

OPTIMIZATION OF GLUCOSE SYRUP FROM CASSAVA PEEL WASTE: DETERMINING THE OPTIMAL COMPOSITION USING THE ANALYTICAL HIERARCHY PROCESS-WEIGHTED PRODUCT METHOD

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ABSTRACT

Cassava is one of Indonesia's largest agricultural commodities. Currently, its use is primarily confined to tubers, resulting in the production of solid cassava peel waste. Notably, cassava peel contains a high carbohydrate content, comprising up to 50% of the carbohydrates found in

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ABSTRACT

the tubers. Additionally, the high cost of granulated sugar and the inability of the national sugar industry to meet Indonesia's sugar demand have become significant concerns. Consequently, this study aimed to explore the use of cassava peel waste as an alternative raw material for glucose syrup, which can potentially serve as a sugar substitute. Nine experimental treatments were tested to determine the optimal glucose syrup. The best glucose syrup was identified using an integration of the analytical hierarchy process (AHP) and weighted product method (WPM). AHP was employed to establish the weighted priorities of the criteria and sub-criteria, followed by WPM to determine the alternative weights and rank the options. The third treatment emerged as the best alternative, with a weight of 0.124, comprising 60 g cassava peel starch, 0.06 mL glucoamylase, and 2 mL α -amylase. The test results for the glucose syrup from this treatment included a reducing sugar content of 33.51%, moisture content of 64.419%, ash content of 0.137%, an organoleptic colour value of 3 (slightly cloudy), a taste rating of 3.93 (sweet), and an aroma rating of 2.93 (slightly odorous). The utilization of this waste is anticipated to enhance its economic value while mitigating its environmental impact.

Introduction

Food production and consumption are among the main causes of global environmental degradation (Cucurachi et al., 2019). Food systems are estimated to contribute between 19% and 37% of anthropogenic greenhouse gas emissions (Coelho et al., 2022). Agriculture is the most promising food sector in the country. Agriculture remains the dominant sector for economic resilience in Indonesia (Tambunan, 2013). According to the data from the Ministry of Agriculture of the Republic of Indonesia, the agricultural sector is expected to grow by 1.12% in 2023 and contribute 11.39% to the national economy. Cassava is one of the largest agricultural commodities, with a harvest of 15,730,971 metric tons in 2021. However, despite large cassava harvests, only the flesh or tuber is commonly used as a raw material for making tapioca flour, cassava chips, getuk, tape, and mocaf (modified cassava flour). Cassava peel contains approximately 50% of the carbohydrates found in tubers, and cassava peels account for approximately 8–25% of the total weight of peeled cassava (Akhadiarto, 2010). Other sources have also mentioned that the percentage of cassava peel from tubers reaches approximately 20% (Ntelok, 2017). These figures illustrate the large amount of cassava peel waste produced, yet it has not been optimally utilized (Widyastuti, 2019). Therefore, efforts are needed to harness the potential of cassava peel waste to reduce the amount of waste produced and increase its economic value. Cassava peel waste has high potential to become a breeding ground for mosquitoes and flies if not managed properly, which can certainly be harmful to health and cause pollution (Kholis et al., 2023). The use of cassava peel waste as a raw material in the food-processing industry represents a new form of innovation that offers a range of benefits and advantages, with the public displaying a positive attitude toward its utilization (Chete, 2022).

Previously, this waste was generally discarded without utilization, although cassava peel has the potential to be processed into valuable products. Several studies have used cassava peel waste as a liquid organic fertilizer (Nahrisah et al., 2020) (Sulistyowati et al., 2023) to

established sustainable cassava production centres, biofuel production (Ogundahunsi et al., 2024), bioethanol production (Permanasari & Yulistiani, 2017) (Mardina et al., 2021); (Syadiah et al., 2022), renewable electricity (Situmorang et al., 2024), adhesives for the manufacture of coconut-shell charcoal briquettes (Rudiyanto et al., 2023), raw materials for bio-briquette production in Indonesia (Fitriyano et al., 2023), bioplastic development (Fadhallah et al., 2022), and bioplastic food packaging from cassava peel and shrimp shells (Dasumiati et al., 2019). (Amadi et al., 2024) used cassava peel waste to increase microbial populations, aid hydrocarbon biodegradation, and promote the restoration of soil health. (Artati et al., 2023) used it as an alternative growth medium for *A. niger* and *Rhizopus oryzae*, with concentration modifications. (Ben, 2024) repurposed it into sustainable engineering materials such as biofuels, bioethanol, and biocomposites. (Okike et al., 2022) utilized it for nutritious animal feed, and (Osorio & Grande-Tovar, 2021) used cassava peel waste as a sorbent to remove metals from wastewater, thereby reducing environmental pollution (Ogbonna et al., 2020) utilized cassava peel waste, specifically cassava peel ash, as an additive in cement for concrete production. This approach encourages the recycling of agricultural solid waste and contributes to environmentally friendly and sustainable infrastructure. (Oghenejoboh et al., 2016) analysed the comparative efficiency of activated carbon produced from fermented cassava peels, unfermented cassava peels, and commercial grade activated carbon in wastewater treatment from refineries.

