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Comparison of starch-based liquid sugar production from local cassava

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Abstract. *Dewi SS, Supangkat G, Hastomo T. 2025. Comparison of starch-based liquid sugar production from local cassava. Asian J Agric 9: 683-688.* Indonesia's rising sugar demand and dependence on imports have sparked interest in alternative sweeteners sourced from local crops. The country currently imports a significant portion of its sugar, leading to concerns about food security and economic stability. Cassava (*Manihot esculenta*), widely cultivated across the country, offers a promising raw material for liquid sugar production due to its high starch content and accessibility. This study evaluates the suitability of three cassava varieties; Cartiva 25, Melati, and Randu for liquid sugar production using enzymatic hydrolysis. The process involved liquefaction with α-amylase followed by saccharification with glucoamylase. Carbohydrate content in the resulting liquid sugar ranged from 76.15 to 80.39%, with Randu and Melati outperforming Cartiva 25. Reducing sugar levels was highest in Randu (65.10%), indicating more efficient starch conversion. Sensory analysis revealed that Randu produced the sweetest and lightest-colored liquid sugar. However, none of the samples met Indonesian National Standards for colorlessness and odorlessness due to the absence of purification steps. While starch yield did not differ significantly among varieties, biochemical and sensory profiles suggest that varietal selection plays a critical role in optimizing sugar output and product quality. Randu and Melati varieties demonstrated superior performance and are recommended for industrial-scale processing. To meet national standards and enhance market viability, future production should incorporate purification techniques such as decolorization and deodorization. These findings offer practical guidance for processors and farmers, highlighting cassava's potential to reduce reliance on imported sugar and support sustainable agriculture. Promoting high-performing varieties like Randu and Melati could strengthen local supply chains and contribute to Indonesia's food system resilience.

Keywords: Cassava variety, enzymatic hydrolysis, food processing, liquid sugar, reducing sugar

INTRODUCTION

Sugar plays a central role in Indonesia's food industry, not only as a key ingredient in processed foods and beverages but also as a strategic commodity with economic and nutritional importance. As the population grows and urbanization accelerates, sugar consumption continues to rise. The United States Department of Agriculture (USDA) projects Indonesia's sugar demand to reach 7.6 million metric tons in 2024/2025, driven by household consumption and industrial use (Sugiarti et al. 2021). However, domestic sugarcane production remains insufficient, with only 2.4 million tons produced in 2022, a modest recovery from the pandemic-induced decline in 2020 (Indonesian Central Agency of Statistics 2022). This shortfall has led to a heavy reliance on imports, with Thailand alone supplying over 40% of Indonesia's imported sugar (Oktarini 2024).

This dependency on foreign sugar sources poses risks to food security, trade balance, and price stability. It also underscores the urgent need for alternative sweeteners that are locally sourced, sustainable, and economically viable. One such alternative is liquid sugar, which offers several advantages over traditional crystalline sugar. Liquid sugar is easier to blend into food and beverage formulations, has enhanced sweetness, and may contain fewer calories depending on its composition (Zulkifli and Karim 2023). Additionally, its production is more energy-efficient, as it bypasses the crystallization stage one of the most energy-intensive steps in conventional sugar processing (Morales et al. 2024).

Cassava (*Manihot esculenta* Crantz), locally known as ubi kayu or ketela pohon, is a widely cultivated tuber crop in Indonesia. It is particularly abundant in regions like Karanganyar District, Central Java, which offers ideal agroclimatic conditions temperatures averaging 22-31°C and annual rainfall between 250-335 mm (Karanganyar District Central Agency of Statistics 2019). In 2020, cassava production in the region reached 306,560 kg/Ha, reflecting its potential as a scalable raw material for food processing (Karanganyar District Central Agency of Statistics 2022).

