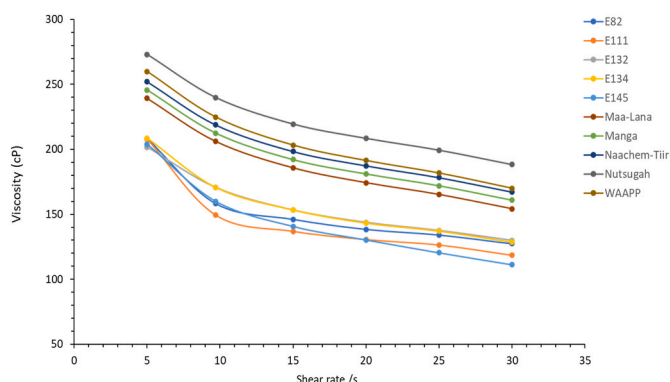


Fig. 4. Viscosity profile of gels from FPF.

Table 9
Viscosity and the degree of non-Newtonian of FPF.

Cultivars	K	n	R ²
E82	2.28 ± 0.01 ^a	0.53 ± 0.00	0.987
E111	2.28 ± 0.00 ^a	0.61 ± 0.00	0.988
E132	2.44 ± 0.01 ^a	0.61 ± 0.00	0.998
E134	2.50 ± 0.01 ^a	0.66 ± 0.00	0.996
E145	2.54 ± 0.01 ^a	0.43 ± 0.00	0.997
Maa-Lana	2.55 ± 0.01 ^a	0.24 ± 0.00	0.996
Manga	2.55 ± 0.00 ^a	0.23 ± 0.00	0.996
Naachem-Tiir	2.56 ± 0.01 ^a	0.22 ± 0.00	0.996
Nutsugah	2.58 ± 0.00 ^a	0.20 ± 0.00	0.997
WAAPP	2.58 ± 0.00 ^a	0.23 ± 0.00	0.996

n (power-law) = flow behaviour index, K = consistency index, R² = Coefficient. Means with the same superscripts in the column are statistically indifferent (p ≤ 0.05).

From Fig. 4, the gels exhibited a characteristic non-Newtonian, shear-thinning (or pseudoplastic) behaviour, characterised by a decline in apparent viscosity with increasing shear rate [43]. Gels produced from the released cultivars were significantly (p < 0.05) more viscous than those from the unreleased E-group cultivars. For instance, at the lowest shear rate, a viscosity range of 239–273 cP and 24–109 cP was respectively recorded for gels from the released and unreleased E-group cultivars. The flow behaviour of slurries made from flours is influenced by their proximate composition and least gel concentration ([10,28]; Peroni et al., 2006). Therefore, the observed variations in the apparent viscosity of FPF gels could be attributed to the differences observed in the proximate composition and least gelation concentrations of the FPF cultivars.

The ‘n’ values suggest whether fluids have a Newtonian or non-Newtonian behaviour. Newtonian fluids have been shown to have n = 1, while non-Newtonian fluids have values below 1 [44]. The results (Table 9) implies that all the FPF cultivars had ‘n’ values less than 1, confirming that they exhibited a non-Newtonian shear-thinning fluid characteristic. Table 9 shows that all the FPF gels had a similar consistency index (K) (p ≤ 0.05). This also indicates the mixing tolerance [8,33,44] of FPF flours in culinary applications such as pastry and porridge.

3.12. Moisture sorption behaviour of FPF (isotherms)

The sorption behaviour of FPF is summarized in Fig. 5 and Table 10. From the figure, it is observed that all the FPF cultivars had the classical sigmoid-shaped curve as expected of dried food ingredients such as flours [29]. E132 had the highest equilibrium moisture content (EMC) across the range of water activity examined (p < 0.05). This indicates that flour from this cultivar had the highest tendency to absorb moisture under constant pressure. It is also observed, in Fig. 5, that beyond 10 % EMC and a_w of about 0.5, the flours begin to absorb higher moisture under constant temperature and pressure. This implies that all the flours have a maximum allowable moisture content for safekeeping at 10 %,

