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ORIGINAL RESEARCH ARTICLE

Physicochemical, Functional, and Nutritional Characteristics of Rhizome and Starch from Two Ginger Varieties (UMUGIN 1 and UMUGIN 2)

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ABSTRACT

This study evaluated two National Root Crops Research Institute, Umudike's newly released ginger varieties; UMUGIN 1 and UMUGIN 2, for the physicochemical, functional properties, and nutritional profiles of the rhizomes flour and extracted starches, to elucidate their potential applications in food, pharmaceutical applications such as excipients and fillers, and other industrial systems. Fresh ginger rhizomes were processed into flour and starch using standard wet extraction methods. The flour and starch were analyzed for proximate composition, mineral and vitamin content, functional properties, pasting characteristics, and estimated glycemic index. The results showed moisture content's range of 84.79 to 85.53 %, protein from 5.3 to 5.4 %, fiber from 0.9 to 1.1 %, fat from 0.6 to 0.7 %, ash from 1.8 to 1.9 %, and carbohydrate from 5.8 to 6.2 %. UMUGIN 2 exhibited slightly higher dry matter, protein, fiber, and carbohydrate content. Mineral analysis revealed appreciable levels of potassium, calcium, magnesium, phosphorus, iron, zinc, and sodium. UMUGIN 1 contained higher levels of vitamins A, C, and E. Starch yield ranged from 21.50 to 28.65 %, with amylose content of 26.10 % in UMUGIN 1 and 18.89 % in UMUGIN 2, and corresponding amylopectin contents of 73.89 % and 81.89 %, respectively. Pasting properties indicated good thickening potential, with peak viscosity ranging from 3478 to 3553 RVU. The estimated glycemic index values (33.90 - 36.42) indicate that both starches fall within the low glycemic index category. Overall, UMUGIN 1 demonstrated higher starch yield and viscosity, suggesting suitability potential for food thickening and excipients applications, while UMUGIN 2 exhibited comparatively higher nutritional attributes and may be considered for incorporation into functional food formulations.
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1. INTRODUCTION

Ginger (*Zingiber officinale Roscoe*) is a widely recognized spice and medicinal plant valued for its distinctive flavor and bioactive compounds. Originating from Southeast Asia, it is now cultivated globally and is known to contain phytochemicals such as gingerols, shogaols, and oleoresins, which contribute to its characteristic aroma and biological activity. Ginger has long been utilized in traditional medicine for the management of nausea, digestive disorders, and inflammation, and contemporary studies have further demonstrated its antioxidant and anti-inflammatory properties. Despite its well-established applications, the full utilization potential of ginger, particularly its starch component, remains underexplored. Ginger rhizomes contain appreciable quantities of starch, which is often discarded during the extraction of essential oils and other bioactive compounds. Given the increasing demand for starch in food, pharmaceutical, and biodegradable material applications, the recovery and characterization of ginger starch could contribute to value addition and waste reduction.

Recently, the National Root Crops Research Institute (NRCRI), Umudike, Nigeria, released two improved ginger varieties, UMUGIN 1 and UMUGIN 2, with promising agronomic and industrial attributes. However, there is limited published information on the physicochemical, functional, and nutritional characteristics of these specific varieties. Therefore, this study aims to evaluate their rhizome composition, starch yield, and functional properties to provide baseline data for potential applications in food systems and industrial processes.

2. MATERIALS AND METHODS

2.1 Source of ginger roots

2.1.1 Source of ginger Rhizomes and sampling procedure

The two ginger varieties (UMUGIN 1 and UMUGIN 2) used in this study were obtained from one of the outstations of the National Root Crops Research Institute (NRCRI), located in Kaduna State, Nigeria. The rhizomes were harvested at physiological maturity (approximately 8 - 9 months after planting) during the main harvest season. Sampling was carried out by randomly selecting healthy, disease-free rhizomes from multiple plants within the experimental field. A total of 20 - 30 rhizomes per variety were collected to ensure representativeness. The samples were obtained from multiple sampling points within the same experimental field under uniform agronomic conditions. This sampling approach was adopted to minimize within-field variability and ensure that the samples were representative of each variety. After harvesting, the rhizomes were thoroughly cleaned to remove adhering soil and debris, pooled per variety, and transported to the laboratory for further processing and analysis.

