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Compositional Properties of Flours and Starches from the Philippine National Seed and Industry Council-registered Root Crops

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Based in the Visayas State University, Philippines, the germplasm collection of the Philippine Root Crops Research and Training Center (PhilRootcrops) is home to several varieties that have not been fully characterized for their potential use in the production of functional foods. This study evaluated the compositional properties, amylose/amylopectin ratio, and glycemic index of flour and starches of 10 varieties of cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas* L. (Lam)), and taro (*Colocasia esculenta* L. Schott); 8 varieties of yam (*Dioscorea alata* L.); and 5 varieties of arrowroot (*Maranta arundinacea* L.), which was the recommended varieties of the National Seed and Industry Council (NSIC). The total starch as well as the amylose/amylopectin ratio of the starch component was determined using Megazyme assay kits, and the glycemic indices were predicted through enzymatic *in vitro* starch hydrolysis. Results revealed significant ($p < 0.05$) varietal variations on flour and starch yield, dry matter, crude protein, crude fiber, amylose/amylopectin ratio, and glycemic index. Among these crops, sweet potato was found to have the highest amylose contents, while taro and arrowroot showed lower glycemic indices. These profiles can serve as fundamental information for processors to develop new products that capitalize on these unique properties.

Keywords: cassava, sweet potato, yam, taro, arrowroot, amylose, glycemic index

Abbreviations: Cv—cassava, GI—glycemic index, GOPOD—glucose oxidase/peroxidase enzymes, MAP—months after planting, NSIC—National Seed and Industry Council, PhilRootcrops—Philippine Root Crops Research and Training Center, PSB—Philippine Seed Board, SP—sweet potato, VG—VSU-gabi, VU—VSU-ube

INTRODUCTION

Root and tuber crops play a significant role in ensuring food security, good nutrition, and favorable income. With an increase of 24% in production relative to the year 2000, the aggregate global production of cassava, sweet potato, taro, and yam reached around 480 MT in 2019, the highest contribution of which came from cassava with 303 MT, and with 30% of the total production coming from Asian countries such as the Philippines (FAOSTAT 2019).

Root crops are primarily grown for their edible underground parts or tubers that provide energy sources and essential nutrients needed by the body. They rank second important crops next to cereals as a global carbohydrate source and an integral components in many packaged foods and feeds for animal and human consumption, as well as industrial use (Chandrasekara and Kumar 2016). Apart from this, they can also be used to develop functional foods and nutraceutical ingredients to help reduce the risk of human chronic diseases (Magbalot-Fernandez and Umar 2018). Cassava roots contain many bioactive compounds such as noncyanogenic glucosides, terpenoids, and flavonoids (Blagbrough et al. 2010). The presence of phytochemicals in sweet potato storage roots potentially affects antioxidant activity and antiproliferative activity of cancer cells (Huang et al. 2004). Taro is rich in dietary fiber, micronutrients, carotenoids, and phenolic acids converted to vitamin A and showed anti-cancer potential (Temesgen and Retta 2015). Yam contains diverse bioactive compounds with potential nutritional and therapeutic properties (Obidiegwu et al. 2020).

Starch is the primary carbohydrate source in root crops, accounting to 16 – 24 % of their total weight (Hoover 2001). While substantial progress on starch structure, composition, and physiochemical properties has been made over the years, the majority of research focused mainly on cereal starches (Hoover 2001; Topping and Clifton 2001). Related studies reported 2 – 40 µm truncated cassava starch granules with an A-type x-ray pattern (Moorthy 2002; Nuwamanya et al. 2010). Specific desired functional properties limit the utilization of starches as hydration occurs quickly upon heating, resulting in cohesive pastes of poor stability and low tolerance to acidity. The ratio of amylose and amylopectin in a given starch is crucial as it will significantly affect product quality. Through chemical modification, this ratio can be adjusted to fit the requirement of a particular product. Hence, knowledge of this basic parameter is essential for a sound product development strategy.

The germplasm collection of the Philippine Root Crops Research and Training Center (PhilRootcrops) is home to several varieties and lines that have not been fully characterized for their potential use in the production of functional foods. The objective of this work was to evaluate and compare the flours and starches from several registered varieties of root crops in terms of flour and starch yield, dry matter, crude protein, crude fiber, amylose and amylopectin content, and glycemic index. The crops that were evaluated were cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas* L. Lam), taro (*Colocasia esculenta* L. Schott), yam (*Dioscorea alata* L.), and arrowroot (*Maranta arundinacea* L.). The results of this investigation can provide convincing evidence of root crops' desirable properties, and can be an entry point for commercialization. Likewise, this study may encourage root crop farmers to increase the production of varieties with desirable properties, thus improving productivity and increasing farmers' income.

MATERIALS AND METHODS

Source of Raw Materials

All root crop samples presented in Table 1 were identified and obtained from the experimental plots and germplasm collection of PhilRootcrops, Visayas State University, Baybay City, Leyte, Philippines, characterized with a neutral soil. The tubers were collected in August 2015 with 112.4 mm rainfall and 102.1, 120.1, 95.2, and 87.5 mm rainfall in the subsequent 5 mo. The average rainfall of that year was recorded at 110.0 mm at an elevation of 7 m asl. Tuber samples were collected each month from 8 – 12 mo after planting (MAP) for cassava and arrowroot, 8 MAP for yam and taro, and 3 – 4 MAP for sweet potato with a uniform interval. Tubers were harvested at different periods based on their maturity (Vimala and Hariprakash 2011; Nzola et al. 2021). Collected tubers were placed in labeled net bags and were immediately

Table 1. List of root crop varieties used in this study.

Sample No.	Cassava *Manihot eculenta* Crantz Variety Name	Flesh Color	Sweet potato *Ipomoea batatas* (L.) Lam		Yam *Dioscorea alata* L. Variety Name	Flesh Color	Taro *Colocasia eculenta* (L.) Schott Variety Name	Flesh Color	Arrowroot *Maranta arundinacea* L.	
1	NSIC Cv-37 Sultan 9	white	PSB-SP 21	light yellow	VU-1	white with purplish tinge	VG-1 Kalpao	creamy yellow	MA-1	white
2	NSIC Cv-38 LSU-Cv 20	white	PSB-SP 22	yellow	VU-2	purple	VG-2 Iniito	light purple	MA-2	white
3	NSIC Cv-39 Rajah 3	yellow	PSB-SP 23	yellow	VU-3	white	PSB G-4	white	MA-3	white
4	NSIC Cv-40 Sultan 10	cream	PSB-SP 24	yellow	VU-4	white	PSB G-5	white	MA-4	white
5	NSIC Cv-41 Sultan 11	yellow	PSB-SP 25	purple	VU-5	off-white	NSIC G-6	light pink	MA-5	white
6	NSIC Cv-42 Rajah 4	white	PSB-SP 26	wwhite	VU-6	white	NSIC G-9	white		
7	NSIC Cv-43 LSU Cv 21	white	PSB-SP 27	yellow	VU-7	purple	NSIC G-10	white		
8	NSIC Cv-44 LSU Cv 22	cream	PSB-SP 28	white	VU-8	purple	Kahislot	white		
9	NSIC Cv-45 LSU-Cv 23	yellow	PSB-SP 29	creamy white			BLSM 151	white		
10	NSIC Cv-46 Sultan 12	yellow	PSB-SP 30	yellow orange			BLSM 132	white		

NSIC- National Seed and Industry Council, Cv- Cassava, LSU- Leyte State University

PSB-Philippine Seed Board, V- Visayas State University, G-Gabi, MA-*Maranta arundinacea, U-Ube.*

transported in the laboratory for processing into flours and starches on the same day. A maximum of 48 h of initial storage at room temperature was allowed, and any form of vascular streaking for cassava was monitored. Analytical grade reagents, chemicals, and enzymes were purchased from Sigma Aldrich Corp. (St. Louis, MO, USA). The Megazyme total starch and amylose/amylopectin assay kit was purchased from Megazyme (Wicklow, Ireland).