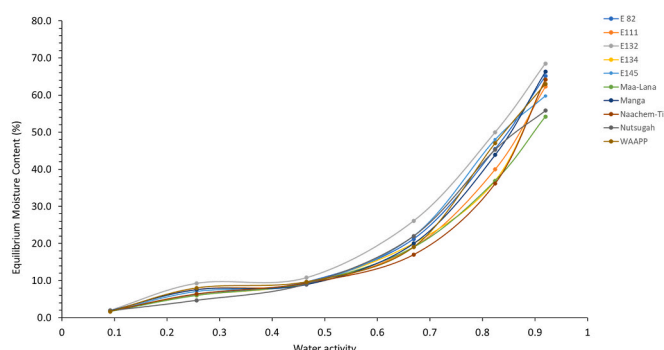


Fig. 5. Moisture sorption behaviour of FPF.

Table 10
Constants and results obtained from isotherm models for FPF.

Cultivar	BET			GAB			Oswin			Henderson			Smith		
	Mo	C	R ²	Mo	C	R ²	A	B	R ²	A	B	R ²	A	B	R ²
E82	4.31	0.19	88.7	3.26	0.14	89.6	0.1	0.48	94.7	0.30	0.16	83.6	0.78	3.02	90.8
E111	3.08	0.07	87.5	2.82	0.18	86.2	0.18	0.47	93.0	0.40	0.16	83.9	0.69	2.10	98.8
E132	4.35	0.08	90.2	2.01	0.13	87.4	0.20	0.45	96.2	0.21	0.16	84.8	0.83	2.02	91.2
E134	6.67	0.05	93.1	7.31	0.15	85.2	0.20	0.57	97.0	0.10	0.16	87.4	0.60	2.14	98.2
E145	5.40	0.43	91.2	8.27	0.41	88.5	0.20	0.58	98.1	0.08	0.16	86.8	0.81	2.33	96.7
Maa-Lana	10.6	0.04	93.3	8.37	0.11	88.2	0.22	0.37	99.1	0.03	0.16	84.4	0.90	1.72	99.1
Manga	3.96	0.09	87.9	3.62	0.08	89.2	0.19	0.47	92	0.39	0.15	82.6	0.73	2.01	88.8
Naachem-Tiir	3.71	0.09	89.9	2.16	0.13	89.6	0.19	0.48	93.6	0.31	0.16	85.5	0.66	2.01	90.8
Nutsugah	6.60	0.56	90.4	7.67	0.47	85.2	0.20	0.39	97.2	0.09	0.16	84.3	0.70	1.73	97.1
WAAPP	4.15	0.08	90.8	2.12	0.14	89.6	0.20	0.45	95.1	0.23	0.16	86.2	0.57	1.98	92.8

R² = Coefficient of regression, RMSE = Root mean square error, Mo = Monolayer moisture content (gH₂O/100 g solid), C = BET constant, G and K = GAB constants, A and B = Henderson and Smith constants.

beyond which they may cake or become lumpy during storage.

Several models are used to explain the moisture sorption characteristics of foods. The popular models are the BET, GAB, Oswin, Henderson, and Smith models [29,32]. This study fitted the data into the five models, as shown in Table 10. The goodness of fit of the models (as indicated by the R² and RMSE values) varied for all the FPF cultivars. The Oswin model was the best fit for the majority of FPF cultivars (WAAPP, Maa-Lana, Naachem-Tiir, Nutsugah, Manga, E82, E132 and E145), this is because the model had higher R² values (93.6–99.1 %) with lower residuals (RMSE ranged between 0.03 – 0.39), which implies it can explain about 94–99 % of the variability in the sorption behaviour of those flours. However, the Smith model was the best fit for E111 and E134. It had higher R² values (98.8 % and 98.2 %, respectively) with very low residuals (0.03 and 0.04, respectively). Using the BET and GAB models, Maa-Lana had the highest monolayer moisture content of 10.6 and 8.4, suggesting a lower safekeeping tendency while in storage under standard conditions [29,32], compared to the other cultivars.