Cassava peel, with its low glycemic index, can be used as a glucose syrup. Glucose syrup is a clear, viscous liquid containing various types of saccharides and is obtained from the hydrolysis of starch using acids or enzymes, with the addition of food ingredients in accordance with the provisions of the Indonesian National Standard (SNI) 2978:2021.

Given the low glycemic index of cassava peel, it can be used to prepare glucose syrup. Glucose syrup is a clear, viscous liquid containing various types of saccharides and is obtained from the hydrolysis of starch using acids or enzymes, with the addition of food ingredients in accordance with the provisions of the Indonesian National Standard (SNI) 2978:2021. Another issue currently faced by the government, according to the data from the Directorate of Distribution Statistics, is the inability of national sugar producers to meet Indonesia's sugar demands. In 2019, Indonesia's sugar production reached 2.33 million metric tons, but declined in 2020 to 2.13 million metric tons, while the per capita sugar demand in Indonesia reached 2.66 million metric tons.

Consequently, the prices of granulated sugar have significantly increased. However, cassava peel waste has considerable potential because of its high starch content, making it a potential raw material for glucose syrup production, which is expected to serve as an alternative to sugar. Glucose syrup is a thick, clear liquid that contains various types of saccharides and is obtained from the hydrolysis of starch using acids or enzymes with the addition of food ingredients, according to the provisions in SNI 2978:2021. One patent for glucose syrup derived from kimpul starch showed results indicating that the glycemic index of glucose syrup was lower than that of granulated sugar (Rejeki, F. S., Puspitasari, D., & Wedowati, 2021). The glycemic index is an important factor that must be considered in individuals with type 2 diabetes mellitus to control blood glucose levels (Kisnawaty et al., 2023). Therefore, the development of glucose syrup from cassava peel waste with a low glycemic index is expected to result in a product that can be used as a healthier and more community-friendly substitute for granulated sugar, particularly for people with diabetes. In addition to its benefits

for the community, especially for those with diabetes, glucose syrup also has potential applications in the industrial sector. Glucose syrup has several advantages over sucrose, including its liquid form, which makes it more practical. This facilitates the use of glucose syrup in various industrial applications (Harni et al., 2021). The food industry also prefers glucose syrup because of its nutritional value and functional properties, including moisture stabilization, softening ability, texture formation, prevention of sucrose crystallization, and crust formation in baked goods (Zargaraan et al., 2016).

Product development that considers environmental, economic, and social impacts is the realization of a sustainable supply chain. From an environmental perspective, a sustainable supply chain seeks to minimize the environmental damage caused by a product. From an economic perspective, the implementation of a sustainable supply chain is expected to create new job opportunities. From a social perspective, implementing a sustainable supply chain empowers local communities by collaborating with suppliers that support community development (Lee & Vachon, 2016).

Glucose syrup is a purified and concentrated saccharide solution derived from starch (Hull, 2010). Therefore, glucose syrup is a clear and viscous liquid with glucose as its main component, resulting from starch hydrolysis. Various carbohydrate sources, such as cassava, sago, sweet potatoes, and corncobs, are the primary raw materials for producing glucose syrup (Harni, Putri, Gusmalini, et al., 2021). In addition to these carbohydrate sources, cassava peels yield a large amount of glucose when sufficient enzymes are used, although this amount is slightly lower than that obtained from the tubers. However, cassava peels can still be utilized to produce glucose syrup, which can serve as an alternative substitute in the manufacture of food additives, such as thickeners, sweeteners, and humectants, as well as in the production of carbonated beverages and bread (Nwalo & Cynthia, 2014). Moreover, using cassava peel waste as a raw material in glucose syrup production has positive environmental impacts, such as reducing waste accumulation, which causes foul odours and attracts insects and diseases, while adding value to waste that has not yet been commercialized.

In this study, the materials used to produce glucose syrup from cassava peel waste included cassava peel waste, α -amylase, and glucoamylase enzymes. Latifah & Martiyana (2023) utilized cassava peel waste for liquid sugar production through an enzymatic method by adding α -amylase and glucoamylase enzymes and reported that cassava peel waste can be effectively converted into liquid sugar, with optimal results achieved using 0.2 mL enzyme. α -Amylase is only capable of hydrolysing 1-4 bonds, whereas in glucose syrup production, two crucial bonds must be hydrolysed: 1-4 and 1-6. Therefore, glucoamylase was used because it can break both bonds to produce dextrose (Hull, 2010).