Processing of Flour and Extraction of Starch

Fresh roots were manually peeled, washed with water, and cut into thin slices of 0.2 cm thickness. For each root crop variety and for each time duration of sample collection as indicated, approximately 500 g of the slices were loaded into trays and replicated thrice, then dried in a convection oven at 40°C for 24 – 48 h or until a constant dry weight (< 1% change in 24 h) was reached. Overall, sample trays of a total of 150 cassava, 60 sweet potato, 30 taro, 24 yam, and 75 arrowroot were processed. The dried chips were milled into flour using a mechanical Osterizer blender and sieved through a 120 μm mesh. The resulting flours were weighed for yield determination and packed in transparent airtight polyethylene bags, which were then stored in a freezer (-4°C) until the conduct of proximate analysis (AOAC 2000). Starch extraction was done following the methods for native cassava starch extraction (Benesi et al. 2005). Extracted starches were properly stored in airtight containers for analyses. The yield of flour and starch expressed as a percentage of dry weight of the sample for each of the crops was presented in Fig. 1 and 2. The crude protein and fiber were determined following the standard plant nutrient analysis methods of Motsara and Roy (2008). All analyses were done in triplicates.

Amylose Content

The Megazyme assay kits were used to determine the total starch and amylose/amylopectin contents of the starches. The amylose/amylopectin assay kit was based on selective quantitative precipitation of amylopectin using concanavalin A (Con A), a quantitative estimation of amylose upon hydrolysis using amylase/amyloglucosidase, and quantification of glucose using glucose oxidase/peroxidase reagent. The assay was calibrated on standardized regular maize starch. Starch

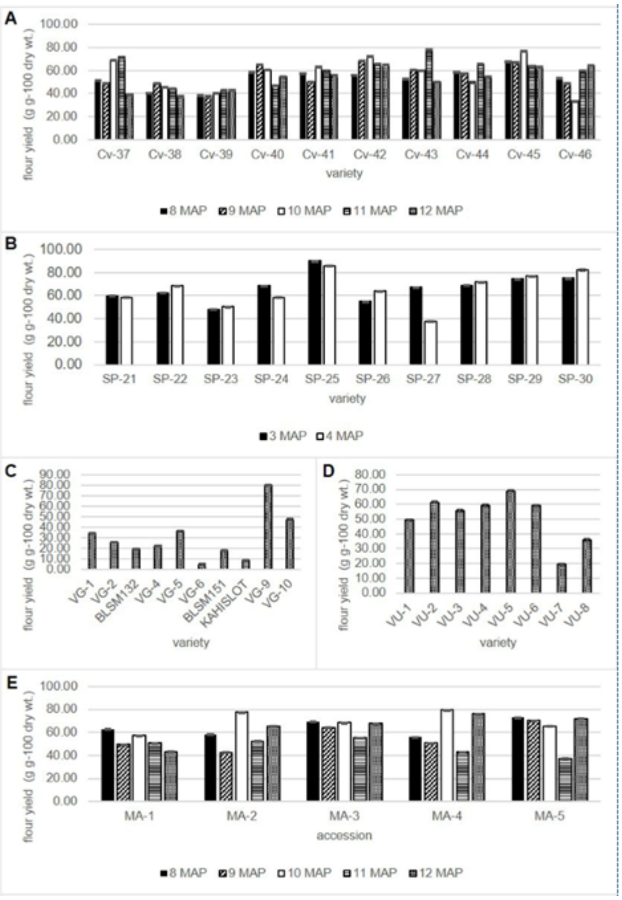

Fig. 1. Flour yield (g g^{-100} dry wt.) of cassava (A), sweet potato (B), taro (C), yam (D), and arrowroot (E).

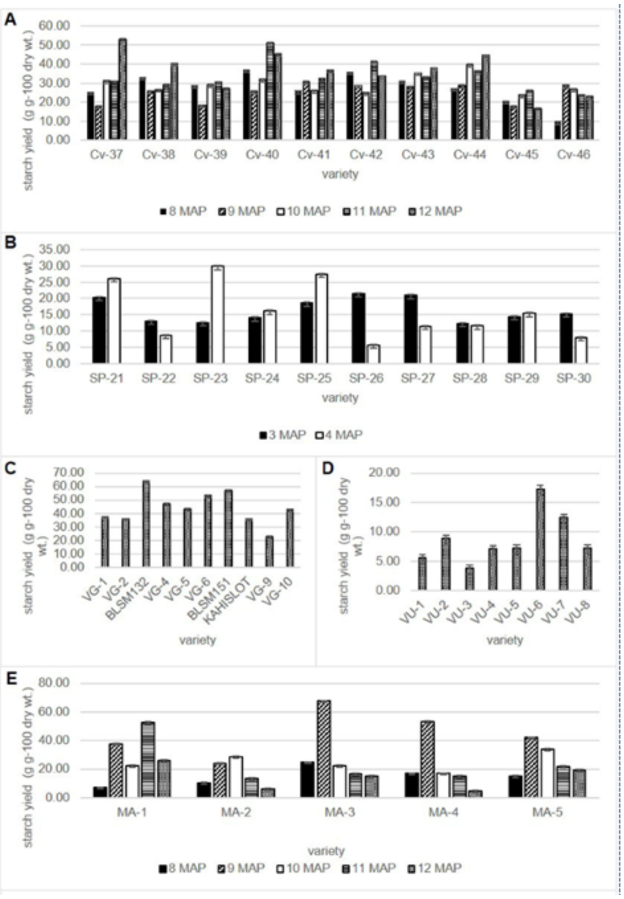

Fig. 2. Starch yield (g g^{-100} dry wt.) of cassava (A), sweet potato (B), taro (C), yam (D), and arrowroot (E).

pretreatment (25 mg) as described in the kit was first performed before (1) Con A precipitation of amylopectin and determination of amylose, and (2) determination of total starch.