2.2 Methodology for starch extraction with yield percentage determination

2.2.1 Starch extraction and yield determination

Starch was extracted from fresh ginger rhizomes using the wet extraction method described by Ellis (2016), with slight modifications. Fresh rhizomes were washed thoroughly with tap water to remove adhering soil and impurities, peeled, and cut into small pieces (approximately 2 - 3 g each). A total of 3 kg of the prepared rhizomes was homogenized with 1.5 liters of deionized water using a Waring blender (Model 51BL30, Torrington, Connecticut, USA). The resulting slurry was filtered through a muslin cloth to separate fibrous material from the starch-containing filtrate. The retained residue was re-extracted by re-blending with an additional 1.5 liters of deionized water and filtered repeatedly until no visible starch remained. The combined filtrate was allowed to sediment for 3 hours, after which the supernatant was decanted. The sedimented starch was re-suspended in deionized water, allowed to settle again, and the supernatant discarded. The final starch sediment was oven-dried at 40 - 45 °C to constant weight, milled into fine powder, and stored in low-density polyethylene bags prior to analysis. Starch yield was calculated on a fresh weight basis using the following expression:

$$\boldsymbol{Starch\ yield}\ (\%) = \frac{weight\ of\ dried\ starch}{weight\ of\ fresh\ rhizome\ sample} x\ 100$$

where the weight of dried starch represents the final oven-dried starch obtained after extraction, and the weight of fresh rhizome sample corresponds to the initial mass of fresh ginger used for extraction.

2.3 Sample preparation for starch and sugar analysis

A 25 mg portion of starch sample was transferred into a centrifuge tube, followed by the addition of 1 mL ethanol and 2 mL distilled water. The mixture was centrifuged at 2000 × g for 10 minutes to separate soluble sugars from the starch fraction. The supernatant containing soluble sugars was collected for further analysis, while the residual sediment was treated with 7.5 mL perchloric acid and allowed to stand at room temperature for 1 hour to hydrolyze the starch. This preparation was used for subsequent determination of starch concentration.

2.4 Analysis of dry matter content and nutritional composition in ginger roots

The dry matter content and proximate composition of the samples, including moisture, protein, fat, ash, and crude fiber, were determined using standard methods of the

Fig. 1. Field grown ginger plants

Fig. 2. UMUGIN 1 rhizomes

Fig. 3. UMUGIN 2 rhizomes

Association of Official Analytical Chemists (AOAC). Moisture content was determined by oven-drying to constant weight (AOAC Official Method 925.10), while ash content was determined by dry ashing in a muffle furnace at 550 °C (AOAC Official Method 923.03). Crude protein was analyzed using the Kjeldahl method (AOAC Official Method 979.09) with nitrogen content converted to protein using a factor of 6.25. Crude fat was extracted using the Soxhlet extraction method with petroleum ether as solvent (AOAC Official Method 920.39). Crude fiber was determined by sequential acid and alkali digestion (AOAC Official Method 962.09). Carbohydrate content was calculated by difference.

2.5 Determination of moisture content

To measure the moisture content, a clean moisture can was initially dried at 80 °C for about 30 minutes, cooled in a desiccator, and its weight recorded (W). Two grams of the ginger root material were then placed in the can, and the combined weight noted (B). The sample was subsequently oven-dried at 70 °C for five hours, or until a constant weight (C) was reached. The moisture content was calculated using the following formula:

$$\boldsymbol{Moisture\ content}\ (\%) = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where:

W_1 = weight of empty container
W_2 = weight of container + wet sample
W_3 = weight of container + dry sample

As a result, the ginger rhizomes' dry matter content was determined using this formula:

$$\boldsymbol{Dry\ matter}\ (\%) = \frac{Wdry}{Wfresh}\ x\ 100$$

2.6 Fat content determination (Soxhlet extraction method)

Lipid content of the sample was measured using the Soxhlet extraction technique. A pre-weighed portion of the sample was placed in a porous thimble, which was then positioned in the extraction chamber above a flask containing ethanol as the extracting solvent. The system underwent five reflux cycles to achieve complete extraction. Subsequently, the solvent was evaporated, and the recovered lipid was weighed. The fat content percentage was then calculated using the following formula:

$$\boldsymbol{Lipid}\ (\%) = \frac{Mass\ of\ lipids}{Mass\ of\ sample}\ x\ 100$$

2.7 Determination of ash content

The inorganic content of the sample (ash) was measured by weighing 2 grams and placing it in a muffle furnace preheated to 600 °C. The sample was incinerated until all organic matter was completely oxidized, leaving only the mineral residue. The remaining ash was weighed, and the percentage of ash content was calculated accordingly.

$$\boldsymbol{Ash\ content}(\%) = \left(\frac{\text{Mass of ash residue}}{\text{Initial sample mass}}\ X\ 100\right)$$

2.8 Crude fibre determination

Crude fiber content was determined using the standard acid - alkali digestion method. Five grams of each defatted ginger sample were first boiled in 1.25 % dilute sulfuric acid, followed by thorough washing with deionized water. The residue was then digested in 1.25% sodium hydroxide solution and filtered. The resulting residue was transferred into a previously weighed crucible (W_1), oven-dried at 80 °C to constant weight, and weighed again (W_2). The crucible containing the dried residue was then incinerated in a muffle furnace at 600 °C for 3 hours, cooled in a desiccator, and reweighed (W_3). Crude fiber content was calculated using the formula:

$$\boldsymbol{Crude\ fiber}\ (\%) \ = \left(\frac{\text{W2} - \text{W3}}{\text{W1}}\ X\ 100\right)$$

where:
W_1 = weight of empty crucible (g)
W_2 = weight of crucible + dried residue before ashing (g)
W_3 = weight of crucible + ash after incineration (g)

