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Effect of Drying Temperature on Cyanogenic Glucoside Content and Physicochemical Properties of Hanatee Cassava Flour Compared with Commercial Cassava Flour

Supichaya Khumkhom[a], Arpathsara Sangnark[b], Pasajee Kongsil[a] & Nongnuch Siriwong[a]*

[a] *Faculty of Agriculture, Kasetsart University, Bangkok, 10900 Thailand*
[b] *Faculty of Home Economics Technology, Rajamangala University of Technology Krungthep, Bangkok, 10120 Thailand*

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Abstract

The impact of drying temperature on the cyanogenic glucoside content and physicochemical properties of Hanatee (HNT) cassava (*Manihot esculenta* Crantz) flour was compared with that of commercially available cassava flour (CCF). This investigation focused on flour derived from the HNT variety subjected to drying temperatures of 50, 60 and 70°C. A comprehensive analysis of both HNT and CCF flours were conducted to assess their proximate compositions, cyanide concentrations, colorimetric properties, water absorption index, swelling power, solubility, pasting characteristics and thermal properties. Moisture, carbohydrate, protein, lipid, ash, crude fiber and amylose contents of HNT cassava flour ranged at 4.63-10.54, 95.08-98.68, 1.14-1.54, 0.03-0.28, 0.11-3.22, 2.55-4.34 and 13.86-15.96%, respectively. While cassava cyanide contents ranged from 59.41-63.01 and 0.72-1.93 mg HCN/kg for roots and flours, respectively. Drying reduced hydrogen cyanide (HCN) concentration from 96.67% to 98.17%. Fresh cassava roots of the Hanatee variety processed into flour and dried at 50, 60 and 70°C showed reduced cyanide content within the international standard of 10 mg HCN/kg. The whiteness index of commercial cassava flour (39.72–41.98) was higher than HNT flour dried at different temperatures (32.40-39.72). Degrees of lightness (L*) ranged between 88.36 and 90.60, yellowness (b*) 7.92-11.84 and redness (a*) 0.74-1.46. The water absorption index, swelling power and solubility of HNT flour samples increased at higher drying temperatures. By contrast, the CCF samples demonstrated the highest values across these parameters. Flour pasting behavior was examined using a Rapid Visco Analyzer (RVA). Peak viscosity values of different cassava flours ranged from 144.06 to 271.41 RVU, with the CCF2 sample registering the highest value and the HNT50 sample giving the lowest. All cassava flour samples displayed higher paste viscosities than their respective pasting temperatures, which ranged from 70.68 to 77.14°C. Variations in thermal properties were influenced by protein retention. The HNT70 flours exhibited the highest peak viscosity, final viscosity and

* Corresponding Author
e-mail: nongnuch.si@ku.th

pasting temperature, while also demonstrating a lower tendency for retrogradation compared with HNT50 flours. Results showed that good quality HNT flour was produced after drying at 60°C. The information gained from this study can be used to increase the industrial potentials of flour from cassava roots.

Introduction

Cassava (*Manihot esculenta* Crantz) is an economic crop providing a source of carbohydrates second only to certain grain crops and yielding up to 20% higher carbohydrate production than rice and maize (Jensen et al., 2015; Lu et al., 2019). In 2023, Thailand's cassava production volume was approximately 30.61 million metric tons. Cassava, a critical economic agricultural commodity, is cultivated in 48 of the country's 76 provinces (Statista, 2024). Cassava is consumed in various forms across different regions of the world and is also a crucial source of raw materials in various industries, including starch, starch derivatives and bioethanol production (Pornpraipech et al., 2017; Agbemafle, 2019). The cassava root contains a high starch content at 38% (Montagnac et al., 2009; Jensen et al., 2015), along with protein, fat, dietary fiber and various minerals (Montagnac et al., 2009; Lu et al., 2019). Cassava cultivated in Thailand is divided into two types: bitter cassava, such as Huay Bong 80 (HB80) and Kasetsart 50 (KU50), which contains higher levels of hydrocyanic acid and sweet cassava, such as Hanatee, which has lower levels of hydrogen cyanide (HCN). Specifically, sweet cassava contains 70.6 mg/kg HCN, while the bitter varieties KU50 and HB80 contain 199.3 mg/kg and 204.6 mg/kg HCN, respectively (The Secretary-General of the OECD, 2016; Chaisenga et al., 2019b). Chronic ingestion of cyanogenic glycosides, leading to elevated cyanide levels, has been implicated in the etiology of various diseases, including iodine deficiency disorder, tropical ataxic neuropathy and konzo. However, World Health Organization (WHO) has deemed the safe level for cyanide in cassava flour at 10 ppm or 10 mg HCN kg^{-1} (FAO/WHO, 1991; Cardoso et al., 2005). The chemical components found in Hanatee cassava flour (per 100 g of dry weight) comprises of protein (0.94), fat (0.34), dietary fiber (2.18) and starch (82.41) (Charoenkul et al., 2011).