Con A Precipitation of Amylopectin and Determination of Amylose

The obtained pretreated starch was reconstituted with dimethyl sulfoxide (DMSO) while gently stirring at low speed on the vortex. The sample was placed on a boiling water bath for 15 min with occasional mixing. Immediately, 4 mL of Con A solvent was added to the sample mixture upon removing the tube from the bath. The mixture was mixed thoroughly, transferred to 25 mL volumetric flasks, and was diluted to volume with Con A solvent. The resulting mixture was labeled as solution A, where an aliquot of 1 mL was transferred into a 2 mL microcentrifuge tube, and the remaining was set aside for part three of the assay. Con A solution (0.50 mL) was added to the tube and was gently mixed by repeated inversion to avoid frothing. The tube was allowed to stand for 1 h at room temperature (25 – 28°C), of which part three of the assay was performed simultaneously. After the incubation, the sample solution was centrifuged at 14,000 rpm (Beckman Coulter microfuge, USA) at room temperature (25 – 28°C) for 10 min. Then, 1 ml of the supernatant was transferred to a 15 mL centrifuge tube where 3 mL of 100 mM sodium acetate buffer (pH 4.5) was added, mixed, and heated in a boiling water bath for 5 min to allow denaturation of Con A. The tubes were allowed to equilibrate for 5 min in a 40°C water bath. Amyloglucosidase/alpha-amylase enzyme of 0.1 mL volume was added and allowed to react for 30 min at 40°C. The tubes were then centrifuged at 2000 x g at RT for 5 min. Finally, an aliquot of the supernatant was obtained and allowed to incubate with 4 ml glucose oxidase/peroxidase enzymes (GOPOD) reagent enzymes in separate glass test tubes. Incubation with the GOPOD enzymes was concurrently done with the total starch aliquot obtained in part three of this assay together with the reagent blank and D-glucose controls.

Determination of Total Starch

An aliquot of 0.5 mL from solution A was transferred into another glass test tube and added with 4 mL of 100 mM sodium acetate buffer (pH 4.5) and 0.1 mL of amyloglucosidase/alpha-amylase enzyme solution. The solution was mixed and incubated at 40°C for 10 min. Following incubation, 1.0 mL aliquot (triplicate) was transferred to another tube. It was added with 4 mL GOPOD reagent enzymes concurrently with the Con A supernatant (obtained during Con A precipitation), reagent blank, and D-glucose standard. These were incubated for 20 min at 40°C. Con A supernatant, total starch aliquot, and D-glucose standard were read at 510 nm against the reagent blank. The percent amylose was determined using the formula:

$$\text{Amylose}(\%) = \left[\left[\frac{\text{Absorbance (Con A Supernatant)}}{\text{Absorbance (Total Starch Aliquot)}}\right] \times \left[\frac{\text{DF Con A}}{\text{DF Total Starch}}\right]\right] \times 100$$

where Absorbance (Con A Supernatant) was the absorbance obtained in part two of the assay; Absorbance (Total Starch Aliquot) was the absorbance of total starch aliquot obtained in part three of the assay; DF Con A was the dilution factor of Con A equal to 6.15; DF Total starch was the dilution factor for total starch equal to 9.2 and; 100 used to express amylose in percentage.

***In Vitro* Glycemic Index Estimation**

To estimate the glycemic indices of the starches, the unrestricted *in vitro* system used to measure starch hydrolysis at various times as described by Goñi et al. (1997) was used for the study.

This method was carried out in a capped tube, which simulates the digestion procedure of food and estimates the glycemic indices following the first-order equation of hydrolysis. For 15 min, 50 mg of the starch samples were boiled in 50 mL of distilled water. After incubation, 10 mL of potassium chloride buffer (pH 1.5) was added to the sample mixture. Then, 0.2 mL of pepsin (1 g in 10 mL potassium chloride buffer) was added and incubated at 40°C in a circulating water bath for 1 h. The volume was completed to 25 mL with Tris-Maleate (TM) buffer (pH 6.9), then 5 mL of alpha-amylase (2.6 U) in TM buffer solution was added. The tubes were allowed to incubate, and 1 mL aliquot of the sample was collected every 30 min (t = 0, 30, 60, 90, 120, 150, 180) to evaluate starch digestibility. Each aliquot was shaken for 5 min in a 100°C water bath and refrigerated until the end of the incubation time. Until the last collection, 3 mL of 0.4 M sodium acetate buffer (pH 4.75) and 60 μL amyloglucosidase were simultaneously added to the sample mixture and placed in a 45°C water bath for 45 min. The samples were adjusted to 10 mL volume with distilled water. Triplicates of 0.5 mL aliquots were taken and were allowed to react with glucose oxidase/peroxidase enzymes at 40°C for 20 min and were then read at 510 nm absorbance. The best-correlated value (r = 0.909, $p \leq 0.05$) with *in vivo* glycemic responses in the improved *in vitro* methods described was the percentage of starch hydrolysis at 90 min as pointed out by Goñi et al. (1997) following the equation:

$$GI = 39.21 + 0.803(H90)$$

where H90 was the total starch hydrolyzed at 90 min and was calculated using the following formula adopted from the total starch assay (Megazyme 2016; AOAC official method 996.11), which follows the same α-amylase hydrolysis principle.

$$H90 = \Delta A \times F \times FV/0.5 \times 1/1000 \times 100/W \times 0.9$$

where ΔA is the sample absorbance against a blank; F, conversion from absorbance to μg (for 100 μg of D-glucose reference); FV, the final volume of the sample; 0.5, the volume of sample analyzed; 1/1000, conversion of μg to mg; 100, factor to express starch as a percentage; W, weight in milligrams of the sample (25 mg); and, 0.9 = Morris factor.

Despite the best-correlated formula with *in vivo* glycemic responses in the improved *in vitro* methods concluded by Goñi (1997), which was the percentage of starch hydrolysis at 90 min, aliquots were still collected at 6x periods. This was done to check the favorable increase in the glucose yield even after 90 min, after which most starches only showed sustained to decreased hydrolysis.

Statistical Analysis

One-way analysis of variance was calculated using a General Linear Model. Significant differences were reported at a 5% level of significance using Tukey's HSD for multiple comparisons. Correlation analysis at 1% level of significance was also used to determine possible relationships between variables. SPSS Statistics v.23 software was used to perform the statistical analysis.

RESULTS AND DISCUSSION

Flour and Starch Yield

The yield of flours showed significant effects ($P < 0.05$) in terms of variety, age of collection, and their interaction (Fig. 1). Sweet potato varieties had the highest yield, which reached 89.85 ± 3.16 g per 100 g dry weight of edible portion (g g^{-100} dry wt. of EP) and showed a strong effect on the yield of flour ($\eta^2 = 0.83$). SP-25 consistently had the highest yield among the sweet potato varieties at 3 and 4 mo after planting. It is reported that the type of variety in sweet potato is a dominant factor that can influence flour quality and its chemical and functional properties (Olatunde et al. 2015), which may also affect the total flour recovered from roots at harvest. Arrowroot flours ranked second with values ranging from 37.5 ± 1.28 to 79.62 ± 3.19 g g^{-100} dry wt. of EP. These accessions showed significant differences ($p < 0.001$), revealing stronger effects of the age of harvest ($\eta^2 = 0.94$) and its interaction with the accession ($\eta^2 = 0.93$) than that of accession alone ($\eta^2 = 0.83$). Results also showed that 96% of the variance in flour yield could be attributed to both variables.