2.9 Oleoresin content determination

Oleoresin content was determined by solvent extraction using acetone in a Soxhlet apparatus as described by Famurewa *et al.* (2011) and Ahmed *et al.* (2021), with slight modifications. Finely milled, oven-dried ginger samples (25 g, dry weight basis) were extracted with 250 mL acetone for 6 - 8 hours. The solvent was recovered using a rotary evaporator at 45 - 50 °C, and the extract was dried to constant weight. Oleoresin yield was calculated and expressed on a dry weight basis as percentage of the dry sample weight.

$$\boldsymbol{Oleoresin\ yield}\ (\%) = \left(\frac{\text{Weight of Oleoresin extract}}{\text{Weight of sample}}\right) X\ \ 100$$

2.10 Evaluation of Vitamins A and E

Fat-soluble vitamins (A and E) were determined using UV–Visible spectrophotometry following extraction based on AOAC (2005) methods, with slight modifications. Approximately 5 g of finely milled ginger sample was homogenized with 25 milliliters ethanol and 15 milliliters petroleum ether. The mixture was shaken for 30 minutes and centrifuged at 3000 rpm for 10 minutes to obtain a clear supernatant.

Vitamin A (retinol) was quantified by measuring absorbance at 325 nm, while vitamin E (tocopherol) was determined at 295 nm using a UV–Vis spectrophotometer. Quantification was performed using calibration curves prepared from standard solutions of retinol and α-tocopherol, respectively. Standard stock solutions were prepared in appropriate solvents, and serial dilutions were used to generate calibration curves. The concentrations of vitamins in the samples were calculated from the respective standard curves and expressed in µg/g of sample.

2.11 Determination of Vitamin C (Ascorbic acid)

Determination of Vitamin C was carried out using the 2,6-dichlorophenol-indophenol (DCPIP) titration method. Approximately 10 grams of the sample was homogenized in 100 milliliters of 3 % metaphosphoric acid and subsequently filtered. A 10-milliliter portion of the filtrate was titrated with a standard DCPIP solution until a stable light pink endpoint was reached. Vitamin C levels were determined from the volume of titrant used and quantified using a standard ascorbic acid calibration curve.

2. 12 Evaluation of the mineral composition

The levels of minerals in the ginger samples were measured using atomic absorption spectrophotometry (AAS) following wet digestion as described by Onwuka (2018). These minerals include calcium (Ca), sodium (Na), potassium (K), iron (Fe), zinc (Zn), phosphorus (P), and magnesium (Mg), Two grams of dried ginger were ashed in a muffle furnace at 550 °C for six hours. The ash obtained was dissolved in 10 milliliters of 1:1 hydrochloric acid (HCl), filtered, and diluted to 50 milliliters with deionized water. The resulting solution was analyzed using an atomic absorption spectrophotometer (PerkinElmer A Analyst 400), with element-specific lamp wavelengths for AAS as follows: Ca (422.7 nm), Na (589.0 nm), K (766.5 nm), Fe (248.3 nm), Zn (213.9 nm), and Mg (285.2 nm). Phosphorus was determined colorimetrically using the vanado-molybdate method, with absorbance read at 400 nm. Calibration curves were generated using standard solutions, and sample concentrations were calculated based on their absorbance.

2.13 Evaluation of starch and sugar composition

The concentrations of starch and sugars in the extracted starch were quantified according to the method of Otegbayo *et al.,* (2019), which hydrolyzes starch into glucose and other sugar components.

2.13.1 Determination of starch concentration

Starch concentration was determined using the phenol–sulfuric acid method following hydrolysis, as described by Otegbayo *et al.* (2019). After hydrolysis, the sample solution was filtered using Whatman filter paper to remove insoluble residues. The filtrate was appropriately diluted with distilled water. An aliquot (0.05 milliliter) of the diluted sample was transferred into a test tube and made up to 1 mL with distilled water. To this, 0.5 milliliter of 5% phenol solution and 2.5 milliliter of concentrated sulfuric acid were added. The mixture was allowed to stand for 10 minutes for color development, and absorbance was measured at 490 nm using a spectrophotometer.

Starch concentration was calculated from a glucose standard calibration curve using the relationship:

$$\boldsymbol{Starch}\ (\boldsymbol{mg/g}) = \left(\frac{\mathrm{A \times V \times DF}}{\mathrm{S \times W}}\right) X\ 100$$

Where:
A = absorbance of the sample
V = total volume of extract (mL)
DF = dilution factor
S = slope of the standard calibration curve (absorbance per µg glucose)
W = weight of sample (mg)

2.13.2 Assessment of the Hydrolysis Index (HI)

The glycemic index (GI) of the starch samples was determined using an in vitro method. The hydrolysis index (HI) was first calculated by comparing the area under the starch hydrolysis curve (AUC) of each test sample with that of white bread on a gram-for-gram basis, with white bread assigned an HI value of 100. The predicted glycemic index was then estimated using the empirical equation proposed by Goñi et al. (1997):

GI = 39.71 + 0.549 × HI

where HI denotes the hydrolysis index obtained from the in vitro starch digestion assay.