To obtain the optimal combination for glucose syrup production, various proportions of α -amylase and glucoamylase were tested in several experiments. After the experiments, organoleptic, reducing-sugar, moisture, and ash content tests were conducted. The organoleptic test utilizes human senses, and the aspects tested included colour, taste, smell, and texture (Ray, 2021). Dextrose and other sugars in glucose syrup are reducing sugars, also known as dextrose equivalents (Hull, 2010). Moisture content analysis is the difference between the weight of the fresh material and its weight when dried, and ash content is a mixture of mineral or inorganic content in food (Pojić et al., 2015).

Subsequently, the best composition combination for producing glucose syrup was determined using multi-criteria decision-making (MCDM) tools, specifically by combining the

analytical hierarchy process (AHP) and weighted product method (WPM). (Hasibuan et al., 2025), using the Analytical Hierarchy Process (AHP) to produce bio-briquettes from coconut shell biochar. AHP was also used by (Mohammed & Suliman, 2023) to analyse the suitability of agricultural land for crop growth, (Sharififar et al., 2013) to evaluate land in an effort to achieve sustainable agricultural production, (Annas et al., 2020) to simulate reverse and green logistics costs and (Benezine et al., 2022) to determine the most suitable location from an environmental and economic standpoint to ensure effective regional management. (Dinulescu & Dobrin, 2022) used fuzzy AHP to classify and prioritize healthcare service quality attributes. (Utomo et al., 2019) developed a decision support system that can assist coaches in selecting talented archery athletes using the weighted product model (WPM). (Yi & Jang, 2022) used WPM to select the best mobile phone. Chinnasami et al. (2023) used the WPM to evaluate drinking water quality. Goswami et al. (2020) used the analytical hierarchy process (AHP) and weighted product model (WPM) to select the best laptop model.

MCDM has not yet been applied in previous studies on the utilization of cassava peel waste in glucose syrup. The analytical hierarchy process (AHP) is a multi-criteria decision-making (MCDM) method or decision-making with multiple criteria and hierarchical components that facilitates the selection of the best (alternative) decision (Kamble, 2024). WPM is a method capable of evaluating many alternatives based on criteria, in which each attribute is independent of others (Aminudin et al., 2018). This method has the advantage of not being highly complex; therefore, its calculation process does not require significant time (Hardiani et al., 2022). These two methods were combined to produce more stable ranking results and reduce subjectivity (Harjanto et al., 2021a). The AHP method was used to determine the priority weights of each criterion and sub-criterion. After obtaining the weights for each criterion and sub-criterion, the best alternative for cassava peel glucose syrup was selected using the WPM. Thus, a conclusion can be drawn regarding the recommended composition combination for utilizing cassava peel waste as an alternative raw material for glucose syrup production.

In this study, MCDM tools were used to determine the best cassava peel glucose syrup recommendations. It is necessary to simultaneously consider multiple criteria and sub-criteria. The use of MCDM tools makes it possible to consider many criteria when making decisions among numerous alternatives (Sahoo and Goswami, 2023). In the product development process of cassava peel glucose syrup, each criterion and sub-criterion have its own consequences if not met according to SNI 01-2978-1992. Therefore, using the AHP method, it was clear which criteria, and sub-criteria should be prioritized for fulfilment, based on pairwise comparisons conducted by experts. The comparisons used can come from actual measurements or fundamental scales that represent the relative strength, preference, or tendency of a relationship (Saaty, 1990). After obtaining the respective weights for each criterion and sub-criterion, the determination of the best combination recommendation for glucose syrup composition continued with the WPM method because AHP has a high degree of subjectivity, whereas alternative ranking requires a method with objective results. Therefore, the WPM method was selected to overcome the limitations of the AHP method (Harjanto et al., 2021). This is the background for the selection of a combination of AHP and WPM methods for data processing rather than using commonly employed methods, such as experimental design methods.

Despite the high volume of cassava processing waste generated annually, limited studies have systematically optimized its conversion into value-added products using an integrated decision-making framework. Most existing research focuses primarily on technical yield improvement without simultaneously considering sensory quality and multi-criteria evaluation. Therefore, this study addresses this gap by combining enzymatic process optimization with a structured multi-criteria decision-making approach (AHP–WPM) to identify the most preferable glucose syrup formulation derived from cassava peel starch. By bridging experimental processing techniques with quantitative decision analysis, this research contributes not only to waste valorisation and sustainable agro-industrial development but also to methodological advancements in selecting optimal formulations based on comprehensive performance criteria.