On the other hand, cassava flours ranged from 33.56 ± 3.02 to 78.33 ± 4.99 g g^{-100} dry wt. of EP. Consequently, the main effects of cassava varieties ($\eta^2 = 0.83$) and the interaction effect ($\eta^2 = 0.77$) were stronger compared to the age of harvest ($\eta^2 = 0.32$). Significant differences were also observed in flour yields of purple yam varieties, which were higher than those of taro varieties. Though the means suggest substantial differences in flour yield among these crops, a significant direct correlation between the yield and the harvest time cannot be established. The high moisture content of starchy root vegetables — which usually ranges from 50 to 70% — contributes to losses during postharvest, as it may reduce the weight and introduce decay (Holcroft 2018).

A related study on the physicochemical properties of traditional Indonesian flours, tubers, and roots reported higher flour yield obtained in terms of cassava with 40.2 ± 2.50%, sweet potato with 30 ± 2.30%, taro flour with 19.0 ± 2.50%, and arrowroot with 32 ± 1.60%; however, lower values were obtained for yam flour with 14.1 ± 1.80% (Aprianita et al. 2014).

All variables showed statistically higher effects in cassava in terms of starch yield (Fig. 2). Nonetheless, the interaction ($\eta^2 = 0.937$) between the age and the variety was still the highest as compared to the effect of variety ($\eta^2 = 0.935$) and age ($\eta^2 = 0.896$) alone. This correlation suggests an increase in yield in an extended harvest period and to a certain extent. In a related study investigating the effect of longer harvest periods (12 – 15 mo) on cassava starch yield and quality grown at different ecological zones (forest and transition), starch yield generally increased with peaks at 13 mo, after which a steady decline was observed for some cultivars (Baafi and Safo-Kantanka 2007). This observation is also consistent with a more recent study evaluating seasonal variation in different cassava genotypes, where the starch yield and content and size of granules continuously increased 4 – 12 MAP (Janket et al. 2020). Although a statistically significant correlation between starch yield and age can be drawn from sweet potato, this correlation cannot be supported as a direct effect of age since only two-time points were accounted for. However, similar to flour yield, there was a significant difference in variety. In the case of arrowroot, the starch yield was significantly affected by age at harvest, accession, and the interaction of both. A statistically significant ($p = 0.003$) negative correlation ($r = -0.342$) of the yield with age at harvest was obtained. Fibrous arrowroot rhizomes were observed during starch extraction, suggesting a decrease in starch recovery in more mature roots. Recent developments have considered starch biopolymer, fibers, and biocomposites capitalizing on arrowroot fibers (Tarique et

Table 2. Dry matter content of cassava tubers 8 – 12 mo after planting (MAP).

Variety	Dry Matter (%)				
	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
Cv-37	34.20 ± 1.10^{fg}	33.71 ± 0.67^{g}	34.92 ±1.19^{fg}	36.60 ± 1.05^{cd}	24.00 ± 0.28^{j}
Cv-38	44.31 ± 1.29^{a}	46.47 ± 0.82^{a}	43.43 ±1.24^{bc}	43.37 ± 1.75^{a}	40.07 ± 1.42^{abc}
Cv-39	33.60 ± 0.34^{gh}	32.72 ± 0.31^{gh}	35.93 ± 2.05^{e}	34.12 ± 1.33^{de}	40.33 ± 0.79^{abc}
Cv-40	36.17 ± 0.77^{d}	42.37 ± 0.76^{bcd}	37.29 ±1.13^{d}	25.81 ± 1.09^{f}	31.67 ± 0.91^{i}
Cv-41	37.77 ± 2.03^{c}	32.57 ± 0.75^{i}	46.13 ± 0.88^{a}	39.48 ± 0.99^{bc}	37.54 ± 0.81^{e}
Cv-42	31.82 ± 1.49^{i}	42.79 ± 1.03^{bcd}	44.59 ± 0.38^{bc}	40.21 ± 1.33^{b}	40.13 ± 1.06^{abc}
Cv-43	34.72 ± 2.61^{ef}	35.19 ±1.08^{ef}	35.14 ± 1.04^{ef}	42.03 ± 0.65^{b}	32.33 ± 0.94^{gh}
Cv-44	35.71 ± 0.60^{de}	35.38 ± 0.70^{e}	29.39 ± 0.34^{h}	41.25 ± 0.83^{b}	33.33 ± 2.21^{fg}
Cv-45	43.57 ± 0.58^{b}	42.26 ± 0.58^{bcd}	45.45 ±1.62^{ab}	40.42 ± 1.20^{b}	39.87 ± 1.08^{cd}
Cv-46	28.12 ± 1.09^{j}	25.69 ± 2.22^{j}	19.19 ± 0.76^{i}	32.97 ± 1.45^{e}	33.67 ± 1.80^{g}
%CV	13.62	16.74	22.02	13.99	14.80

Values expressed as mean ±SD; different superscripts on the same column are significantly different at 0.05 level. Cv-Cassava, MAP-months after planting.

al. 2021). Taro corms obtained an average yield of 43.89 g g^{-100} dry wt. of EP, of which BLSM 132 was the highest at 64.13 ± 0.99 g g^{-100} dry wt. of EP. In this study, yam varieties obtained the lowest starch yield among other root crops. An average of 8.72 g g^{-100} dry wt. of EP was obtained with VU-6 with 17.32 g g^{-100} dry wt.

Dry Matter

The dry matter contents of tubers from different varieties of root crops at various maturity periods were presented in Tables 2 – 4. Dry matter was a good indicator of a crops' potential for biomass production — since the dry matter represented all the solid contents after water was removed, it showed how water was effectively assimilated and transpired by plants. This relationship between the amount of biomass produced per unit of water used by a crop is often expressed in the plants' water-use efficiency (Hatfield and Dold 2019). Of the 10 cassava varieties, roots from Cv-38 and Cv-45 had the highest dry matter contents ranging from 39 – 46%. In sweet potato, SP-28, SP-29, and SP-30 were also observed to have higher dry matter content ranging from 37 – 44%. Kahislot showed the highest dry matter of the ten taro varieties with 47.84%. The dry matter contents of yam and arrowroot were also found to be relatively lower than the other root crops.