2.13.3 Measurement of amylose content

Amylose content in the ginger starch was assessed using the iodine colorimetric method, following the procedures of Williams (2008) and Juliano (2007). About 0.1 gram of starch was dissolved in a solution containing 1 milliliter of 95 % ethanol and 9 milliliters of 1 N sodium hydroxide (NaOH). The resulting mixture was heated in a boiling water bath for 10 minutes and then cooled to room temperature.

A 1 milliliter portion of the cooled extract was diluted to 10 milliliters with distilled water. From this solution, 0.5 milliliter was put into a separate test tube and treated with 0.1 milliliters of 1 N acetic acid and 0.2 milliliters of iodine solution, prepared by dissolving 0.2 gram of iodine and 2.0 gram of potassium iodide in 100 milliliters of distilled water. The resulting blue solution was further diluted to 10 milliliters with distilled water and allowed to stand for 20 minutes to ensure complete color development. The mixture was vortexed to achieve uniformity, and absorbance was measured at 620 nm using a spectrophotometer. Amylose content was then determined by comparing the absorbance values with a standard calibration curve prepared using pure corn amylose.

2.14 Assessment of pasting characteristics

Pasting properties of the starch samples were assessed using a Rapid Visco Analyzer (RVA Super 4, Newport Scientific, Australia), according to the method of Zhang *et al.*, (2016). For each measurement, 3.0 gram of starch (dry weight basis) was combined with 25.0 milliliters of deionized water in an RVA sample canister. The starch samples were analyzed following the RVA Standard 1 profile, with an initial mixing speed of 960 rpm for 10 seconds, then 160 rpm for the remaining duration. Temperature increased from ambient to 95 °C at 6 °C/min, held for 1 minute, cooled to 50°C at the same rate, and held for 2 minutes. All analyses were conducted in triplicate.

2.15 Data analysis

Statistical analysis was performed using R software (version 4.3.1, R Core Team, 2023). Data were expressed as mean ± standard deviation of triplicate determinations. One-way analysis of variance (ANOVA) was used to determine significant differences among sample means at a 5 % probability level ($p \leq 0.05$). Where significant differences were observed, means were separated using the Least Significant Difference (LSD) post hoc test.

3. RESULTS AND DISCUSSION

3.1 Proximate composition of ginger roots

3.1.1 Moisture content

Lower moisture content is an important quality parameter because it influences shelf stability, susceptibility to microbial growth, and ease of processing (Ahmed *et al.*, 2021). In this study, UMUGIN 2 recorded slightly lower moisture content (84.79 %) compared to UMUGIN 1 (85.53 %) ($p < 0.05$). This difference suggests a marginally higher dry matter concentration in UMUGIN 2, which may be associated with improved storability under appropriate postharvest conditions, although this would require further shelf-life evaluation to confirm. Generally, reduced moisture levels can help limit microbial activity and enzymatic degradation during storage (Onwuka *et al.*, 2022). However, the extent to which this translates into industrial advantages depends on processing conditions and specific end-use requirements.

3.1.2 Ash, ether extract, and crude fiber contents

Ash content shows the total mineral makeup of a food and gives an idea of its inorganic nutrient value (AOAC, 2000). Comparison between the samples showed that UMUGIN 1 had a significantly higher ash content (1.86 %) than UMUGIN 2. (1.78 %) ($p < 0.05$) (**Table 1**). This means

UMUGIN 1 might have better mineral content, making it a good option for food fortification or nutraceutical uses.

The ether extract, which shows the crude fat or lipid content, was higher in UMUGIN 2 (0.70 %) compared to UMUGIN 1 (0.59 %) ($p < 0.05$) **(Table 1).** While ginger is not a big source of fat, these lipids matter a lot because they help develop flavor and make certain bioactive compounds, like gingerols and shogaols, more soluble (Baliga *et al.*, 2011).