Experimental design methods are generally conducted with the aim of explaining the causes of response variation in each observed unit by determining influential factors, obtaining recommendations or optimal conditions for the observed response, comparing responses from various combinations of different levels, creating response models, and minimizing the impact of uncontrolled factors to produce robust products or processes (Dwitama, 2019). The main objective of this study was to obtain the best cassava peel glucose syrup recommendation by simultaneously considering four criteria in the decision-making process: reducing sugar content, moisture content, ash content, and organoleptic properties, including the sub-criteria of colour, taste, and aroma. Because numerous criteria and sub-criteria must be considered simultaneously in the decision-making process with many alternatives, MCDM tools have been used in data processing to achieve this goal.

Materials and Methods

The Experimental Design

The research began with the production of glucose syrup derived from cassava peel waste using a controlled laboratory procedure. This approach follows an experimental research design in which specific variables are deliberately manipulated to observe their effects on the outcome (Cooper & Schindler, 2014). The selection of enzyme levels was informed by several previous studies to ensure methodological relevance and comparability. Pontoh & Low (1995a) applied 35 units of α -amylase and 60 units of glucoamylase per 60 g of starch. Ardiansyah et al., (2018) used 0.15 mL of α -amylase and 0.9 mL of glucoamylase for 300 g of starch, whereas (Latifah & Martiyana, 2023) employed 1 mL of α -amylase and 1 mL of glucoamylase for 30 g of starch. These references provided a scientific basis for determining the treatment ranges and proportional adjustments of enzyme concentrations in the present work. Based on this foundation, two factors were varied at three levels: the amount of α -amylase and the amount of glucoamylase. With the starch quantity fixed at 60 g, different combinations of both enzymes were applied to establish the treatment structure, as presented in Table 1.

Table 1.
Treatment design

Enzymes		α -amylase		
		0.035 mL	0.03 mL	2 mL
Glucoamylase	0.06 mL	Treatment 1 (T1)	Treatment 2 (T2)	Treatment 3 (T3)
	0.12 mL	Treatment 4 (T4)	Treatment 5 (T5)	Treatment 6 (T6)
	2 mL	Treatment 7 (T7)	Treatment 8 (T8)	Treatment 9 (T9)

Starch Extraction

Several basic tools and materials are required to extract starch from cassava skin. These include a blender or grinding machine for size reduction, a filter cloth for separating solid residues, an 80-mesh sieve to ensure particle uniformity, and containers for holding and settling the starch slurry. The primary raw material was fresh and clean peel material, and water served as the extraction medium.

Starch was extracted from the outer layer of cassava using a procedure similar to the one used for cassava tubers. The peel material was first washed thoroughly to remove adhering impurities and then ground with clean water until a smooth slurry was formed. The resulting mixture was filtered and pressed to obtain the filtrate, which was subsequently allowed to settle until sediment accumulated at the bottom of the container. The supernatant, typically clear and slightly yellowish, was carefully removed, leaving the starch sediment. The collected sediment was then dried in a well-ventilated area (Ardiansyah et al., 2018).

Glucose Syrup Production

The production of glucose syrup from cassava peel starch offers an innovative and sustainable method for utilizing agro-industrial waste. This process involves the conversion of starch extracted from cassava peel into glucose through enzymatic hydrolysis, specifically liquefaction and saccharification. The necessary equipment included a reaction vessel, valve, dropper, micropipette, measuring cylinder, Erlenmeyer flask, thermometer, pH meter, digital scale, stirrer, funnel, and storage bottle. The ingredients required for pH adjustment were cassava peel starch, distilled water (Aquadest), α -amylase, glucoamylase, and 1 N HCl. According to the method described by (Pontoh & Low, 1995), the process begins with dissolving cassava peel starch in distilled water, with the total mixture (starch + water) weighing approximately 200 g. The mixture was stirred for approximately five minutes while α -amylase was added. It was then heated to 80°C and maintained at that temperature for three minutes to reduce viscosity. The temperature was then rapidly increased to 106°C and held for five minutes to complete the liquefaction phase. Subsequently, the temperature was lowered to 60°C, and the pH was adjusted to 4.5 using 1 N HCl before adding glucoamylase. The mixture was gently stirred and allowed to stand for 48–73 h to enable optimal saccharification, during which starch was converted into glucose syrup.