Cassava starch is composed of approximately 17% amylose and 83% amylopectin, which influence its gelatinization, viscosity, and enzymatic digestibility (Palencia et al. 2025). Enzymatic hydrolysis specifically liquefaction using α-amylase followed by saccharification with glucoamylase has been shown to effectively convert cassava starch into fermentable sugars like glucose and maltose (Agustina et al. 2024; Musdalifa et al. 2024). Recent studies have demonstrated that integrating pectinase into this process can enhance hydrolysis efficiency by up to 98%, improving sugar yield and reducing cyanogenic compounds (Collares et al. 2012; Hargono et al. 2025).

Despite these promising developments, cassava-based liquid sugar remains underutilized in Indonesia's sweetener industry. Most existing research focuses on process optimization, enzyme combinations, or cassava waste valorization, with limited attention to varietal differences in cassava performance. Moreover, few studies evaluate the sensory attributes of cassava-derived liquid sugar or its compliance with national standards for color, aroma, and sweetness. These gaps hinder the broader adoption of cassava sugar in commercial applications and limit its potential as a substitute for imported sugar.

This study aims to fill these gaps by evaluating three local cassava varieties Cartiva 25, Melati, and Randu for their suitability in liquid sugar production. Using enzymatic hydrolysis, the study compares carbohydrate content, reducing sugar levels, starch yield, and sensory properties of the resulting liquid sugar. It also assesses whether the products meet the Indonesian National Standard for liquid sugar (SNI 8779:2019) (National Standards Agency 2019), particularly in terms of reducing sugar content, color, and odor. By identifying high-performing cassava varieties and highlighting areas for process improvement such as purification and deodorization this research contributes to the development of sustainable, locally sourced sugar alternatives. The findings have practical implications for industrial producers seeking to diversify sweetener sources and for local farmers. They provide valuable information and preparation for aligning their cultivation practices with emerging market demands.

MATERIALS AND METHODS

This study was conducted in Karanganyar District, Central Java, Indonesia, a region known for its optimal conditions for cassava cultivation. The area features an average temperature range of 22-31°C, an altitude of 511 meters, and annual precipitation between 247.92 to 335.08 mm, making it highly suitable for cassava farming. Cassava from this region has been widely utilized for various food products, but its potential in liquid sugar production remains underexplored.

Cassava varieties and sample preparation

Three cassava varieties, Randu, Melati, and Cartiva 25 were selected based on their availability and relevance to local agricultural practices. Fresh roots were harvested at 8 months of age, washed, peeled, and grated. The grated pulp was then filtered to extract the liquid fraction, which was used for subsequent carbohydrate and sugar analysis.

Carbohydrate and reducing sugar analysis

Total carbohydrate content was determined using the phenol-sulfuric acid method, while reducing sugars were quantified via the DNS (3,5-dinitrosalicylic acid) assay. All measurements were performed in triplicate to ensure reproducibility.

Starch yield determination

Starch was precipitated from the grated pulp by sedimentation, dried at 50°C, and weighed to determine yield. Yield was expressed as a percentage of fresh root weight. Subsequently, it was filtered using a filter cloth. The carbohydrate content was calculated using this equation:

$$\textbf{Carbohydrate content}\ (\%) = \frac{X \times df \times 0.9}{\text{weight of the sample (mg)}} \times 100\%$$

Where:
X : Sample's concentration
df : Dilution factor
0.9 : Conversion factor

Reducing sugar measurement

The reducing sugar content analysis is done according to the Nelson-Somogyi method (Nelson 1944). One gram of the sample is transferred to a 100 mL Erlenmeyer flask, and water is added to the flask until the volume reaches 100 mL. The mixture is then mixed and filtered using filter paper. One milliliter of the filtered transparent liquid was taken and added to one milliliter of Nelson C reagent (a combination of Nelson A and Nelson B solutions in a ratio of 25:1). The mixture was heated in a water bath at 100°C for 30 minutes. Subsequently, the solution was cooled by letting the mixture cool out of the water bath before adding 1 mL of arsenomolybdate reagent and mixing the solution by shaking it vigorously. Then, 10 mL of distilled water was added to the mixture and mixed using a vortex until the solution was evenly distributed. Subsequently, the UV-Vis spectrophotometer was utilized to measure the optical density of the mixture at a wavelength of 540 nm. The reducing sugar content was calculated using this equation:

$$\textbf{Reducing sugar}\ (\%) = \frac{\frac{OD_{sample} - OD_{blank}}{OD_{standard} - OD_{blank}} \times df}{\text{Weight of sample (mg)}} \times 100\%$$