Crude fiber, which is important for digestive health, was also higher in UMUGIN 2 (1.08 %) than in UMUGIN 1 (0.93 %) ($p < 0.05$). This suggests UMUGIN 2 could be a better option for foods aimed at supporting gut health. Dietary fiber works as a prebiotic and helps regulate bowel movements, blood sugar, and cholesterol (Mashhadi et al., 2013; Shukla & Singh, 2007). Ginger varieties with more fiber are especially useful in functional foods and health supplements

Table 1. Proximate composition of ginger roots (% wet basis)

Sample	MC (%)	DM (%)	ASH (%)	EE (%)	CF (%)	CP (%)	CHO (%)
UMUGIN1	85.52 ± 0.43^{b}	14.47 ± 0.42^{a}	1.86 ± 0.06^{b}	0.59 ± 0.06^{a}	0.93 ± 0.08^{a}	5.34 ± 0.08^{a}	5.74 ± 0.25^{a}
UMUGIN2	84.78 ± 0.43^{a}	15.21 ± 0.44^{b}	1.78 ± 0.06^{a}	0.70 ± 0.07^{b}	1.08 ± 0.10^{a}	5.44 ± 0.08^{b}	6.20 ± 0.27^{b}
LSD	**0.69**	**0.69**	**0.10**	**0.11**	**0.15**	**0.14**	**0.44**

***MC** = moisture content; **DM** = dry matter; **ASH** = ash content; **EE** = ether extract; **CF** = crude fiber; **CP** = crude protein; **CHO** = carbohydrate. Values are mean ± standard deviation of triplicate determinations (n = 3). Data were analyzed using one-way analysis of variance (ANOVA), and mean separation was performed using the Least Significant Difference (LSD) test. Values within the same column with different superscript letters (a–b) differ significantly at $p < 0.05$.*

Protein is an important nutrient that helps with growth, repair, and metabolism (Tester and Karkalas, 2001). Even though ginger is not usually eaten for its protein content, UMUGIN 2 had slightly more crude protein (5.44 %) than UMUGIN 1 (5.34 %) ($p < 0.05$). This small boost could improve the nutritional and functional value of ginger - based foods like soups, stews, and dietary supplements by adding a bit to their amino acid content. Carbohydrates, especially starch, are important in ginger because they provide energy and affect texture in foods (Bello-Pérez *et al.*, 2020). UMUGIN 2 also had higher carbohydrates (6.20 %) compared to UMUGIN 1 (5.74 %) ($p < 0.05$), which matches its lower moisture and higher dry matter. This means UMUGIN 2 is appropriate for applications that need starch - rich material, such as thickeners, adhesives, or even biodegradable plastics (Zhu, 2015).

3.1.3 Mineral content of ginger roots

Minerals are important for human health because they help with enzyme activity, body structure, and regulation (Bender, 2009). The mineral content of UMUGIN 1 and UMUGIN 2 is shown in **Table 2**, and there were notable differences in several key minerals. Compared to published values for ginger, these UMUGIN varieties have mineral levels in line with what is expected for ginger, though the exact amounts can vary depending on the variety and growing conditions.

Calcium (Ca)

Calcium content ranged from 320 mg/100 g in UMUGIN 1 to 360 mg/100 g in UMUGIN 2. Calcium is essential for bone mineralization, muscle contraction, and nerve impulse transmission (Murray *et al*., 2018). The values obtained are within the range reported for dried ginger products and spice powders, although variability is commonly observed due to differences in genotype, soil composition, and agronomic practices. Studies have shown that soil fertility and mineral availability significantly influence calcium accumulation in ginger rhizomes, with fertilizer application playing a key role in modulating mineral uptake (Jabborova *et al*., 2021). Similar variability in calcium content has also been reported in other root and rhizome crops, confirming the strong environmental dependency of mineral composition (Hussain *et al*., 2009).

Sodium (Na)

Sodium content was relatively low in both UMUGIN 1 (45 mg/100 g) and UMUGIN 2 (52 mg/100 g). This aligns with previous findings that ginger is naturally low in sodium compared to potassium-rich plant foods. Low sodium content in plant-based foods is considered beneficial for cardiovascular health, particularly in reducing the risk of hypertension when combined with higher potassium intake (Appel *et al.,* 2011). Variability in sodium concentration in dried ginger products has been linked to soil salinity, water quality, and processing conditions such as drying and dehydration, which can concentrate mineral content on a dry weight basis (Ali *et al*., 2008).

Potassium (K)

Potassium was the most abundant mineral in both UMUGIN 1 (1800 mg/100 g) and UMUGIN 2 (1950 mg/100 g). This dominance of potassium in ginger is consistent with previous reports on spice crops and medicinal rhizomes, where potassium is typically the major macro-element involved in osmotic regulation and enzyme activation. Potassium is essential for maintaining electrolyte balance and supporting cardiovascular health, particularly in regulating blood pressure (Aburto *et al*., 2013). Similar high potassium concentrations have been reported in ginger and related rhizomes, confirming its physiological importance and nutritional relevance in plant-based diets (Singh *et al.,* 2014; Ali *et al*., 2008).

Iron (Fe)

For trace minerals, iron ranged from 11.5 mg/100 g in UMUGIN 1 to 13.2 mg/100 g in UMUGIN 2. Iron is essential for oxygen transport, hemoglobin synthesis, and cellular respiration. The values obtained are consistent with reported iron levels in ginger and spice powders, which typically fall within low to moderate ranges depending on soil iron availability and plant uptake capacity (Singh *et al.,* 2014). However, bioavailability of iron in plant-based foods may be influenced by the presence of phenolic compounds and dietary inhibitors such as phytates (Bhowmik *et al*., 2012; Hallberg and Hulthén, 2000).