After completing the technological process and obtaining results from the nine treatment combinations, these data were further analysed using a multi-criteria decision-making

(MCDM) approach, namely AHP and WPM, to identify the most preferable glucose syrup formulation. The best glucose syrup was selected using weighted criteria and sub-criteria priorities, as assessed by two expert respondents. The first respondent was an expert from the Food Engineering and Agricultural Products Laboratory, and the second respondent was a lecturer from the Department of Food Technology with expertise in food chemistry and microbiology. The criteria and sub-criteria used to determine the optimal glucose syrup from cassava peel waste are as follows:

1. Organoleptic

An organoleptic test is a method that utilizes five senses, in which the evaluated aspects include colour, taste, aroma, and texture (Ray, 2021). The organoleptic test criteria for cassava peel glucose syrup are as follows:

a. Colour

According to SNI 01-2978-1992, glucose syrup is expected to be colourless and clear. To evaluate this attribute, a five-point Likert scale was applied, with 1 indicating very cloudy/coloured, 2 cloudy/coloured, 3 slightly cloudy/coloured, 4 clear, and 5 very clear.

b. Aroma

According to SNI 01-2978-1992, the product should not have any noticeable odour. The sensory evaluation of aroma therefore employed a five-level Likert scale ranging from 1 (strong odor) to 5 (completely odourless), with intermediate categories representing decreasing odour intensity

c. Taste

In accordance with SNI 01-2978-1992 standards, glucose syrup should exhibit a sweet flavour. Taste preference was assessed using a five-point Likert scale, where the lowest score (1) represented not sweet at all and the highest score (5) indicated very sweet, with gradual sweetness levels between these two extremes.

2. Reducing sugar content

Dextrose and other sugars present in glucose syrup are reducing sugars, also referred to as dextrose equivalents (DE). Glucose syrup generally has a DE value, expressed as d-glucose, of not less than 20%, based on dry matter (Hull, 2010). According to SNI 01-2978-1992, the minimum reducing sugar content in glucose syrup is 30%.

3. Moisture content

Moisture content analysis is the difference between the weights of fresh and dry materials (Kristiandi et al., 2021). The moisture content represents the percentage of water in the glucose syrup, the higher the moisture content, the thinner the syrup. According to SNI 01-2978-1992, the maximum moisture content in glucose syrup is 20%.

4. Ash content

Ash content refers to the mixture of mineral or inorganic substances present in food ingredients (Kristiandi et al., 2021). According to SNI 01-2978-1992, the maximum ash content in glucose syrup is 1%. Therefore, a lower ash content is preferable.

The purpose of decision-making is to obtain the best glucose syrup to determine the most suitable combination of compositions according to the criteria and sub-criteria described above. Next, a hierarchy or decision-making model was developed to illustrate the relationship between the goal, criteria, sub-criteria, and available alternatives. The decision-making hierarchy for identifying the optimal glucose syrup is shown in Figure 1.

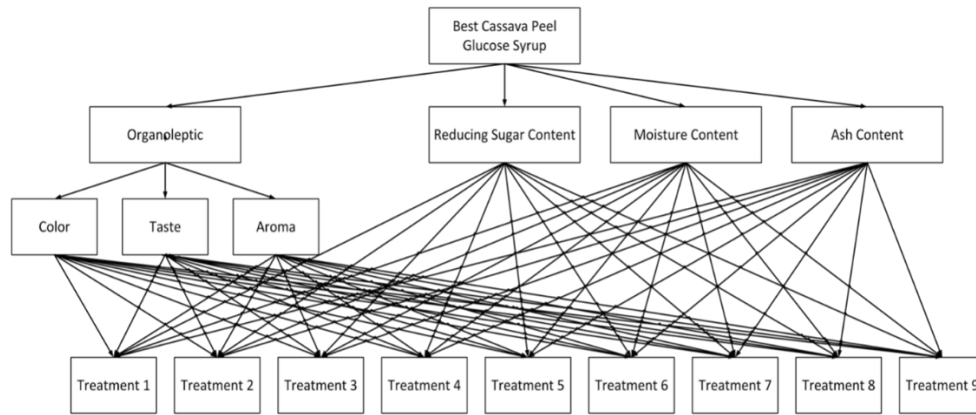


Figure 1. Decision-making hierarchy

The Analytical Hierarchy Process (AHP)

The analytical hierarchy process (AHP), developed by (Saaty, 1990), is a structured technique for organizing and analysing complex decisions based on mathematics and psychology. AHP is a reliable, rigorous, and robust method for eliciting and quantifying subjective judgments in multi-criteria decision-making (Tavana et al., 2023). AHP is a mathematical recipe that allows the user to insert data into the input and obtain a ready-to-use solution from the output (Kulakowski, 2020). The process begins with defining relevant criteria related to the decision problem. A pairwise comparison matrix was then created to evaluate the importance of one criterion over another. Each column of the matrix is summed, and each element is normalized by dividing it by the total of its respective columns. The average of each row was then calculated to obtain the weight vector or eigenvector, which represents the relative importance of each criterion.