The Hanatee cassava (HNT) variety, when consumed, has a non-bitter taste and is marketed in both soft and grainy textures. Cassava flour is processed into various products for consumption, but no analysis has been previously conducted on the cyanogenic glucoside content in cassava. Cyanogenic glucosides can be transformed and released as cyanides, that accumulate in HNT cassava. Heating cassava through cooking methods such as boiling and roasting may help to reduce the cyanogenic glucoside content. Therefore, finding an effective method to eliminate or reduce cyanides in cassava flour is an important and interesting topic. Thaweewong et al., (2023) conducted a study on the effect of drying temperatures on the concentration of free cyanide in cassava flour. Their findings indicated that during the initial forty minutes of drying at varying temperatures (60, 70 and 80°C), the free cyanide concentration increased markedly before subsequently decreasing. Extended drying for 4 h resulted in a reduction of HCN levels by 53.6-78.5% from the initial concentration. Atlaw (2018) conducted a comparative analysis of different drying methods to reduce cyanide levels in cassava tubers. Among the analyzed samples, the highest cyanide concentration was found in tray-dried cassava. The reduction rates of cyanide were 34.9% with oven drying and 93.14% with sun drying, compared to tray drying. The efficiency of reducing cyanides in cassava flour depends on the processing and drying methods used. Cassava flour contains high proportions of carbohydrate (83.48–86.10%), protein (0.73–1.15%), fat (0.49-0.64%), dietary fiber (1.83-2.71%), ash (2.13-3.58%) and moisture (5.95-11.18%) (Agbemafle, 2019). The physicochemical properties of cassava starch significantly contribute to the texture and sensory attributes of cassava-based food products. Environmental factors, such as growth temperature, rainfall and altitude, have a substantial impact on starch production and its properties. According to Santisopasri et al. (2001), cassava crops subjected to initial water stress for the first six months exhibited significantly higher peak viscosity and swelling power of their starch, along with a notably lower pasting temperature during gelatinization. Additionally, Zhang et al. (2020) suggested that it is possible to predict the quality and pasting properties of cassava flour based on the environmental conditions at various stages of cassava growth. Their study provided a deeper understanding of the relationship between the pasting properties of cassava flour and its mediating factors, such as proximate composition contents and characteristics. Ginting and Widodo (2013) found that heating at 70°C resulted in a decrease in the cyanide content from 85 to 50 mg/kg. However, the effect of drying temperature on the change in cyanide content in cassava pulp has not been studied. Cassava flour production begins with peeling because the cassava root has a layer of outer skin called the cortex. This cortex layer contains the highest levels of cyanogenic glucoside compounds at 60–70% of the total cyanogenic glucoside content in the cassava root. By contrast, fresh cassava root comprises parenchyma tissue, where 30-40% of the total cyanogenic glucoside content accumulates. Cyanogenic compounds are found in the skin rather than in the parenchymal tissue (Ndam et al., 2019). Reducing the size of the root is a crucial step in decreasing the amount of cyanogenic compounds, which accumulate mainly in the parenchymal tissue and can be easily released (Bradbury & Denton, 2010). The process of grating cassava into fine pieces destroys the tissue and leads to the release of the enzyme linamarase, which subsequently breaks down cyanogenic glucoside compounds into products such as acetone cyanohydrins and glucose. Acetone cyanohydrins naturally decompose to produce hydrogen cyanide, which can be eliminated through heat treatment or dissolution in water (Chiwona-Karltun et al., 2015).

Finding methods to reduce the size of fresh cassava root can significantly enhance the efficiency of reducing cyanogenic compound levels in cassava flour. Drying is a crucial factor in the cassava flour production process and drying temperature and time are aspects that need to be studied to gain knowledge on improving the efficiency of reducing cyanogenic compound levels in cassava flour. This study investigated how different drying temperatures impacted the cyanogenic glucoside content and physicochemical characteristics of Hanatee cassava flour and then compared them with commercially available cassava flour. The Hanatee cassava variety was prepared using a grater scrape method and drying temperatures at 50, 60 and 70°C was investigated. The impact of processing methods on physicochemical properties and the number of cyanogenic compounds were also examined and compared with commercial cassava flour, as essential attributes for food safety.

Materials and methods

1. Sample preparation of Hanatee cassava flour (HNT) and commercial cassava flour (CCF)

Commercial cassava flour (CCF) as an example of industrially utilized flour are available on the market and Hanatee cassava roots grown in Pathum Thani Province, Thailand were used in these experiments. The cassava roots were cleaned to remove soil and debris and processed into flour following Chotineeranat et al. (2006) and Chisenga et al. (2019b). The cleaned roots were peeled, manually chopped with a knife into small pieces and washed twice in potable water. The chopped cassava was grated using a motorized grating machine with an inbuilt spiked stainless-steel sheet mounted on a wooden roller before oven-dried at 50, 60 and 70ºC for 7 hr. The dried cassava was then milled by a hammer mill and sifted through a 180 µM aperture sieve using a sieving machine. The cassava flour was packed in polyethylene bags and stored at room temperature (27±2°C) until analysis.

2. Determination of physicochemical properties of Hanatee casava flour and commercial casava flour

2.1 Proximate analysis

The chemical compositions of moisture, protein, ash, fat and crude fiber were analyzed following the method of the Association of Official Analytical Chemists (2005). Carbohydrate content was obtained by deduction after estimating all the other components by proximate analysis.

2.2 Amylose content determination

Amylose content was determined using the methods of Takeda and Hizukuri (1987) and Gibson et al. (1997) by an amperometric titration using potassium iodate solution.

2.3 Cyanide content determination

Cyanide content was measured according to the method of O'Brien et al. (1991). The sample extraction solution was prepared by mixing three parts of 0.1 M phosphoric acid and one part of absolute ethanol and adjusting to pH 5.0 using 0.1 M sodium hydroxide solution. The sample was crushed using a stone mortar and sieved through a 100-mesh sifter. The sample (0.3g) was then weighed and placed in a centrifugal tube, with 1.0 mL of extraction solution (V). The tube was incubated in a shaking water bath at 50°C for 60 min before centrifuging at 9000 g at 4ºC for 15 min. Incubation at 50ºC for 60 min is necessary for the endogenous enzyme to convert cyanogenic glycosides into free HCN. The supernatant (V_s = 0.1 mL) was pipetted into a test tube, mixed with 3.9 mL of pH 4.0 buffer solution and vortexed. The mixture was then added with 0.2 mL of 0.5% chloramine-T solution and refrigerated at 4ºC for 5 min. After that, 0.8 mL of pyridine/pyrazolone solution was added and mixed well to yield the final assay volume of 5 mL. The mixture was left at room temperature for 90 min and the absorbance at 620 nm (A_{620}) of the mixture was measured by a spectrophotometer. The cyanide content ([HCN]) in mg/kg of sample was calculated as:

$$[HCN] = \frac{\mathrm{V} \times \mathrm{A}_{620}}{V_s \times \mathrm{W} \times \mathrm{A}_{620,\ \text{standard}}}$$

where the $A_{620,\ \text{standard}}$ is the absorbance at 620 nm of the standard solution containing 1 µg of HCN in a final assay volume of 5 mL.