Crude Protein

Among the five root crops, only taro showed no significant difference (p = 0.20) in the crude protein content (dry wt. basis) among varieties (Fig. 3). Arrowroot flour showed the highest average crude protein content which ranged from 2.86 – 8.24% and then slightly increased with time. A significant correlation (r = 0.743) can be inferred, suggesting that an extended collection of arrowroot rhizomes may increase crude protein content. This can be observed in the increased crude protein content of MA-1–MA-3 varieties at 12 MAP. Yam flours also showed high crude protein values ranging from 3.20 – 8.33% with the VU-8 variety having the highest value. Crude protein of sweet potato ranged from 2 up to 5%, which was evident in the SP-22 variety at 4 mo of harvest. SP-26 was also consistently high in crude protein at both periods of harvest. The crude

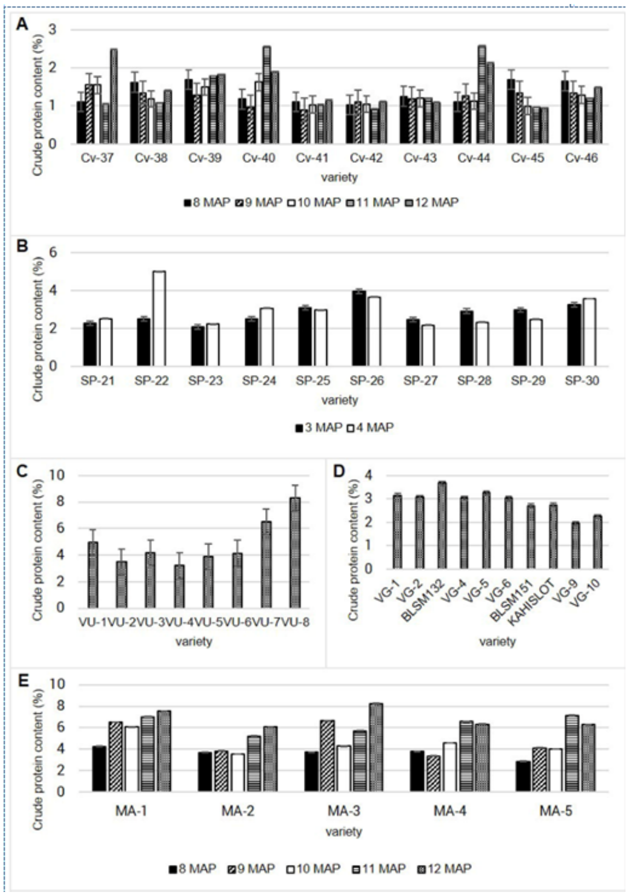

Fig. 3. Crude protein content (%) of cassava (A), sweet potato (B), taro (C), yam (D), and arrowroot (E).

Table 3. Dry matter content of sweet potato tubers at 3 – 4 MAP, yam tubers at 8 MAP and taro corm at 8 MAP.

Sweet Potato			Yam		Taro	
Variety	Dry Matter (%)		Variety	Dry Matter (%)	Variety	Dry Matter (%)
	3 MAP	4 MAP		8 MAP		8 MAP
SP-21	38.71 ± 0.98^{cde}	37.00 ± 1.71^{fg}	VU-1	23.33 ± 1.58^{bc}	VG-1	38.54 ± 1.90^{d}
SP-22	33.81 ± 0.67^{g}	39.33 ± 1.09^{de}	VU-2	19.67 ± 1.89$^{e f}$	VG-2	36.24 ± 1.99^{ef}
SP-23	31.79 ± 1.03^{i}	35.33 ± 1.76^{h}	VU-3	24.67 ± 0.97^{b}	BLSM132	32.21 ± 1.12^{i}
SP-24	30.96 ± 0.61^{j}	27.00 ± 0.76^{j}	VU-4	33.33 ± 1.79^{a}	VG-4	40.72 ± 1.99^{c}
SP-25	38.30 ± 0.75^{cde}	32.00 ± 1.55^{i}	VU-5	20.00 ± 0.75^{de}	VG-5	35.33 ± 0.92^{fg}
SP-26	33.80 ± 1.86^{gh}	39.33 ± 0.98^{d}	VU-6	20.67 ± 1.66^{d}	VG-6	31.00 ± 0.26^{j}
SP-27	38.79 ± 1.03^{cde}	37.67 ± 1.79^{f}	VU-7	10.00 ± 1.82^{g}	BLSM151	34.90 ± 1.55^{gh}
SP-28	40.21 ± 0.93^{b}	42.00 ± 1.24^{bc}	VU-8	19.00 ± 0.97^{f}	Kahislot	47.84 ± 0.80^{a}
SP-29	43.17 ± 1.18^{a}	44.00 ± 1.52^{a}			VG-9	42.12 ± 0.59^{b}
SP-30	37.14 ± 1.07^{f}	42.33 ± 1.81^{b}			VG-10	37.40 ± 0.94^{de}
(%)CV	10.63	13.59		29.78		13.10

Values expressed as mean ±SD; different superscripts on the same column are significantly different at 0.05 level. SP-Sweet potato,Visayas State University(VSU) Ube, VG-VSU Gabi, MAP-months after planting.

Table 4. Dry matter content of arrowroot rhizomes from 8 – 12 mo after planting (MAP).

Variety	Dry Matter (%)				
	8 MAP	9 MAP	10 MAP	11 MAP^{ns}	12 MAP
MA-1	35.67 ± 2.48^{a}	19.33 ± 0.45^{b}	25.33 ± 2.78^{a}	19.67 ± 1.50	15.00 ± 1.06^{c}
MA-2	35.00 ± 2.75^{a}	24.00 ± 1.14^{a}	26.00 ± 1.85^{a}	20.67 ± 1.61	25.33 ± 1.30^{a}
MA-3	27.33 ± 0.96^{b}	14.67 ± 1.64^{c}	23.67 ± 1.54^{a}	19.00 ± 1.04	21.00 ± 1.75^{b}
MA-4	32.67 ± 1.40^{a}	15.33 ± 1.00^{c}	26.00 ± 1.05^{a}	20.67 ± 1.98	21.67 ± 0.86^{b}
MA-5	24.67 ± 1.47^{b}	19.33 ± 1.26^{b}	20.00 ± 0.48^{b}	16.67 ± 1.17	19.67 ± 1.09^{b}
(%)CV	15.39	19.49	11.42	10.27	17.63

Values expressed as mean ± SD; different superscripts on the same column are significantly different at 0.05 level. MA-Maranta arundinacea Accession, MAP-months after planting.

protein of taro flour ranged from 1.9 – 3.6%, with the promising variety BLSM 132 as the highest and VG-9 as the lowest. In this study, cassava had the lowest crude protein content among the five root crops, with values ranging from 0.91 – 1.80%. Aprianita et al. (2009) also reported crude protein values of arrowroot, yam, sweet potato, taro, and cassava flour with average values of 7.7, 5.3, 3.3, 5.5, and 1.4 %, respectively, comparable to the values obtained in this study. However, variations in the results are not unexpected as crude protein of tubers may be affected by agro-ecological conditions (Bartova et al. 2009) and unidentical sample materials. Data on the protein content of arrowroot and some yam varieties showed these crops to be excellent alternative protein sources to many packaged foods for commercial and industrial use. Compared to rice with 7% protein — one of the lowest among other cereals (Juliano et al. 2009) — arrowroot can also be a good substitute for protein components in the diet, especially in Asian countries where resource- poor households lacking in resources — particularly in low-income countries of Southeast Asia and sub-Saharan Africa — were reportedly at higher risk of protein deficiency associated with diet mainly composed of starchy roots and cereals with very low protein components (Tarique et al. 2021).