Zinc (Zn)

Zinc content ranged from 2.8 mg/100 g in UMUGIN 1 to 3.6 mg/100 g in UMUGIN 2. Zinc is an essential trace element involved in immune function, protein synthesis, and enzyme regulation. Ginger has been reported as a moderate dietary source of zinc among spice crops, although concentrations are highly dependent on soil micronutrient status and cultivar genetics (Singh *et al.,* 2014). Similar findings have been reported in spice mineral profiling studies, where zinc levels vary significantly with environmental conditions and fertilization practices (Jabborova *et al.,* 2021).

Phosphorus (P)

Phosphorus content also followed a similar trend, with UMUGIN 2 (240 mg/100 g) showing higher levels than UMUGIN 1 (210 mg/100 g). Phosphorus is a critical component of ATP, nucleic acids, and phospholipids, and plays a central role in energy metabolism. Its concentration in plant tissues is strongly influenced by soil phosphorus availability and fertilizer application, as well as plant uptake efficiency (Marschner, 2012). In ginger, phosphorus levels have been reported to vary significantly across cultivars and growing conditions, reinforcing the role of environmental factors in mineral composition (Jabborova *et al*., 2021).

Magnesium (Mg)

Magnesium levels were higher in UMUGIN 2 (150 mg/100 g) compared to UMUGIN 1 (120 mg/100 g). Magnesium is a cofactor in over 300 enzymatic reactions involved in energy metabolism, protein synthesis, and neuromuscular function (Rosanoff *et al.,* 2012). The observed levels are consistent with reported magnesium concentrations in ginger and other medicinal spices, where magnesium is typically present as a secondary macro-element after potassium and calcium. Variation in magnesium content has been attributed to soil type, nutrient availability, and genetic differences among cultivars (Singh *et al*., 2014).

Table 2. Mineral Composition of Ginger Roots

Sample	Ca (mg/100g)	Na (mg/100g)	K (mg/100g)	Fe (mg/100g)	Zn (mg/100g)	P (mg/100g)	Mg (mg/100g)
UMUGIN 1	320 ± 12.00^{a}	45.00 ± 2.00^{a}	1800 ± 60.0^{a}	11.51 ± 0.40^{a}	2.8 ± 0.10^{a}	210 ± 8.00^{a}	120 ± 53^{a}
UMUGIN 2	360 ± 16.20^{b}	52 ± 3.00^{b}	1950 ± 70.00^{b}	13.2 ± 05^{b}	3.6 ± 0.20^{b}	240 ± 9.00^{b}	150 ± 60^{b}
LSD	**30.50**	**6.20**	**141.00**	**1.05**	**0.45**	**19.61**	**12.70**

Ca *= calcium;* ***Na*** *= sodium;* ***K*** *= potassium;* ***Fe*** *= iron;* ***Zn*** *= zinc;* ***P*** *= phosphorus;* ***Mg*** *= magnesium. Values are mean ± standard deviation of triplicate determinations (n = 3). Data were analyzed using one-way analysis of variance (ANOVA), and mean separation was performed using the Least Significant Difference (LSD) test. Values within the same column with different superscript letters (a–b) differ significantly at* $p < 0.05$

3.1.3 Vitamin content in ginger roots

Table 3 compares the vitamin content of the two new ginger varieties, UMUGIN 1 and UMUGIN 2, focusing on vitamins A, C, and E. UMUGIN 1 had significantly higher vitamin A content (12.41 µg/g) than UMUGIN 2 (8.68 µg/g) ($p < 0.05$), suggesting a greater potential contribution to vision and immune function (Tanumihardjo *et al*., 2016). Similarly, UMUGIN 1 exhibited significantly higher vitamin C content (14.41 µg/g) compared to UMUGIN 2 (9.68 µg/g). Vitamin C is a well-known antioxidant that contributes to immune support and protection against oxidative stress associated with chronic diseases such as cardiovascular diseases and cancer (Carr and Maggini, 2017). In addition, UMUGIN 1 showed higher vitamin E content (3.61 µg/g) than UMUGIN 2 (2.87 µg/g). Vitamin E plays an important role in protecting cellular membranes against lipid oxidation and oxidative damage due to its antioxidant properties (Traber and Stevens, 2011).

3.2 Amylose and Amylopectin content

The functional behavior of starch is strongly influenced by the relative proportions of amylose and amylopectin. In this study, UMUGIN 1 exhibited higher amylose content (26.10 %) compared to UMUGIN 2 (18.89 %) (**Table 4**). Higher amylose content is generally associated with increased gel firmness and a greater tendency for retrogradation, which may be advantageous in products requiring structural stability. In contrast, the higher amylopectin content observed in UMUGIN 2 (81.89 %) is associated with enhanced swelling and viscosity, making it potentially suitable for applications such as sauces and instant food systems. This mix affects texture, processing, and digestibility. Amylose helps make gels firm and can cause retrogradation, which is useful in products that need structure, while amylopectin, with its branched shape, boosts viscosity and gelatinization - perfect for sauces, thickeners, and instant foods (Jane *et al*., 1999).