2.4 Color analysis

The color of the flours HNT and CCF was measured using a HunterLab ColorFlex instrument (Hunter Associates Laboratories Inc., Reston, VA, USA), with results reported as L* (lightness), a* (redness to greenness) and b* (yellowness to blueness). The whiteness Index (WI) was then calculated as:

$$WI = 100 - \sqrt{(100 - \mathrm{L}^{*})^{2} + (\mathrm{a}^{*})^{2} + (\mathrm{b}^{*})^{2}}$$

3. Functional properties of Hanatee cassava flour and commercial cassava flour

The water absorption index (WAI) of different cassava flour type was determined following the method of Cornejo and Rosell (2015) with slight modifications. Briefly, a 1.5 g flour sample was dispersed in 30 mL of distilled water and cooked at 90ºC for 10 min in a water bath. The sample was centrifuged at 3,000 rpm for 10 min. The supernatant was decanted into an evaporating dish to determine its solid content and the sediment was weighed. Swelling power and water solubility were assessed utilizing the method described by Kusumayanti et al. (2015). For the determination of swelling power, a 0.1 g flour sample was combined with 10 mL of distilled water and heated at 90°C for 1 h., with continuous agitation. Subsequently, the suspension was rapidly cooled, equilibrated at 25°C and subjected to centrifugation for 30 min at 1,600 rpm using refrigerted centifuge (5810R, Eppendorf, Germany). The resultant sediment was then weighed. In the determination of water solubility, 0.5 g flour sample was heated in 10 mL of distilled water at 60°C in a water bath for 30 min without stirring. Following this, the sample underwent centrifugation at 1600 rpm for 10 min. The supernatant (5 mL) was separated, dried and weighed. The water absorption index, swelling power and water solubility of the flour were calculated as follows:

$$\text{Water absorption index (g/g)} = \frac{\text{Weight of sediment}}{\text{Initial weight of flour sample}}$$

$$\text{Swelling power (g/g)} = \frac{\text{Weight of the sediments}}{\text{Weight of intial flour}}$$

$$\text{Solubility (\%)} = \frac{\text{Dried supernant weight}}{\text{Weight of intial flour}}\text{x100}$$

4. Morphology of starch granules of Hanatee cassava flour and commercial cassava flour

The morphology of the starch granules was examined utilizing a scanning electron microscope (Model JCM-7000, JEOL Co., Ltd., Japan) with a magnification of 1500x at an accelerating voltage of 10 kV.

5. Pasting properties of Hanatee cassava flour and commercial cassava flour

The pasting properties of Hanatee cassava flour and commercial cassava flour (at a concentration of 8 g/100 g dwb) were determined following the method of the American Association of Cereal Chemists (AACC., 1997) using a Rapid-Visco Analyzer (RVA-Super4, Newport Scientific, Pty Ltd., Warriewood, Australia). For sample preparation on a dry weight basis, the flour samples were directly weighed into an aluminum RVA canister. Distilled water was added to achieve a total weight of 28 g and the mixture was homogenized. The sample was maintained at 50ºC for 1 min, subsequently heated to 95ºC at a rate of 12ºC per minute, held at 95ºC for 2.5 min, cooled to 50ºC at a rate of 12ºC/min and finally held at 50ºC for 2.5 min. Throughout the experiment, the paddle's rotational speed was consistently maintained at 160 rpm. Key parameters, including peak viscosity, breakdown (difference between peak viscosity and minimum viscosity), final viscosity and setback (difference between final viscosity and peak viscosity) and pasting temperature were determined.

6. Thermal properties of Hanatee cassava flour and commercial cassava flour

The thermal properties of the starches were determined by a differential scanning calorimeter (DSC 8000, Perkin Elmer, Inc, USA), as described by Charoenkul et al. (2011). A starch sample (about 2 mg flour, dry weight basis) was weighed in a DSC pan and water (about 4 mg) was added. The pan was sealed and allowed to stand for 24 hr at 4ºC. The scanning temperature range and the heating rate were 30-90ºC and 5ºC/min, respectively. Transition temperatures were reported as onset temperature (T_o), peak temperature (T_p) and conclusion temperature (T_c). The enthalpy of gelatinization (ΔH) was estimated by integrating the area between the thermogram and a base line under the peak and expressed in terms of J/g of dry flour.

7. Statistical analysis

The results were expressed as mean±standard deviation (SD) of three replicates and analyzed using the SPSS Statistical Package (Version 25.0, SPSS Inc., Chicago, IL, USA). Differences in means and variance were analyzed at 95% significance using Ducan's multiple range test.