Crude Fiber

Sweet potato flours had the highest crude fiber content with values ranging from 4.81 – 18.92%, the highest of which was observed on SP-26 at 3 MAP, followed by SP-27 with 15.66%. The arrowroot flours contained 2.44 – 7.88 % crude fiber with MA-3 and MA-4 accessions having the highest values at 8 MAP. A statistically significant ($p = 0.0$) negative correlation ($r = -0.721$) can be established based on the results, suggesting a decrease in crude fiber content with extended harvest periods. In this study, the crude fiber content of cassava flour samples obtained was 11 MAP greater than half of the cassava varieties tested. Although this observation was based on a single planting season with a 5 mo (8 – 12 MAP) harvesting period and a characterized environmental condition as previously described, this result was generally consistent with the results obtained in other experiments. This value may support the significant (p = 0.004) positive correlation (r = 0.232) of the crude fiber content values obtained and the age at which they were collected. However, these values still suggest lower fiber content in cassava flours than in sweet potato and arrowroot. Yam flour contained 1.0 – 5.0 % of crude fiber, while taro showed the least crude fiber content with the highest value of 4.41% from BLSM 132. These values were slightly higher as compared to the previous reports of 6.12% in arrowroot (Capiña and Capiña 2017), 0.2 – 6.5% in sweet potato (Jangchud et al. 2003), 1.46 – 2.53% in yam (Behera et al. 2009), 0.35 – 3.78% in taro (Mbofung et al. 2006), and 1.17 – 2.05% in cassava (Girma et al. 2015). Variations were attributed to differences in processing methods (e.g., sieving), agro-climatic conditions, tuber origins, and types of varieties used. It is important to note that crude fiber differs from dietary fiber. Dietary fiber was the sum total of soluble and insoluble fibers including non-starch polysaccharides, while crude fiber was the insoluble fiber or indigestible moiety after extraction and acid-base treatments. However, the evolving concept of dietary fiber has gradually replaced crude fiber. Nonetheless, both are essential in digestion and gut health (Dai and Chau 2017). Recent studies also revealed that dietary non-fermentable crude fiber content could alter the metabolic profile and gut microbiota, promoting specific autoimmune suppressive responses (Berer et al. 2017 and 2018).

Amylose and Amylopectin

Amylose and amylopectin were the two types of polymers that form the starch synthesized by plant cells. Amylose is essentially a linear chain of α-1,4-glucans with limited branching points and constitutes 15 – 30 % of the total starch content, while amylopectin is a highly branched linear chain of glucose units formed through an α-1,4 glycosidic bond constituting about 70 – 85 % of the total starch content (Alcáazar-Alay and Meireles 2015). These starch components were quantified since they affect most functional properties related to food processing such as gelatinization and retrogradation, swelling power, and enzymatic susceptibility.

Results revealed that the amylose content of cassava starch ranged from 13.07 ± 2.13% to 26.36 ± 2.00%, with Cv-42 having the highest value (Table 5). It can be observed that starches obtained from cassava collected at 11 MAP gave higher amylose values; however, no significant correlation between the two parameters can be established. On the other hand, the amylose content of most sweet potato starches investigated (SP-2–SP-28) revealed a significant positive correlation (r = 0.626) to the age at which they were harvested, suggesting an increase in amylose content in mature roots. The highest amylose content (34.48% ± 3.53) was observed in SP-24 (Table 6). For taro varieties, VG-2 revealed the significantly highest amylose content. In the case of arrowroot starch, no significant differences in amylose content were observed at 8, 9, 11, and 12 MAP. However, at 10 MAP, significant differences were observed among varieties (Table 7). No direct correlation can be inferred between the amylose content and the roots' maturity upon collection. However, the values obtained in this

Table 5. Amylose content of cassava starch at 8 – 12 mo after planting (MAP).

Variety	Amylose (%)				
	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
Cv-37	15.33 ± 0.56^{hi}	13.37 ± 4.25^{cd}	14.28 ± 1.77^{b}	22.65 ± 0.62^{abc}	23.17 ± 4.63^{a}
Cv-38	17.42 ± 1.01^{ef}	19.55 ± 1.19^{bc}	17.26 ± 3.66^{ab}	20.57 ± 1.10^{ef}	20.83 ± 0.70^{abc}
Cv-39	15.03 ± 0.73^{ij}	19.95 ± 1.68^{bc}	15.28 ± 1.90^{b}	21.85 ± 0.20^{cd}	21.77 ± 2.56^{ab}
Cv-40	23.39 ± 6.15^{ab}	21.09 ± 0.19^{ab}	19.99 ± 1.97^{ab}	23.34 ± 3.26^{a}	17.94 ± 2.4^{abc}
Cv-41	22.41 ± 1.87^{bc}	12.48 ± 3.50^{d}	24.20 ± 0.83^{a}	22.79 ± 2.03^{ab}	15.95 ± 1.40^{bc}
Cv-42	17.22 ± 0.85^{fg}	26.36 ± 2.00^{a}	21.94 ± 1.65^{ab}	18.22 ± 3.96^{hi}	18.08 ± 2.58^{abc}
Cv-43	17.05 ± 2.96^{fgh}	19.10 ± 0.95^{bcd}	15.30 ± 4.44^{b}	20.38 ± 1.48^{gh}	18.16 ± 3.04^{abc}
Cv-44	21.68 ± 4.28^{cd}	20.66 ± 3.70^{ab}	15.25 ± 1.78^{b}	13.07 ± 2.13^{j}	13.84 ± 0.92^{c}
Cv-45	25.84 ± 6.43^{a}	19.68 ± 0.93^{bc}	15.78 ± 2.60^{b}	21.67 ± 1.35^{de}	13.79 ± 2.60^{c}
Cv-46	18.48 ± 1.54^{e}	19.93 ± 0.31^{bc}	20.33 ± 0.09^{ab}	20.41 ± 1.11^{fg}	15.62 ± 0.50^{bc}
(%)CV	23.29	22.40	19.40	16.43	20.78

Values expressed as mean ±SD; different superscripts on the same column are significantly different at 0.05 level. Cv-Cassava, MAP-months after planting.

Table 6. Amylose content of sweet potato starch at 3 – 4 MAP, yam starch at 8 MAP and taro starch at 8 MAP.