3.3 Glycemic Index (GI) and Its Implications

Glycemic index (GI) shows how quickly foods with carbohydrates raise blood sugar after eating. UMUGIN 1 has a glycemic Index of 36.42, a bit higher than UMUGIN 2 at 33.90, meaning it releases glucose slightly faster. Both are still considered low glycemic index foods. Low glycemic index starches are usually better for managing blood sugar, especially for people with diabetes, because they provide a slower energy release and help prevent spikes in blood glucose after meals (Englyst *et al*., 1992).

Table 3. Vitamin Content of the Ginger Roots (µg/g)

Sample	A (Vitamin A) (µg/g)	C (Vitamin C) (µg/g)	E (Vitamin E) (µg/g)
UMUGIN1	12.41 ± 2.54^b	14.41 ± 1.90^b	3.61 ± 0.62^b
UMUGIN2	8.68 ± 1.78^a	9.68 ± 1.28^a	2.87 ± 0.49^a

Values are expressed as mean ± standard deviation (n = 3). Data were analyzed using one-way ANOVA, and mean separation was performed using LSD post-hoc test at p < 0.05. Different superscript letters within the same column indicate significant differences (p < 0.05).

Table 4: Physicochemical and Glycemic characteristics of starches from UMUGIN ginger varieties

Sample	Starch content (%)	Starch Yield (%)	Oleoresin (%)	Amylose (%)	Amylopectin (%)	GI (%)
UMUGIN1	13.66 ± 3.39^b	28.65 ± 4.72^b	10.32 ± 0.93^b	26.10 ± 6.53^b	73.89 ± 11.82^a	36.42 ± 6.19^b
UMUGIN2	8.83 ± 2.19^a	21.50 ± 3.54^a	8.83 ± 0.80^a	18.89 ± 4.72^a	81.89 ± 13.10^b	33.90 ± 5.76^a
LSD	**10.0**	**14.7**	**3.1**	**20.0**	**43.8**	**21.0**

GI *= Glycemic Index, Values are mean ± standard deviation of triplicate determinations (n = 3). Data were analyzed using one-way analysis of variance (ANOVA), and mean separation was performed using the Least Significant Difference (LSD) test. Values within the same column with different superscript letters (a–b) differ significantly at p < 0.05.*

3.4 Pasting properties of starch samples

Table 5 presents the pasting properties of starches extracted from UMUGIN 1 and UMUGIN 2 ginger varieties. Peak viscosity, which reflects the maximum swelling of starch granules during heating under shear, was slightly higher in UMUGIN 1 (3553 RVU) than in UMUGIN 2 (3478 RVU). This suggests that UMUGIN 1 starch exhibits a marginally greater swelling capacity, which may be associated with differences in granule structure and composition. Trough viscosity, representing the minimum viscosity during the holding phase at high temperature, was higher in UMUGIN 1 (2631 RVU) compared to UMUGIN 2 (2534 RVU). This indicates that UMUGIN 1 starch maintained a slightly higher viscosity under continued heating and mechanical shear, suggesting comparatively improved resistance to thermal and shear breakdown. This behavior is further reflected in the breakdown viscosity values, where UMUGIN 2 (944 RVU) showed a slightly greater reduction in viscosity from peak to trough than UMUGIN 1 (922 RVU), indicating that UMUGIN 2 starch is marginally less stable under heat and shear conditions.

Final viscosity, which reflects the ability of starch to form a viscous paste after cooling and re-association of starch molecules, was slightly higher in UMUGIN 1 (3625 RVU) than in UMUGIN 2 (3539 RVU). This suggests that UMUGIN 1 may form a somewhat firmer paste upon cooling. In contrast, setback viscosity, which is associated with the retrogradation tendency of starch during cooling, was higher in UMUGIN 2 (1005 RVU) than in UMUGIN 1 (994 RVU), indicating a slightly greater tendency of UMUGIN 2 starch to reassociate and form gel structures after cooling.

Regarding pasting behavior, UMUGIN 1 exhibited a longer peak time (5.8 min) compared to UMUGIN 2 (5.4 min), suggesting a slower attainment of maximum viscosity during heating. Similarly, UMUGIN 1 recorded a slightly higher pasting temperature (71.9 °C) than UMUGIN 2 (71.1 °C), indicating that UMUGIN 1 starch requires marginally more thermal energy to initiate gelatinization. Overall, both starches exhibited typical pasting profiles characteristic of root and tuber starches, with subtle differences likely attributable to variations in granule morphology, amylose–amylopectin ratio, and internal molecular organization between the two ginger varieties.