Results and discussion

1. Physicochemical properties of Hanatee cassava flour and commercial cassava flour

A proximate analysis was conducted to identify the key components of cassava flour, including moisture, ash, crude fiber, protein, lipid and total carbohydrate content, as shown in Table 1. The moisture, carbohydrate, protein, lipid, ash and crude fiber contents on a dry basis of both HNT cassava flour and commercial cassava flour (CCF1 and CCF2) ranged from 4.63% to 10.54%, 92.37% to 95.51%, 1.14% to 1.54%, 0.03% to 0.28%, 0.10% to 3.17% and 2.55% to 4.34%, respectively. Protein, lipid, ash and crude fiber contents of the flour samples were present in small quantities compared with carbohydrates, which were the major component. Previous research reported carbohydrates as the bulk of the nutrients in cassava root including starch (Rasaq et al., 2020). The proximate composition data in this study concurred with earlier reports (Charles et al., 2005; Chisenga et al., 2019b; Rasaq et al., 2020). Table 1 presents the proximate composition of HNT cassava flour (HNT50, HNT60 and HNT70) after dehydration at 50, 60 and 70°C, respectively. An increase in the drying temperature from 50 to 70°C, resulted in a significant decrease in moisture, protein and ash content levels ($p < 0.05$), but there were no significant differences in carbohydrate, lipid and crude fiber contents among samples dried at different temperatures. The moisture content of HNT cassava flour significantly decreased from 8.60% to 4.63%, because higher drying temperatures generated more water vapor pressure, thereby facilitating vaporization (Thaweewong et al., 2023). Moisture content is one of the factors that determine the shelf life of cassava flour, with low moisture in most of the flour samples giving a longer shelf life. Low moisture content increases microbial stability and may also contribute to reducing the tendency of staling in baked food products (Ogiehor & Ikenebomeh, 2006).Moisture content of the flour samples were lower than the 10% maximum recommended for dried products, indicating better storage stability (Sanni et al., 2004). Moisture content and the storage period have significant effects on the proximate composition (Ogbonnaya & Hamza, 2015). Ash contents of HNT50, HNT60 and HNT70 cassava flour, significantly ($p < 0.05$) differed with the highest found in HNT50 (3.17%) and the lowest in HNT70 (2.80%). Results indicated the presence of inorganic nutrients in the flour samples as a possible source of mineral elements with nutritional importance. As the drying temperature increased, the ash content decreased. Therefore, HNT50 and 60 may be used for sample drying in subsequent processing. Protein contents of HNT50, HNT60 and HNT70 significantly ($p < 0.05$) differed from each other. The HNT50 sample displayed the highest protein content at 1.54%, with the lowest recorded in the HNT60 sample at 1.14%. Hasmadi et al. (2020) and Peprah et al. (2020) reported protein content of cassava flour ranging from 1 to 3% on a dry basis. The protein content of HNT cassava flour decreased significantly from 1.54% to 1.14% following dehydration, with increasing temperature showing a concurrent decrease in protein content attributed to protein denaturation (Ajala et al., 2014). When comparing HNT and CCF, moisture, carbohydrate, and crude fiber content exhibited higher values in HNT, whereas protein, fat and ash gave lower values (Table 1).

The amylose content of HNT cassava flour and CCF ranged from 13.86% (HNT50) to 15.96% (CCF2). No significant differences were found in the amylose contents of the three HNT cassava flours dried at different temperatures (13.86-14.12%). The amylose contents of both CCF1 and CCF2 were significantly higher than HNT50, HNT60 and HNT70 (Table 1). High amylose content in flour increases the pasting temperature. Amylose plays a crucial compositional and functional role in cassava starch, influencing properties such as crystallinity, gelatinization, retrogradation, gelling and pasting (Ayetigbo et al., 2018). The HNT50, HNT60 and HNT70 flour samples were classified as low amylose (less than 20%). All cassava flour samples conformed to the low amylose (13.86-15.96%) classification (Thumrongchote et al., 2012). These results concurred with Hasmadi et al. (2021) who reported that the amylose content of cassava flour from Tawau at 13.87%. Cassava with low amylose content has relatively high crystallinity due to the reduced amorphous region within the starch granules. High amylose starch

Table 1 Chemical compositions of Hanatee cassava flour (HNT) dried at different temperatures compared with commercial cassava flour (CCF)

Sample	Moisture Content (%WB)	Proximate analysis (% DB)					Amylose content (% DB)	Cyanide (mg HCN/kg. %DB)
		Carbohydrate	Protein	Lipid	Ash	Crude Fiber		
HNT50	8.60 ± 0.09^{c}	92.37 ± 0.45^{cd}	1.54 ± 0.16^{a}	0.15 ± 0.01^{b}	3.17 ± 0.09^{a}	3.10 ± 0.22^{b}	13.86 ± 0.36^{b}	1.93 ± 0.32^{a}
HNT60	8.21 ± 0.10^{d}	92.85 ± 0.03^{c}	1.14 ± 0.08^{b}	0.23 ± 0.09^{ab}	3.01 ± 0.20^{a}	2.55 ± 0.09^{b}	14.12 ± 0.41^{b}	1.01 ± 0.48^{b}
HNT70	4.63 ± 0.04^{e}	92.98 ± 0.48^{c}	1.24 ± 0.04^{b}	0.28 ± 0.05^{a}	2.80 ± 0.09^{b}	2.77 ± 0.34^{b}	13.89 ± 0.20^{b}	0.72 ± 0.17^{b}
CCF1	10.54 ± 0.08^{a}	94.07 ± 0.17^{b}	1.15 ± 0.01^{b}	0.04 ± 0.01^{c}	0.41 ± 0.15^{c}	4.34 ± 0.13^{a}	15.23 ± 0.01^{a}	0.73 ± 0.03^{b}
CCF2	9.82 ± 0.05^{b}	95.51 ± 0.15^{a}	1.16 ± 0.01^{b}	0.03 ± 0.10^{c}	0.10 ± 0.03^{d}	3.09 ± 0.11^{b}	15.96 ± 0.30^{a}	0.97 ± 0.03^{b}

Remarks: Results are averages of three determinations expressed as dry weight ± standard error
Values in the same column followed by different superscripts at $p < 0.05$
HNT50, HNT60 and HNT70 = Hanatee cassava flour dried at 50, 60 and 70°C, respectively for 7 hr
CCF1 = Commercial cassava flour 1, CCF2 = Commercial cassava flour 2

retrogrades easily (Tukomane et al., 2007). Falade and Christopher (2015) reported low-amylose flour generally imparts chewiness, softness and dampness to product textures. These qualities can bΩe applied to make soft cakes, meat products and puddings. On the other hand, high-amylose flour, as proposed by Wang et al. (2016), contributes crispness and firmness to products through the formation of a three-dimensional network and is suitable for use in food products that demand a firm texture, including extruded snacks and noodle products. Understanding the textural differences between low-amylose and high-amylose flours highlights their distinct roles in the culinary landscape.