Sweet potato			Yam		Taro	
Variety	Amylose (%)		Variety	Amylose (%)	Variety	Amylose (%)
	3 MAP	4 MAP		8 MAP^{ns}		8 MAP
SP-21	12.62 ± 2.64^{defg}	21.68 ± 0.31^{ef}	VU-1	26.00 ± 1.62	VG-1	24.14 ± 0.47^{de}
SP-22	10.80 ± 0.68^{hi}	26.24 ± 0.22^{cd}	VU-2	25.70 ± 0.46	VG-2	32.11 ± 1.15^{a}
SP-23	12.61 ± 0.43^{defgh}	27.90 ± 0.28^{bc}	VU-3	24.94 ± 1.96	BLSM132	23.21 ± 1.01^{efg}
SP-24	12.71 ± 2.93^{def}	34.48 ± 3.53^{a}	VU-4	22.37 ± 1.63	VG-4	28.31 ± 0.49^{b}
SP-25	15.20 ± 0.78^{bc}	24.58 ± 2.73^{de}	VU-5	25.21 ± 8.10	VG-5	23.14 ± 1.27^{efgh}
SP-26	13.03 ± 2.72d^{e}	20.59 ± 1.11^{fg}	VU-6	32.58 ± 4.93	VG-6	21.66 ± 3.78ij
SP-27	14.35 ± 1.02^{cd}	28.06 ± 0.25^{b}	VU-7	27.07 ± 3.24	BLSM151	23.45 ± 2.04^{ef}
SP-28	9.75 ± 4.16^{ij}	16.14 ± 0.53^{h}	VU-8	28.25 ± 4.08	Kahislot	24.36 ± 2.70^{cd}
SP-29	18.62 ± 2.79^{b}	13.97 ± 0.42^{ij}			VG-9	21.96 ± 0.97^{hi}
SP-30	22.89 ± 5.21^{a}	15.99 ± 0.55^{hi}			VG-10	26.33 ± 2.15^{bc}
(%)CV	30.90	28.00		16.33		14.01

Values expressed as mean ±SD; different superscripts on the same column are significantly different at 0.05 level. SP-Sweet potato,Visayas State University(VSU) Ube, VG-VSU Gabi, MAP-months after planting.

Table 7. Amylose content of arrowroot starch from 8 – 12 mo after planting (MAP).

Variety	Amylose (%)				
	8 MAP^{ns}	9 MAP^{ns}	10 MAP	11 MAP^{ns}	12 MAP^{ns}
MA-1	13.40 ± 1.31	15.80 ± 3.43	17.16 ± 0.43^{cd}	17.44 ± 0.83	17.47 ± 2.02
MA-2	14.64 ± 0.37	22.55 ± 1.56	18.11 ± 1.66^{bc}	17.78 ± 0.89	16.60 ± 0.36
MA-3	12.60 ± 2.10	25.89 ± 2.46	19.96 ± 1.82^{b}	18.44 ± 0.80	14.29 ± 0.82
MA-4	12.91 ± 0.89	23.76 ± 0.64	20.74 ± 1.31^{a}	17.27 ± 0.94	14.70 ± 0.26
MA-5	14.59 ± 3.54	26.31 ± 2.33	16.68 ± 0.65^{de}	16.36 ± 0.13	17.20 ± 5.36
(%)CV	13.86	18.74	10.27	5.54	16.09

Values expressed as mean ±SD; different superscripts on the same column are significantly different at 0.05 level. MA-Maranta arundinacea Accession, MAP-months after planting.

study were comparable to the amylose content value for arrowroot reported by Aprianita et al. (2014), which was found to be at 21.9%. In contrast, the results of the study were lower than the values reported by Sandoval Gordillo et al. (2014) at 40.86%.

A related study of parental cassava lines and cassava progenies conducted by Nuwamanya et al. (2010) reported comparable amylose content, ranging from 23.01 – 26.98 % and from 19.69 – 26.63 %, respectively. Also, studies on structural and physiochemical characteristics revealed that cassava and sweet potato starches had amylose mean values of 19.8 and 22.6%, respectively. In contrast, yam starches had a higher amylose content of 32.6% (Peroni et al. 2006), comparable to the yam amylose values obtained in this study.

Glycemic Index

Glycemic index (GI) measures the potential of available carbohydrates in food to raise blood sugar levels (Wolever 2016). Digestible carbohydrates in food are converted to glucose which energizes cells and signals the pancreas to produce insulin, which in turn helps cells absorb glucose (Providence Health Team 2016). Absorption and conversion of carbohydrates occur at different rates. This principle, along with the type (i.e.. high- or low- GI foods) and the amount of food consumed, can influence the insulin system (Preuss and Bagchi 2020). Low-GI foods promote slow and gradual digestion and absorption of carbohydrates, thereby gradually increasing blood sugar and insulin levels. Conversely, the absorption rate is quicker in high-GI foods, rapidly increasing blood sugar which then triggers the rapid release of insulin (Preuss and Bagchi 2020). This may quickly lower blood glucose levels resulting in hunger, increased appetite, and drowsiness (Providence 2016). Several reports demonstrated high-GI foods' influence and associated risks for irreversible Type 2 diabetes, obesity, hypertension, and other complications (Alavi 1991; Wolever 2006; Providence 2016; Preuss et al. 2017; Preuss and Bagchi 2020). While blood glucose levels may be involved in these disease mechanisms, it is also important to note that association does not prove causality and that the complexity of diseases is still an interplay of many other factors (Wolever 2006).

Table 8. Glycemic index of cassava starch at 8 – 12 mo after planting (MAP).

Variety	Glycemic Index				
	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
Cv-37	50.74 ± 0.27^{ab}	51.19 ± 0.23^{a}	48.89 ± 0.06^{c}	47.70 ± 0.49^{f}	51.17 ± 0.08^{a}
Cv-38	47.02 ± 0.32^{d}	47.42 ± 2.29^{c}	47.85 ± 0.24^{d}	49.34 ± 0.33^{cd}	48.47 ± 0.07^{d}
Cv-39	46.71 ± 0.15d^{e}	49.91 ± 0.16^{ab}	49.74 ± 0.14^{bc}	50.45 ± 0.24^{ab}	50.08 ± 0.08^{bc}
Cv-40	46.04 ± 0.06d^{e}	47.53 ± 0.28^{bc}	51.41 ± 0.47^{a}	51.16 ± 0.17^{a}	50.38 ± 0.16^{b}
Cv-41	45.86 ± 0.04^{e}	51.39 ± 0.26^{a}	50.13 ± 0.62^{b}	48.41 ± 0.35^{ef}	47.71 ± 0.24^{e}
Cv-42	44.65 ± 0.17^{f}	50.06 ± 0.28^{a}	48.95 ± 0.30^{c}	50.69 ± 0.19^{ab}	50.92 ± 0.21^{a}
Cv-43	43.54 ± 0.15^{g}	49.59 ± 0.60^{abc}	49.41 ± 0.23^{bc}	51.25 ± 0.08^{a}	48.18 ± 0.24^{d}
Cv-44	49.37 ± 0.42^{c}	51.41 ± 0.61^{a}	49.41 ± 0.19^{bc}	48.70 ± 0.30^{de}	48.24 ± 0.10^{d}
Cv-45	51.54 ± 0.83^{a}	49.19 ± 0.44^{abc}	48.97 ± 0.13^{c}	48.95 ± 0.30d^{e}	49.86 ± 0.09^{c}
Cv-46	50.39 ± 0.25^{bc}	50.87 ± 0.67^{a}	49.72 ± 0.17^{bc}	50.15 ± 0.15^{bc}	49.87 ± 0.13^{c}
(%)CV	5.62	3.17	1.92	2.43	2.43

Values expressed as mean ±SD; different superscripts on the same column are significantly different at 0.05 level. Cv-Cassava, MAP-months after planting.