Where:
OD_{sample} : Optical density of the sample
OD_{blank} : Optical density of the blank (0.063)
$OD_{standard}$: Optical density of the sample (5.681)
df : Dilution factor

Starch yield analysis

The calculation of starch yield was conducted to compare the production of starch from different varieties of local cassava. The starch yield was obtained by dividing the weight of the produced starch by the total weight of cassava used for production. The results were expressed in percentages.

Sensory analysis

The organoleptic test in this study employed a scoring-descriptive test, where the panelists were asked to measure and rate each attribute on a four-point scale. There were ten untrained panelists, and all panelists analyzed the three liquid sugars produced from local cassava varieties. The scoring explanation for each investigated attribute is displayed in Table 1.

Table 1. A four-point scale used in the sensory analysis for liquid sugar produced from different local cassava varieties

Score	Color	Aroma	Taste
1	Brown	Very smelly	Not sweet
2	Brownish-yellow	Smelly	A little bit sweet
3	Yellow	A little bit smelly	Sweet
4	No color	Odorless	Very sweet

Statistical analysis and data visualization

To evaluate the differences in carbohydrate content, reducing sugar levels, and starch yield among the three cassava varieties, the study employed Duncan's Multiple Range Test (DMRT) at a 95% confidence level ($p < 0.05$). This post-hoc test was selected for its ability to detect pairwise differences following ANOVA, especially when comparing multiple treatment groups with relatively small sample sizes.

In the Figures 1 and 2, different alphabetical letters above the bars and lines indicate statistically significant differences between cassava varieties based on DMRT results. For example, in Figure 1, the carbohydrate content of Randu and Melati varieties shares the same letter, indicating no significant difference between them. At the same time, Cartiva 25 is labeled with a different letter, signifying a statistically lower value. Similarly, reducing sugar content is annotated to reflect significant differences where applicable.

All statistical analyses and visualizations were conducted using R (version 4.1.3) and RStudio (version 2024.04.1). Data were plotted using base R graphics and the ggplot2 package to ensure clarity in presenting both bar plots (for carbohydrate content) and line plots (for reducing sugar and yield). This statistical approach confirms that differences in sugar content and yield are not due to random variation but reflect meaningful varietal differences that can guide cassava selection for liquid sugar production.

RESULTS AND DISCUSSION

Results

We evaluated three cassava varieties Randu, Melati, and Cartiva 25, on their capacity to produce liquid sugar, focusing on sugar conversion efficiency, starch reserves, and sensory quality. Across all metrics, Randu and Melati outperformed Cartiva 25, highlighting their promise for scalable sugar production.

Figure 1 illustrates the reducing sugar content and starch yield of each variety. Randu achieved the highest reducing sugar level (65.10%), followed by Melati (61.87%) and Cartiva 25 (51.63%), with all pairwise differences significant ($p < 0.05$). In contrast, starch yield did not differ statistically among varieties, indicating that the observed sugar output hinges on conversion efficiency rather than starch availability. Despite differences in sugar content, starch yield showed no significant variation across the three cassava varieties (Figure 1). This suggests that while sugar concentration varies, the overall conversion efficiency from raw cassava to starch remains relatively stable.

Yield outcomes depend on starch granule structure and the amylose-to-amylopectin ratios, which influence enzymatic breakdown and digestibility (Wang et al. 2022). Smaller starch granules, formed under higher temperatures, provide more surface area for enzymatic action, potentially enhancing hydrolysis speed and yield. For industrial applications, understanding starch morphology can inform enzyme selection and processing conditions. Farmers and cooperatives could benefit from training on optimal harvest timing to maximize starch recovery and product quality.