When fresh cassava roots of the Hanatee variety were processed into flour using the grater scrape method and dried at 50, 60 and 70°C, the steps of size reduction and drying at different temperatures played a crucial role in reducing the cyanide compound content, as shown in Table 1. Cyanide compounds accumulate in the parenchymal tissue of cassava. They are volatile and can easily dissipate when the temperature exceeds 28°C, because cyanide compounds have a boiling point of 25°C (Akande et al., 2017; Chisenga et al., 2019a). Ndam et al. (2019) found that the cyanide peel content of 20 cassava varieties ranged from 98.43 to 210.07 ppm and higher than in fresh cassava root (61.031-81.33 ppm). Flesh cassava roots of the Hanatee variety had total cyanide contents ranging from 59.40 to 63.01 mg HCN/kg. When processed using the grater scrape method and dried at 50, 60 and 70°C, total cyanide content in the resulting HNT flour reduced to 0.72-1.93 mg HCN/kg, representing a reduction of 96.67-98.17% (Table 1). Total cyanide content significantly decreased inversely with drying temperature from 50 to 70°C. Furthermore, the total cyanide contents of HNT flour dried at different temperatures were significantly higher than commercial cassava flours (0.73 mg HCN/kg for CCF1 and 0.97 mg HCN/kg for CCF2). The World Health Organization (WHO) has set the safe level of cyanogen in cassava flour at 10 ppm or 10 mg HCN/kg. However, fresh cassava roots of the Hanatee variety processed to flour using the grater scrape method and dried at 50, 60 and 70°C could reduce the cyanide flour content to the international standard of 10 mg HCN/kg (Codex Alimentarius Commission, 1989) (Table 1).

The color parameters (L* a* b*) and whiteness index (WI) of cassava flour dried at different temperatures exhibited significant differences ($p < 0.05$), as depicted in Table 2. The L* values of HNT cassava flour decreased, while a*, b* and WI values increased with higher drying temperatures from 50 to 70°C. The characteristics of lightness L* values were between 90.17 and 90.60. The HNT50 flour produced higher lightness (L* value) than the HNT60 and HNT70 flours. The average a* value (red-green degree) of flour samples ranged between 0.89 and 0.92. The flour sample derived from HNT60 had the highest redness, while, the three cassava flour samples showed low redness. Redness (a* values) were higher in HNT60 samples than in HNT50 samples. Higher browning in the HNT60 and HNT70 flours may be responsible for this. The main reasons for HNT browning during drying are enzymatic browning of phenolic substances, non-enzymatic browning such as the Maillard reaction and ascorbic acid oxidative browning. Hot air drying (HA) was carried out under high temperatures (60-70°C) and aerobic conditions. Enzymatic browning and non-enzymatic browning occurred simultaneously during HA, turning the sample color red and dark (Li et al., 2019). The b* average (yellow-blue degree) was between 11.19 and 11.84, indicating a slight yellowness of the flours. Yellowness (b* value) was lower in HNT50 flour than in the (HNT60 and HNT70 flours) possibly due to carotenoid loss. The yellow color of cassava is attributed to carotenes (Ayetigbo et al., 2018). Heat treatment caused an increase in beta carotene due to the breakdown of cellular constituents. The higher b* values (yellowness) were attributed to higher amounts of beta carotene. The color values (L* a* b*) and whiteness index of HNT cassava flour were significantly different from the commercial cassava flour ($p < 0.05$), as shown in Table 2. The WI of CCF (39.72-41.98) is higher than that of HNT flour (32.40-37.99) and was attributed to impurities or pigments that remained after the drying process and were not eliminated by water. Chisenga et al. (2019b) reported that the difference in flour color was due to composition such as ash, protein, pigment and starch contents. Furthermore, a decrease in the whiteness index of the flour may result from a browning process like the Maillard reaction, occurring in the presence of reducing sugars and amino acids in the flour. Therefore, the high WI values of cassava flours suggested that they could be used in food production without changing the food color and may improve the acceptance value of a finished product (Chimphepo et al., 2021).

Table 2 Color of Hanatee cassava flour dried at different temperatures compared with commercial cassava flour

Sample	L*	a*	b*	WI
HNT50	90.60 ± 0.01^{a}	0.89 ± 0.01^{b}	11.19 ± 0.03^{c}	32.40 ± 0.19^{c}
HNT60	90.17 ± 0.01^{d}	0.92 ± 0.01^{b}	11.64 ± 0.03^{b}	37.99 ± 0.20^{b}
HNT70	90.27 ± 0.01^{c}	0.90 ± 0.01^{b}	11.84 ± 0.01^{a}	37.87 ± 0.54^{b}
CCF1	88.36 ± 0.03^{e}	1.46 ± 0.02^{a}	8.81 ± 0.01^{d}	39.72 ± 0.43^{ab}
CCF2	90.48 ± 0.02^{b}	0.74 ± 0.02^{c}	7.92 ± 0.06^{e}	41.98 ± 0.81^{a}

Remarks: Results are averages of three determinations expressed as dry weight ± standard error

Values in the same column, followed by different superscripts are significantly different at $p < 0.05$