Once the weights were determined, a consistency test was performed to ensure the reliability of the judgments in the pairwise comparison. The test begins by multiplying the comparison matrix with the weight vector, yielding a new vector. Each element of the resulting vector was then divided by its corresponding weight to obtain a consistency vector. The average of the elements in this vector provides the maximum eigenvalue ($\lambda_{\max}$), which is used to calculate the consistency index (CI) using Equation 1.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (1)$$

where:

n – denotes the number of criteria. The consistency ratio (CR) was obtained by comparing the CI to the random index (RI), a standard value based on matrix size.

According to Umbara (2016), pairwise comparison inputs were considered consistent if $CR \leq 0.1$. If the CR value exceeded this threshold, the comparison matrix must be revised for a more consistent judgment.

Weighted Product Method

The weighted product (WP) method is an approach within the multi-attribute decision-making (MADM) framework. This method is widely used to evaluate and rank multiple alternatives based on a set of predefined criteria, wherein each attribute or criterion is assumed to be independent of others (Aminudin et al., 2018). A key advantage of the WP method is its simplicity and computational efficiency, making it the preferred choice when a quick and effective decision-making tool is required (Hardiani et al., 2022).

Amelia (2019) outlined the decision-making process using the WP method, which involves several steps. The first step is to adjust the criterion weights. This process involves normalizing the assigned weights and classifying each criterion as either a benefit or a cost. Benefit criteria positively contribute to the objective, whereas cost criteria represent undesirable factors that must be minimized.

Subsequently, the S vector for each alternative is determined. This is calculated by multiplying all performance values of an alternative for each criterion, each raised to the power of the weight assigned to that criterion, using Equation (2). Mathematically, the S vector reflects the overall performance of an alternative across all criteria.

$$S_i = \prod_{j=1}^n X_{ij} w_j \quad (2)$$

Subsequently, vector V is calculated by dividing the S vector value of each alternative by the total of all S vectors, as shown in Equation 3. The resulting V values are then used to rank the alternatives, with the highest V indicating the most favourable option.

$$V_i = \frac{\prod_{j=1}^n X_{ij} w_j}{\prod_{j=1}^n (X_{ij*}) w_j} \quad (3)$$

After obtaining the priority weights for the criteria and sub-criteria, the next step was to weigh and rank the alternatives to determine the best cassava peel glucose syrup alternative using the WPM method. For the WPM calculations, the assessment of each alternative based on the criteria of moisture content, ash content, reducing sugar content, and organoleptic characteristics, including colour, taste, and aroma, is shown in Table 2.

Table 2.
Value scale of the criteria used

Value	Color	Taste	Aroma	Reducing sugar content -X (%)	Moisture content - Y (%)	Ash content - Z (%)
1	Very cloudy / coloured	Not sweet at all	Very smelly	$X < 7.5$	$Y < 5$	$Z < 0.25$
2	Cloudy / coloured	Not sweet	Smelly	$7.5 \leq X < 15$	$5 \leq Y < 10$	$0.25 \leq Z < 0.5$
3	Slightly cloudy / coloured	Slightly sweet	Slightly smelly	$15 \leq X < 22.5$	$10 \leq Y < 15$	$0.5 \leq Z < 0.75$
4	Clear	Sweet	Odourless	$22.5 \leq X < 30$	$15 \leq Y < 20$	$0.75 \leq Z < 1$
5	Very clear	Very sweet	Completely odourless	$X \geq 30$	$Y \geq 20$	$Z \geq 1$

Calculation of Production Costs

After determining the best glucose syrup composition, the cost was calculated to estimate the cost of goods sold and the selling price per bottle (approximately 120 mL) using the full costing method, based on the production process and with several adjustments for MSME-scale production.

Results and Discussion

Experimental Results

Based on the experiments conducted, 27 glucose syrup samples were obtained, consisting of nine treatments, each replicated thrice. The samples obtained from each experiment using different combinations of α -amylase and glucoamylase enzyme volumes are presented in Table 1. The experimental results for each treatment are presented in Figures 2a to 2i.

Next, tests were performed using experimental glucose syrup. The tests included determining the reducing sugar, moisture, and ash contents, as well as assessing the colour, taste, and aroma. Each treatment was replicated thrice, resulting in three samples for each treatment, and a total of 27 glucose syrup samples were tested. The test results from the three samples for each treatment were averaged to obtain the test results for the nine treatments in the experiment on glucose syrup from cassava peel waste, as shown in Table 4.