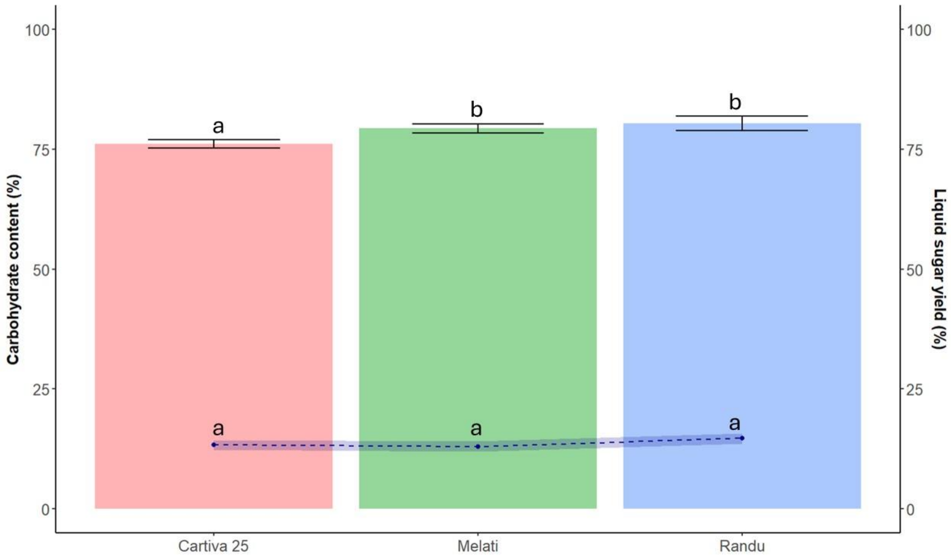

Figure 1. Reducing sugar content and starch yield of three cassava varieties. Lines and points represent mean values ± standard deviation (n = 3). Different letters adjacent to each data point indicate statistically significant differences among varieties for each parameter, as determined by DMRT at $p < 0.05$

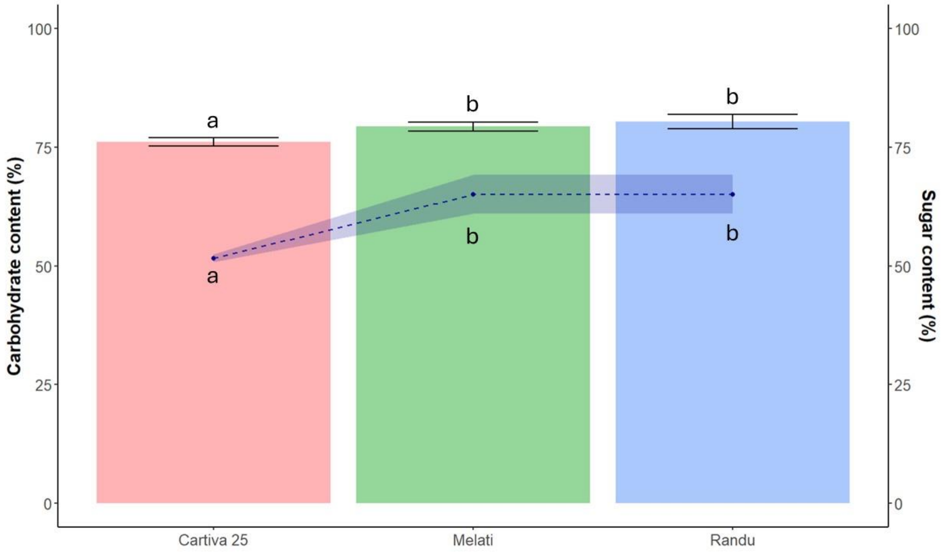

Figure 2. Total carbohydrate content of three cassava varieties (Randu, Melati, Cartiva 25). Bars represent mean values ± standard deviation (n = 3). Different letters above the bars indicate statistically significant differences among varieties based on Duncan's Multiple Range Test (DMRT) at $p < 0.05$