HNT50, HNT 60 and HNT 70 = Hanatee cassava flour dried at 50, 60 and 70°C, respectively for 7 hr

CCF1 = Commercial cassava flour 1, CCF2 = Commercial cassava flour 2

2. Functional properties of Hanatee cassava flour and commercial cassava flour

The water absorption index (WAI) is a crucial metric used to assess the water absorption capacity of starch and serves as an indicator of starch gelatinization (Qi et al., 2023). Fig. 1A, presents the WAI values of HNT cassava flour after dehydration at 50, 60 and 70°C. A substantial significant increase in WAI levels ($p < 0.05$) was observed as the drying temperature increased from 50 to 70°C. The WAI of HNT flour exhibited a notable increase from 6.87 to 8.23 g/g (Fig. 1). This augmentation in WAI was attributed to the disruption of the ordered structure and rigid granular morphology of starch by the drying process, thereby enhancing the permeation of water molecules into the starch granules compared with their native counterparts. The drying procedure instigated alterations in intra- and intermolecular interactions within the amorphous and crystalline structure, thereby influencing WAI. The application of high heat stress during the drying process resulted in the rupture of hydrogen bonds between the hydroxyl groups in the double helices of cassava starch molecules. These hydroxyl groups were able to establish novel hydrogen bonds with water molecules, thereby increasing WAI (Qi et al., 2023).

Results indicated a significant increase in both swelling power (SP) and solubility (SB) of all HNT cassava flours as the temperature increased from 50°C to 70°C. The SP and SB of HNT cassava flour exhibited a noticeable increase from 4.14 g/g to 5.43 g/g and from 13.24% to 17.01%, respectively (Fig. 1B and 1C). The increase in swelling power at higher temperatures was attributed to starch gelatinization in the flours. HNT displayed lower swelling power and solubility within the ranges of 4.14-5.43 g/g and 13.24-17.01%, respectively, compared with CCF (SP ranging from 7.26 to 7.48 g/g and SB from 22.75% to 48.79%). During starch gelatinization, the disruption of hydrogen bonds between the hydroxyl groups within the double helices of starch molecules facilitates the formation of new bonds with water molecules. This interaction leads to the swelling of starch granules, thereby enhancing the accessibility of the starch molecules. Consequently, this increased accessibility allows starch molecules to leach out from the inner part of the granules, resulting in an elevated solubility of the starch molecules.The solubility results further suggested that CCF had a greater capacity to hold water than HNT flour (Fig. 1). Kayode et al. (2021) reported that the distribution of amylose and amylopectin within starch granules directly affects starch solubility. Amylose tends to concentrate in the central region of starch granules, where it plays a key role in maintaining their structure. Starch granules with high amylose content typically exhibit a denser, more compact structure, which restricts the overflow of starch from the granules and consequently reduces starch solubility. Therefore, starches with lower amylose content may experience increased swelling power and solubility due to their less rigid granular structure. However, the experimental results revealed that CCF1 and CCF2 contained a higher amount of amylose than HNT. Surprisingly, the swelling power (SP) and solubility (SB) of both CCF1 and CCF2 were higher than all HNT flours, as depicted in Table 1. This discrepancy suggested that factors beyond amylose content may influence the swelling power of HNT cassava flour. Previous research indicated that swelling power was influenced not only by the structure and granulation degree of amylose and amylopectin but also by other starch components and other factors. Chisenga et al. (2019a) reported that various flour components such as starch, protein, dietary fiber and minerals, contribute to apparent differences in swelling power and solubility. The high levels of protein and lipid present in HNT flour granules may reduce the ability of water to permeate into the granules, thereby inducing a low level of swelling power (Table 1 and Fig. 1).

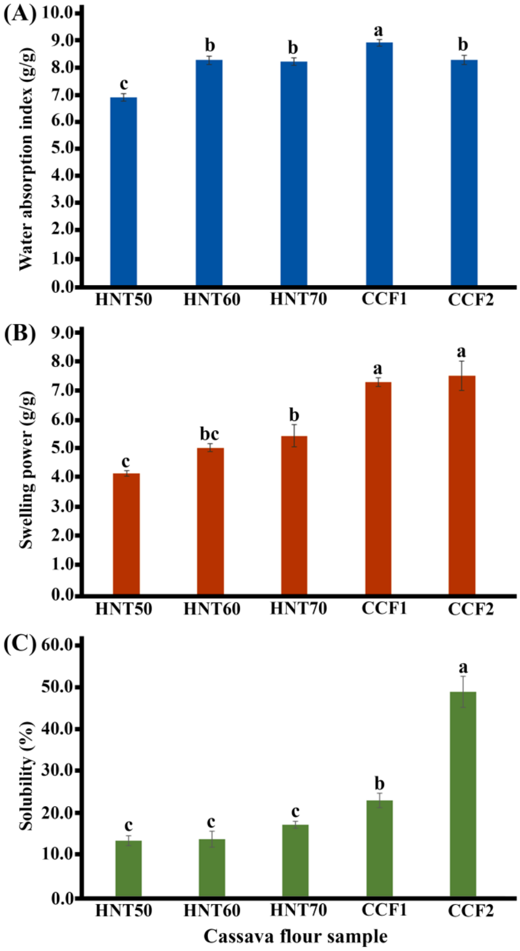

Fig. 1 Effect of drying temperature on the water absorption index (A), swelling power (B) and solubility of cassava flour (C)