Table 9. Glycemic index of sweet potato starch at 3 – 4 MAP, yam starch at 8 MAP and taro starch at 8 MAP.

Sweet potato			Yam		Taro	
Variety	Glycemic Index		Variety	Glycemic Index	Variety	Glycemic Index
	3 MAP	4 MAP		8 MAP		8 MAP
SP-21	44.44 ± 0.10^{d}	46.02 ± 0.66c^{de}	VU-1	48.63 ± 0.11^{a}	VG-1	43.82 ± 0.15^{bc}
SP-22	44.77 ± 0.21^{cd}	44.99 ± 0.59^{e}	VU-2	48.38 ± 0.33^{a}	VG-2	43.22 ± 0.05^{cd}
SP-23	44.73 ± 0.05^{d}	49.37 ± 0.45^{a}	VU-3	47.73 ± 0.29^{a}	BLSM132	44.93 ± 0.16^{a}
SP-24	44.83 ± 0.18^{cd}	47.19 ± 0.33^{bc}	VU-4	43.29 ± 0.75^{c}	VG-4	44.38 ± 0.26^{ab}
SP-25	43.66 ± 0.19^{e}	45.76 ± 0.31^{de}	VU-5	46.56 ± 0.17^{b}	VG-5	43.76 ± 0.27^{bc}
SP-26	45.76 ± 0.10^{b}	46.16 ± 0.72^{bcde}	VU-6	47.87 ± 0.71^{a}	VG-6	42.88 ± 0.37^{de}
SP-27	43.37 ± 0.40^{e}	46.48 ± 0.19^{bcd}	VU-7	46.04 ± 0.13^{b}	BLSM151	43.82 ± 0.05^{bc}
SP-28	43.62 ± 0.46^{e}	47.42 ± 0.23^{b}	VU-8	44.42 ± 0.17^{c}	Kahislot	42.45 ± 0.24^{e}
SP-29	47.51 ± 0.16^{a}	43.19 ± 0.14^{f}			VG-9	42.82 ± 0.09^{de}
SP-30	45.43 ± 0.20^{bc}	46.45 ± 0.72^{bcd}			VG-10	42.58 ± 0.37^{de}
(%)CV	2.68	3.46		4.03		1.89

Values expressed as mean ±SD; different superscripts on the same column are significantly different at 0.05 level. SP-Sweet potato,Visayas State University(VSU) Ube, VG-VSU Gabi, MAP-months after planting.

Table 10. Glycemic index of arrowroot starch at 8 MAP–12 MAP.

Variety	Glycemic Index				
	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
MA-1	43.95 ± 0.15^{bc}	44.56 ± 0.10^{b}	43.45 ± 0.10^{a}	44.11 ± 0.09^{a}	42.45 ± 0.39^{c}
MA-2	44.04 ± 0.29^{b}	43.06 ± 0.06^{d}	42.66 ± 0.06^{b}	43.46 ± 0.10^{b}	48.60 ± 0.18^{a}
MA-3	43.39 ± 0.20^{c}	44.00 ± 0.15^{c}	41.82 ± 0.15^{c}	42.23 ± 0.07^{d}	42.44 ± 0.07^{c}
MA-4	45.00 ± 0.32^{a}	45.21 ± 0.24^{a}	40.94 ± 0.24^{d}	43.12 ± 0.12^{c}	42.51 ± 0.59^{c}
MA-5	41.95 ± 0.13^{d}	42.77 ± 0.12^{d}	42.86 ± 0.12^{ab}	43.58 ± 0.18^{b}	44.09 ± 0.31^{b}
(%)CV	2.42	2.16	2.21	1.50	5.63

Values expressed as mean ±SD; different superscripts on the same column are significantly different at 0.05 level. MA-Maranta arundinacea accession, MAP-months after planting.

Results revealed that the different varieties of root crops showed significant differences in their glycemic indices (Tables 8 – 10). Compared to cassava, sweet potato, and yam, a lower glycemic index was observed in taro and arrowroot starches. The highest glycemic index of 51.54 was observed from the cassava Cv-45 variety, and the lowest GI of 40.94 was observed from the arrowroot MA-4 variety harvested 10 MAP. Their low GI values make arrowroot and taro potential healthier alternatives to agents used in baking; they can also be used as functional foods for those with high blood sugar levels or those who have issues with glucose metabolism.

The *in vitro* starch hydrolysis also revealed a significant but weak positive correlation between the glycemic index and age of harvest in cassava (r = 0.282) and sweet potato (r = 0.472). This was likely because factors such as rigidity of cell walls, amylose content, enzyme inhibitors, and reorganization of granules can also affect hydrolysis rate, starch digestibility, and absorption.

Furthermore, differences in values obtained using various methods may also be due to the destruction of food structures during preparation such as chewing, mincing, homogenizing, and cooking — all of which may modify the rate of hydrolysis. Starch granules start to swell and break in the presence of water upon cooking, making it more available for enzymes to be digested and readily absorbed in healthy individuals, while some parts of these may reorganize after cooling and degradation and become resistant starches that are harder to absorb (Goñi et al. 1997).

Although the classification of foods in the revised International Table of Glycemic Index and Glycemic Load values described ≤ 55, 56 – 69, and ≥ 70 as low-, medium-, and high-GI, respectively, the glycemic index of any food and food products may also vary with the method of preparation (Atkinson et al. 2021). Foster-Powell et al. (2002) compiled the GI values of foods, taking note of the type of preparation — some were prepared as boiled root crops and not as root starches, similar to what was conducted in this study. Foster-Powell and Miller (1995) also emphasized the directly proportional effect of particle size and degree of gelatinization of the starch granules on GI measurements. An increase in these factors might also increase the GI value of the food. These factors may also explain some higher GI values obtained in this study, considering that high purity of raw starch was used in this investigation. Starch samples in *in vitro* glycemic index studies allow a more efficient and accurate estimation of values due to the simpler composition of their glucose units compared to flour. The pretreatment method of starch samples to obtain pure samples was also much more efficient and straightforward than in flour samples, where other crude components may be present and may create complexes during the hydrolysis process.

CONCLUSION

The compositional characteristics of flours and starches from cassava, sweet potato, taro, yam, and arrowroot revealed significant variations in flour and starch yield, dry matter, crude protein and fiber, amylose/amylopectin ratio, and glycemic index. The highest amylose content of 34.48 ± 3.53 was observed in sweet potato (SP-24), while the lowest GI of 40.94 ± 0.24 was observed in arrowroot (MA-4). Low glycemic index (GI) values were observed from taro and arrowroot starches compared to cassava, sweet potato, and yam. These variations may reveal outstanding properties in root crops that can support further commercialization and utilization of specific varieties.

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