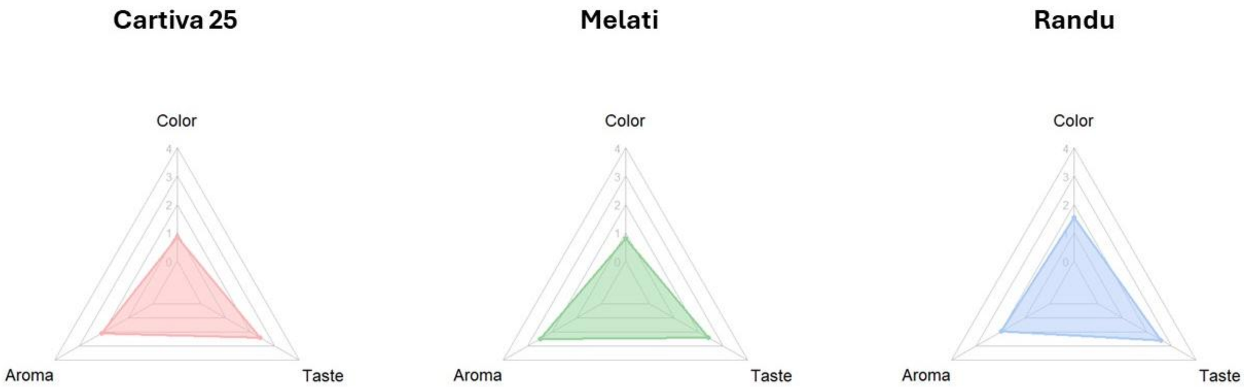

Figure 3. Organoleptic attributes of liquid sugar produced with different cassava varieties

The carbohydrate content of cassava-based liquid sugar ranged from 76.15% (Cartiva 25) to 80.39% (Randu), with Melati and Randu varieties showing significantly higher values than Cartiva 25 (Figure 2). Similarly, reducing sugar content varied between 51.63 and 65.10%, with Randu and Melati outperforming Cartiva 25. These results suggest that varietal selection plays a critical role in optimizing sugar yield.

The higher carbohydrate and reducing sugar levels in Randu and Melati varieties may be attributed to their starch composition and maturity stage. Mature cassava typically contains more starch, while overripe cassava accumulates fiber, reducing extractable carbohydrate content (Nurdjanah et al. 2020; Wahyuni et al. 2024). Additionally, processing losses during grating and filtration, where 13-20% of starch may be lost, can influence the final sugar concentrations (Subroto et al. 2020). From an industrial perspective, selecting cassava varieties with higher starch and sugar levels can boost production efficiency and reduce enzyme consumption. For local farmers, growing high-yield varieties like Randu and Melati could increase crop value and create opportunities for contract farming with sugar processors.

Figure 3 reports sensory scores for sweetness, color brightness, aroma, and overall acceptability. Randu's liquid sugar scored highest in sweetness (2.93) and brightness (2.17), with Melati and Cartiva 25 scoring lower across attributes. None met the Indonesian National Standard for complete colorlessness or odorlessness, underscoring the crucial need for post-processing refinement despite all varieties exceeding the minimum sweetness threshold.

Sensory analysis revealed that liquid sugar from Randu had the lightest color (score: 2.17), while Cartiva 25 and Melati scored closer to 1, indicating a darker brown hue. According to Indonesian National Standard (SNI 8779:2019) (National Standards Agency 2019), liquid sugar should be colorless; none of the samples met this criterion. The absence of a purification step, such as decolorization using bone char or activated carbon, likely contributed to the colored appearance (Aljohani et al. 2018; Rika and Dewi 2020).

Aroma scores ranged from 2.07 (Randu) to 2.87 (Melati), indicating that panelists detected some odor in all samples. Again, this deviates from the standard requirement for odorless liquid sugar. Deodorization techniques, such as activated carbon filtration, are commonly used in industrial settings to remove volatile compounds (Kayiwa et al. 2021; Khiaomang 2024).