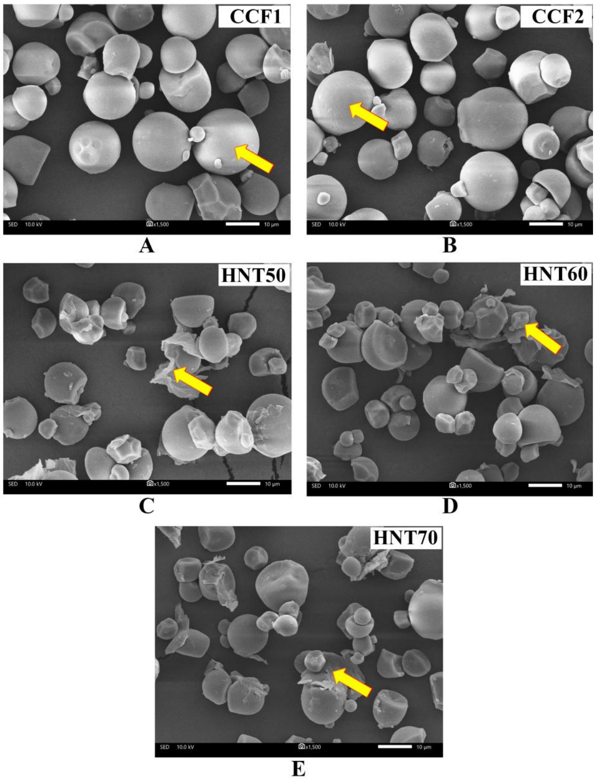

Fig. 2 Scanning electron micrographs (1500×magnification): CCF1 (A), CCF2 (B), HNT50 (C), HNT60 (D) and HNT70 (E).

3. Pasting properties of Hanatee cassava flour and commercial cassava flour

The pasting property assesses the structural and functional features of cassava flour samples, providing a foundation for use in industrial processing. The pasting properties of cassava flours processed under different drying temperatures and commercial cassava flour are shown in Fig. 3. Peak viscosity (PV) reflects the ability of starch to bind water and is often used as an index to evaluate the thickening power. The peak viscosity (PV) values of various HNT flours ranged from 144.06 to 157.67 RVU, with the highest value observed in HNT60 flour and the lowest in HNT50 flour. HNT flour exhibited lower PV values, ranging between 144.06 and 157.67 RVU, while CCF flours displayed higher PV values ranging from 231.38 to 271.41 RVU, suggesting that CCF flour samples had significantly higher peak viscosity values. Peak viscosity represents the maximum viscosity attained during the gelatinization process in food preparation, reflecting the water-binding capacity of starch or a mixture. PV is closely linked to the quality of the final product. Research indicated that a higher peak viscosity contributed to better paste texture, primarily influenced by high viscosity and moderately high gel strength (Ekeledo et al., 2023). As shown in Fig. 3, pasting temperatures of HNT flours were in the range of 76.96–77.14°C, and higher than commercial cassava flours (70.68–72.25°C). Pasting temperature relates to water-binding capacity. A higher pasting temperature implies higher water- binding capacity, higher gelatinization and lower swelling properties of starch due to a high degree of association between the starch granules (Kayode et al., 2021). The experimental results revealed a higher pasting temperature in HNT than in CCF1 and CCF2 (Fig. 3). Intriguingly, the swelling power (SP) of both CCF1 and CCF2 were higher than all HNT flours, as depicted in Fig. 1B. Pasting temperature indicates the minimum cooking temperature required for a specific sample. Alamu et al. (2017) reported that a higher pasting temperature results from a strong association between starch granules and can lead to a higher water-binding capacity and a lower swelling ability of starch. The breakdown viscosity indicates how well the paste can resist shear stress and maintain stability during thermal treatment. A lower breakdown viscosity suggests that the paste is less resilient to interruptions caused by heat and shear, which is crucial for determining paste stability (Aidoo et al., 2022). Fig. 3, shows the breakdown viscosity values of HNT flour after dehydration at 50, 60 and 70°C. A significant increase in breakdown viscosity levels was recorded as the drying temperature increased from 50 to 70°C. The breakdown viscosity values of HNT flour showed a noticeable rise from 54.75 to 72.47 RVU, with the highest value recorded in HNT70 flour and the lowest in HNT50 flour. Hugo et al. (2000) and Bakare et al. (2012) demonstrated that a reduction in breakdown viscosity correlated with an augmentation in paste stability. By contrast, CCF, exhibited higher breakdown viscosity values ranging from 79.33 to 92.13 RVU. Findings suggested that CCF flour samples had higher breakdown viscosity values, implying that HNT flour samples with lower breakdown viscosities could better endure high heat treatment and shear stress, making them more suitable for use in products requiring high temperature treatment. The final viscosity is the change in viscosity after holding cooked starch at 50°C and represents the cooked starch stability (Alamu et al., 2017). Final viscosity values ranged from 120.83 to 270.34 RVU (Fig. 3). The highest final viscosity, 270.34 RVU, was observed in sample CCF2, whereas sample HNT50 exhibited the lowest final viscosity, 120.83 RVU. Final viscosity is a critical parameter for assessing the quality of a sample, as it indicates the material's capacity to form a viscous paste or gel after cooking and cooling processes. This parameter also reflects the resistance of the paste to shear force during stirring. The viscosity measured after cooling to 50°C, known as the setback or the viscosity of the cooked paste, represents the stage at which retrogradation or reordering of starch molecules occurs. The setback viscosity has been correlated with the texture of various products. Moreover, a high setback is associated with syneresis, or weeping, during freeze/thaw cycles. A lower setback was observed for cassava flour dried at different temperatures (HNT50, HNT60 and HNT70) indicating that the flours exhibited a low tendency to undergo retrogradation during freeze/thaw cycles (Ekeledo et al., 2023). Setback values ranged from 31.52 to 78.25 RVU, with CCF2 recording the highest setback (78.25 RVU), while HNT50 exhibited the lowest setback (31.52 RVU). The lower setback viscosity observed in HNT samples was attributed to the presence of non-starch carbohydrates, small saccharides, or soluble fiber, which can impede starch retrogradation (Thaweewong & Anuntagool, 2023). Results implied that HNT samples retrograded more slowly than CCF samples after cooking.