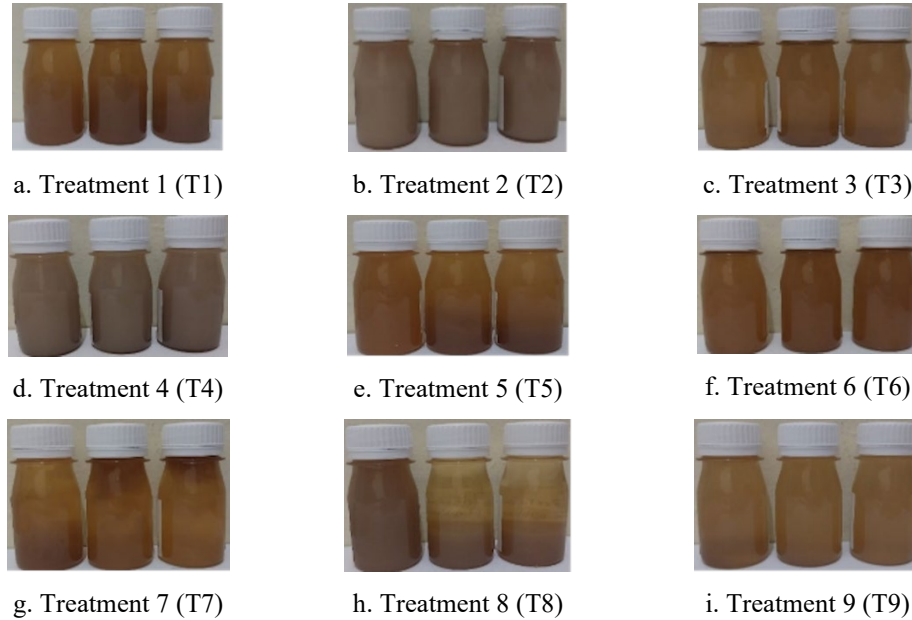


Figure 2. Experimental result

Table 4.
Test results of cassava peel glucose syrup

Treatments	Reducing sugar content (%)	Moisture content (%)	Ash content (%)	Organoleptics		
				Colour	Taste	Aroma
T1	20.870	69.099	0.066	2.67	3.47	2.47
T2	25.760	66.442	0.046	1.60	3.87	2.80
T3	33.507	64.516	0.158	3.00	3.93	2.93
T4	30.033	69.172	0.068	1.00	3.20	2.27
T5	30.290	70.184	0.046	2.80	3.07	3.20
T6	28.887	65.371	0.208	1.80	4.13	2.73
T7	29.097	67.146	0.070	2.80	3.93	2.60
T8	27.073	69.983	0.069	2.13	4.27	2.93
T9	25.127	66.287	0.112	2.40	4.40	2.67

Dextrose and other sugars present in glucose syrup are reducing sugars, also known as dextrose equivalents (Hull, 2010). The reducing sugar content directly affects the sweetness of glucose syrup; the higher the reducing sugar content, the sweeter the cassava peel glucose

syrup. According to the Indonesian National Standard (SNI), the minimum reducing sugar content in glucose syrup is 30%, and only the third, fourth, and fifth treatments met this requirement, with Treatment 3 showing the highest value, while the lowest value was observed in Treatment 1. Higher reducing sugar content results in sweeter taste (Zhang et al., 2024). Variations in the reducing sugar content between treatments may be influenced by the structural characteristics of cassava peel starch, specifically its amylose–amylopectin composition and chain architecture. Starch consists of linear amylose linked by α -(1→4) glycosidic bonds and highly branched amylopectin containing α -(1→4) and α -(1→6) bonds, whose susceptibility to enzymatic hydrolysis depends on the molecular structure, granule organization, and crystalline–amorphous distribution (Zhang et al., 2015). Enzymatic hydrolysis of starch is generally described by the Michaelis–Menten kinetic model, where the reaction rate depends on the substrate concentration, maximum reaction velocity (V_{max}), and the Michaelis constant (K_m), which reflects the enzyme–substrate affinity. α -Amylase primarily cleaves internal α -(1→4) bonds to produce dextrin, whereas glucoamylase hydrolyses α -(1→4) and α -(1→6) bonds from the non-reducing end to release glucose.

The synergistic interaction between these enzymes increases saccharification efficiency and affects the reducing sugar yield, especially under conditions near substrate saturation (Chamorro et al., 2025). In more complex catalytic systems involving multiple intermediates, kinetic equations can be derived using systematic approaches, such as the King–Altman method. Therefore, the higher reducing sugar content observed in Treatment 3 likely reflects favourable starch structural characteristics and more efficient enzymatic kinetics. Although specific kinetic parameters, such as K_m and V_{max} , were not determined experimentally in this study, future kinetic evaluations will provide deeper insights into the relationship between starch structure and glucose yield optimization.