Taste scores exceeded 2.8 for all varieties, with Randu achieving the highest at 2.93, indicating a sweet flavor that complies with national standards. This validates the potential of cassava-based liquid sugar as a viable sweetener, provided purification steps are added. Overall, Randu and Melati stand out as superior feedstocks for liquid sugar offering high biochemical yields and stronger sensory profiles while Cartiva 25 may require targeted improvements in conversion or purification.

Discussion

Analysis of the compositional and performance metrics across the three cassava varieties reveals a strong correlation between carbohydrate reserves and sugar release, with corresponding impacts on sensory perception. Randu and Melati, supported by their higher total carbohydrate levels, consistently achieved greater reducing sugar yields and scored highest in sweetness, whereas Cartiva 25's lower reserves resulted in modest sugar output and more subdued sensory attributes. These patterns underscore the pivotal role of varietal starch structure and endogenous enzyme systems in determining both biochemical efficiency and taste quality.

A closer examination of starch-to-sugar conversion suggests that differences in granule morphology, amylose-to-amylopectin ratios, and native enzyme cofactors drive the superior hydrolysis observed in Randu and Melati. Although absolute starch content was similar across varieties, the enhanced reducing sugar production suggests specific enzymatic advantages, possibly related to varietal gene expression or post-harvest physiological responses that merit targeted molecular and proteomic studies.

Sensory data further illuminate how non-carbohydrate factors influence product acceptability. The close correlation between sugar yield and sweetness validates the biochemical findings. Yet, the off-white hue and faint aroma detected in all samples signal contributions from phenolic pigments, residual glycosides, and Maillard reaction by-products. Future work should explore mild detoxification or selective adsorption techniques such as activated charcoal, ion-exchange resins, or membrane ultrafiltration—to strip chromophores and odorous compounds without sacrificing sweetness.

From an engineering perspective, fine-tuning the hydrolysis process offers a valuable opportunity for optimization. Creating customized enzyme blends that combine endo- and exo-glucanases with debranching enzymes could better match each starch type's structure. Using kinetic modeling of temperature, pH, and substrate levels along with real-time sugar monitoring will help identify operational parameters that maximize yield, reduce energy consumption, and control color formation.

Therefore, to apply these laboratory insights in industrial practice, it is essential to conduct broader techno-economic and life-cycle assessments. These assessments, which will compare energy inputs, water footprints, and production costs per kilogram of sugar from each variety, are crucial in identifying the most sustainable feedstock. Moreover, the role of parallel breeding efforts in enhancing amylopectin content and reducing bound phenolics cannot be overstated. These efforts could significantly bolster the potential of Randu and Melati as elite candidates, paving the way for scalable cassava-based sweetener platforms that meet both regulatory standards and consumer expectations.

In conclusion, this study confirms that selecting a cassava varietal plays a decisive role in determining the quality and yield of liquid sugar. Among the three tested varieties, Randu and Melati demonstrated superior carbohydrate and reducing sugar content, along with favorable sensory qualities, making them well-suited for industrial-scale liquid sugar production. Cartiva 25, while still viable, showed comparatively lower performance across key parameters. These findings offer practical guidance for processors seeking to optimize sugar output and product quality, and for policymakers aiming to reduce reliance on imported sugar. For industry stakeholders, these findings highlight the importance of integrating purification technologies to meet regulatory standards. For small-scale producers, modular filtration systems could be introduced to improve product quality without significant capital investment.

Prioritizing high-performing cassava varieties like Randu and Melati in agricultural extension programs and procurement schemes could strengthen local supply chains and enhance Indonesia's food system resilience. Aligning varietal promotion with industry standards and market demand will be essential to unlocking cassava's full potential as a sustainable sweetener source. Additionally, promoting cassava-based sweeteners could decrease Indonesia's reliance on imported sugar, boost rural economies, and support food system resilience. Future research should focus on scalable purification methods and assessing economic feasibility to encourage wider adoption.

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