3.13. Principal components analysis of FPF characteristics

The Principal Component Analysis (PCA) was used to objectively determine which features significantly impacted the differences and similarities amongst the flours from the ten cultivars of Frafra potato. The PCA map generated displays for positioning the ten FPF cultivars based on their physicochemical characteristics. Majority of the variance (81.13 %) was explained in the first 2 dimensions (DIM1 = 49.19 %, DIM2 = 31.94 %) as shown in Fig. 6.

From Fig. 6, PCA clustered the flours from the ten cultivars of FPF into two main groups, with the released cultivars in one group and the unreleased E-group cultivars in the other group. The released FPF cultivars were mainly characterised by their protein, lysine, glutamine and DL-β-phenylalanine concentrations, foaming capacity, foam stability, solubility, pasting time, and paste clarity. The second group was characterised by their vitamin A, tryptophan, aspartic acid valine and crude fibre concentrations, paste breakdown, and equilibrium moisture content. According to Ezekiel and Singh [6], Klunklin and Savage [27] and Dzedzoave et al. [31], these characteristics significantly influence the differences in flours. They are also important factors considered in flour selection for food applications.

4. Conclusion

The findings revealed that flour yields varied from 59 % to 70 %, with no noticeable distinction between the released and most unreleased E-group cultivars, except for E134. Compositional analyses indicated disparities in protein, ash, fiber, and mineral content among the flours from the ten cultivars of Frafra potato. The released Frafra potato exhibited higher concentrations of protein and ash compared to the

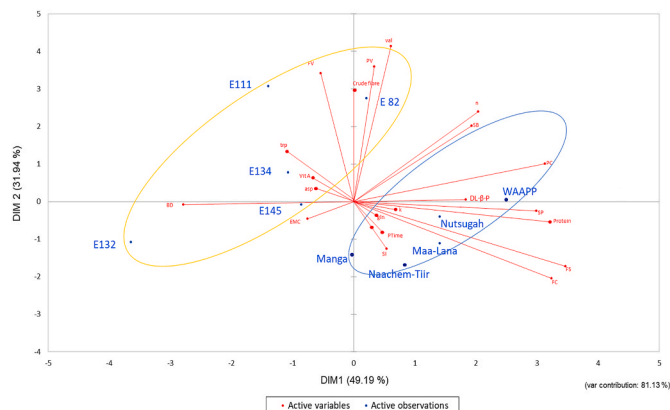


Fig. 6. PCA plot for FPF cultivars.

unreleased E-group cultivars. The protein profile analysis showed the prevalence of three major storage proteins (patatin, sporamin, and tarin) and two others (lipoxygenase and BBIs). Amino acid analyses identified nineteen amino acids in Frafra potato flours, seven of which were essential. Substantial variations were observed in the rheological properties of slurries produced from the flours, with Manga displaying the highest stability and WAAPP exhibiting the greatest tendency to retrograde. Pastes derived from the released cultivars were relatively more viscous than those from the E-group. Principal Component Analysis (PCA) distinguished flours from the released and unreleased E-group cultivars. The characteristics of the flours from the ten Frafra potato cultivars provide crucial data for practical culinary applications, offering versatility for uses such as in baked goods, noodles, thickeners, and weaning meals, among others. These findings are pertinent for both household and commercial-scale processing, packaging, and handling of Frafra potato flour. Given that this study did not incorporate other known potatoes, introducing known tuber crops as controls could provide additional insights into the observations.

CRedit authorship contribution statement

Crossby Osei Tutu: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Joris Gerald Niilante Amisshah:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization. **Jacqueline Naalamle Amisshah:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization. **Paa Toah Akonor:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Agnes Simpson Budu:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Methodology, Investigation. **Firibu Kwesi Saalia:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The paper contains the data that was utilized for this study.

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