Table 5. Pasting properties of ginger starch (UMUGIN1 and UMUGIN2)

Sample	Peak Viscosity (RVU)	Trough Viscosity (RVU)	Breakdown Viscosity (RVU)	Final Viscosity (RVU)	Setback Viscosity (RVU)	Peak Time (min)	PT (°C)
Umugin1	3553	2631	922	3625	994	5.8	71.9
Umugin2	3478	2534	944	3539	905	5.4	71.1

Values are presented descriptively. Each RVA parameter was measured from a single scan per sample; no replicates were performed, and therefore no standard deviation or statistical comparisons are reported.

3.5 Starch granule microstructure

The microstructural characteristics of starch granules from UMUGIN 1 and UMUGIN 2 ginger varieties, as observed under light microscopy **(Figures 4 and 5**), revealed noticeable differences in granule morphology and size distribution. UMUGIN 1 starch granules appeared relatively larger and more irregular in shape, exhibiting predominantly polyhedral to oval morphology. In contrast, UMUGIN 2 starch granules were comparatively smaller, more uniform, and showed a more consistent shape distribution. Quantitative measurements indicated that UMUGIN 1 starch granules exhibited average dimensions of 24.4 ± 8.7 µm in length and 21.1 ± 7.0 µm in width, whereas UMUGIN 2 granules measured 18.6 ± 5.4 µm in length and 15.9 ± 4.8 µm in width. These observations are consistent with previous reports indicating that starch granule size and morphology vary among cultivars and are influenced by both genetic and environmental factors (Hoover, 2001; Jane *et al.,* 1994). Differences in granule size and morphology are known to influence functional properties such as gelatinization temperature, pasting behavior, and swelling capacity. Larger and more irregular granules may exhibit slightly higher water absorption and swelling tendencies, contributing to increased peak viscosity during heating, whereas smaller and more uniform granules tend to display more stable and predictable thermal transitions (Srichuwong and Jane, 2007; Kim *et al*., 2012). The observed variations in granule morphology between UMUGIN 1 and UMUGIN 2 may therefore partly explain the subtle differences observed in their physicochemical and pasting properties.

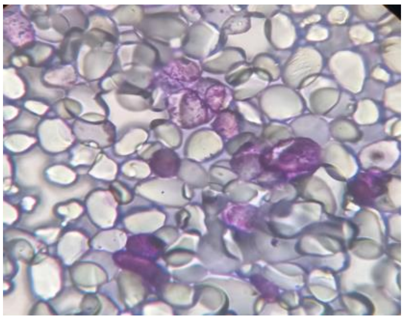

***Fig.** 4. Light microscopy image of UMUGIN 1 starch granules at approximately 400× magnification, showing predominantly polyhedral to oval granules with average dimensions of 24.4 ± 8.7 µm (length) and 21.1 ± 7.0 µm (width).*

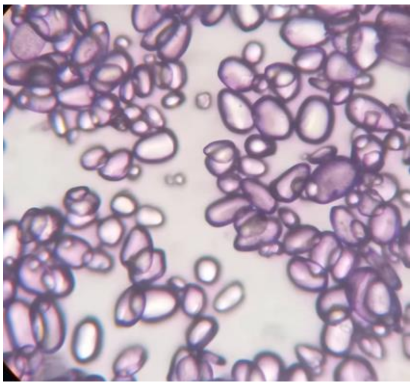

***Fig. 5**. Light microscopy image of UMUGIN 2 starch granules at approximately 400× magnification, showing relatively smaller and more uniform granules with average dimensions of 18.6 ± 5.4 µm (length) and 15.9 ± 4.8 µm (width).*

CONCLUSION

This study provides a comparative evaluation of the physicochemical, nutritional, functional, and starch characteristics of two improved ginger varieties (UMUGIN 1 and UMUGIN 2). The results demonstrate that both varieties possess valuable compositional and functional attributes, although with distinct differences in their quality profiles. UMUGIN 1 showed relatively higher starch yield, amylose content, viscosity-related parameters, and oleoresin content, which may suggest stronger potential in applications requiring thickening, gel formation, and flavor enhancement. In contrast, UMUGIN 2 exhibited higher levels of several nutrients, including protein, crude fiber, carbohydrates, minerals (Ca, K, Fe, Zn, P, Mg), and amylopectin content, indicating a comparatively richer nutritional profile and potentially better suitability for functional food formulations.

Both varieties exhibited low glycemic index values, suggesting that their starches may be suitable for applications where slower glucose release is desirable. However, observed differences in pasting behavior, microstructure, and composition should be interpreted with caution, particularly given the limited quantitative granule size data and the inherent variability associated with biological materials and processing conditions.

Overall, the findings suggest that UMUGIN 1 and UMUGIN 2 have complementary attributes rather than one being universally superior. Further studies involving expanded replication, complete microstructural quantification, and application-based performance testing are recommended to better validate their suitability in specific food and industrial systems.

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CONFLICT OF INTEREST

The authors confirm that they have no conflicts of interest to disclose regarding the publication of this manuscript.

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