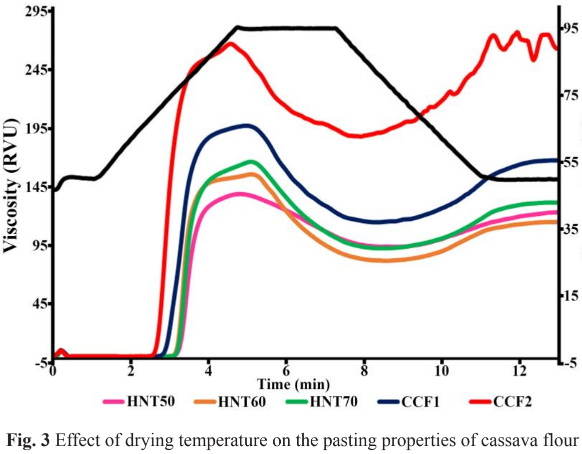

Fig. 3 Effect of drying temperature on the pasting properties of cassava flour

4. Thermal properties of Hanatee cassava flour and commercial cassava flour

The enthalpy (ΔH) and temperatures of gelatinization of cassava flour dried at different temperatures (HNT50, HNT60 and HNT70) and commercial cassava flour (CCF1 and CCF2) were determined by differential scanning calorimetry (DSC), as presented in Table 3. The values of To, Tp, and Tc of HNT60 samples were the highest. The peak temperature (Tp), often referred to as the gelatinization temperature of cassava flour dried at different temperatures ranged from 74.17 to 75.69°C and was higher than the commercial cassava flours (65.30–67.12°C). This result agreed well with the pasting temperatures determined by RVA. The existence of protein increasing the competition of water in dispersion and thus reducing the amount of water available for starch gelatinization has been reported as the main reason for the higher Tp values in the HNT samples (Correia et al., 2012). The enthalpy of gelatinization (ΔH) is the latent heat absorbed by microcrystalline particles. This depends on various factors such as crystallinity, intermolecular interaction and the presence of other chemicals (Zhang et al., 2014). The ΔH of commercial cassava flour samples ranged from 0.91 to 2.12 J/g, whereas ΔH of cassava flour dried at different temperatures was 2.94 to 5.98 J/g. The higher enthalpy of cassava flour dried at different temperatures could be attributed to the higher starch content (82.41 g/100 g dwb) reflected by the higher crystallinity (Charoenkul et al., 2011).

HNT flours have lower peak and breakdown viscosities but higher pasting temperatures, indicating better thermal resistance and stability. They are disposition to retrogradation, making them suitable for products requiring high-temperature processing. The higher gelatinization temperatures and enthalpy values in HNT flours reflect greater stability and crystallinity. This suggests that HNT flours are better suited for applications requiring high thermal stability. These properties make HNT flours ideal for industrial applications where high thermal resistance and stability are crucial such as in baking and other high-temperature food processing operations.

Table 2 Effect of drying temperatures on the thermal properties of cassava flour

Sample	To (°C)	Tp (°C)	Tc (°C)	ΔH (J/g)
HNT50HNT50	71.38±0.21^{b}	74.17±0.06^{c}	80.48±0.03^{c}	3.85±0.01^{b}
HNT60	71.18±0.08^{b}	74.90±0.05^{b}	80.90±0.06^{b}	5.98±0.01^{a}
HNT70	72.60±0.24^{a}	75.69±0.05^{a}	84.30±0.02^{a}	2.94±0.01^{c}
CCF1	64.13±0.03^{c}	67.12±0.03^{d}	72.12±0.02^{d}	0.91±0.01^{e}
CCF2	63.17±0.07^{d}	65.30±0.07^{e}	71.04±0.06^{e}	2.12±0.01^{d}

Remarks: Results are averages of three determinations expressed as dry weight ± standard error

Values in the same column, followed by different superscripts are significantly different at ($p < 0.05$)

HNT50, HNT 60 and HNT 70 = Hanatee cassava flour dried at 50, 60, and 70°C, respectively for 7 hr

CCF1 = Commercial cassava flour 1, CCF2 = Commercial cassava flour 2

Conclusion

The cyanogenic glucoside content and physicochemical properties of Hanatee (HNT) cassava flour, prepared by drying at different temperatures, were evaluated to determine its suitability for various industrial applications. All the parameters examined were impacted by the drying temperature. An increase in drying temperature from 50 to 70°C resulted in a decrease in the values of proximate content (moisture, protein, ash and crude fiber) except for the carbohydrate, lipid and amylose contents. HNT50 retained higher cyanide content than HNT70 samples, while HNT70 flour samples showed higher L*, a*and b* values, whiteness index, water absorption index, swelling power and solubility than HNT50. Both pasting and thermal properties increased at higher drying temperatures. Drying temperatures impacted the pasting properties of HNT flour, with the highest peak viscosity, breakdown viscosity, setback, final viscosity and pasting temperature shown by HNT70 samples and a lower tendency of retrogradation than HNT50 samples. The highest T_p was achieved by HNT70 samples, attributed to higher protein retention. The morphology of HNT starch granules was not significantly affected by different drying temperatures. Good quality flour was produced from HNT cassava root dried at 60°C. This study provides significant insights into the impact of varied drying temperatures on the proximate, functional, pasting, and thermal properties of HNT flours, thereby augmenting their appropriateness for commercial utilization as thickeners or nutraceuticals within the food industry. The investigation into the physicochemical properties of HNT flour elucidates its advantageous chemical functionalities, underscoring its physicochemical properties as a fundamental raw material in the manufacturing of a broad spectrum of food products, including pasta, sauces, soups and dressings.

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