Moisture content analysis is the difference between the fresh and dry weights of a material (Kristiandi et al., 2021). Thus, moisture content indicates the amount of water contained in a substance. According to SNI, the maximum moisture content in glucose syrup is 20%. Based on the results of the moisture content test for glucose syrup made from cassava waste, the moisture content still far exceeded the standard set by the SNI. Therefore, improvements are necessary because moisture content is an important parameter in the food industry for determining the quality and shelf life of a product (Gowen, 2012). During production, the water content is meticulously managed through methods such as boiling point elevation, which directly affects the texture and stability of the product (Ergun et al., 2010). Based on interviews with lecturers from the Food Technology Department, efforts to reduce the moisture content of glucose syrup involve conducting a longer cooking process. High moisture content in glucose syrup can be tolerated as long as the syrup remains sweet; however, it would be better if it met the SNI standard. The higher the temperature and the longer the cooking process, the greater the evaporation of water. Consequently, the moisture content decreased, leading to a higher total sugar yield (Chen et al., 2020).

Ash content refers to the mixture of minerals and inorganic substances in food materials. According to the Indonesian National Standard (SNI), the maximum ash content in glucose syrup is 1%. Based on the results of the ash content tests for each treatment, it was found that the ash content in all treatments met the quality standards set by SNI, with no more than 1%. The quality of glucose syrup is greatly influenced by its ash content. Ash is the inorganic residue remaining after the organic matter of the syrup is completely oxidized or ignited. Ash

content assessment is usually part of proximate analysis for nutritional assessment and is regarded as a crucial quality characteristic for various food ingredients (Ismail, 2017). In addition to indicating the mineral content of a product, ash content also reflects the purity and cleanliness of the resulting product. Therefore, the low ash content found in these tests indicates that the glucose syrup produced from cassava peel waste does not contain contaminants that could affect its cleanliness and purity. Maintaining the purity of glucose syrup is crucial, especially because it is a key ingredient in candies and beverages. The presence of additional sugars or substances can alter the taste, texture, and shelf life of these products. Therefore, regulations ensuring the purity and quality of glucose syrup are essential for preventing contamination and ensuring consumer safety (Permanasari et al., 2018).

Organoleptic testing is a method that utilizes the five senses, in which the aspects tested can include colour, taste, aroma, and texture. Therefore, organoleptic testing results are closely related to consumer acceptance. Organoleptic testing is important for evaluating the quality and safety of food and beverage products (Tanone & Prasetya, 2019). Thus, to utilize cassava peel waste as an alternative raw material for producing glucose syrup, organoleptic tests were conducted, covering colour, taste, and aroma. This is essential for determining consumer acceptance and guiding product development (Iragaba et al., 2021).

The organoleptic colour test was conducted using a Likert scale ranging from 1 (very cloudy/coloured) to 5 (very clear). According to SNI standards, glucose syrups should be colourless. Based on the experimental results, a slightly cloudy colour was observed in the first, third, fifth, and seventh treatments. In the second, sixth, eighth, and ninth treatments, the colour was cloudy. The fourth treatment resulted in a cloudy product.

Based on the results of the organoleptic colour test conducted by the panellists, the combination in the third treatment (60 g of starch; 0.06 mL glucoamylase and 2 mL α -amylase) had an organoleptic colour value of 3, indicating that the glucose syrup was still slightly cloudy (brownish). However, according to SNI standards, glucose syrup should be colourless or clear. Therefore, improvements or additional processes are required for glucose syrup production to achieve the desired colour. The colour is one of the parameters that influence consumer perception of food products, along with taste, texture, and nutritional content. Moreover, brightly coloured food products are more attractive to consumers (Tutuhatunewa, 2020).

The organoleptic taste test was conducted using a Likert scale ranging from 1 (not sweet at all) to 5 (very sweet). According to the Indonesian National Standard (SNI), glucose syrup should have a sweet taste. Based on the experimental results of glucose syrup production using cassava peel waste, the resulting glucose syrup had a sweet taste. The first, fourth, and fifth treatments produced sweet glucose syrup. The second, third, sixth, and ninth treatments resulted in sweet-tasting glucose syrup. These four treatments met the SNI quality standard, in which glucose syrup has a sweet taste. Cassava peel glucose syrup, which is used as a sugar substitute, has a sweet taste. A requirement for a substance to be used as a sugar substitute is its sweet taste (Soesilo et al., 2006).

The organoleptic test for aromas was conducted using a Likert scale ranging from 1 (very odorous) to 5 (completely odourless). According to the Indonesian National Standard (SNI), glucose syrup should be completely odourless. Based on the experimental results obtained using cassava peel waste as a raw material for glucose syrup production, the first and fourth treatments were odorous, whereas the remaining seven treatments were slightly odorous. The organoleptic aroma test results revealed that glucose syrup produced from cassava peel waste

was generally odorous and, thus, did not meet the SNI quality requirements, indicating that glucose syrup should be odourless. Interviews with panellists revealed that the aroma of glucose syrup from cassava peels is generally described by the characteristic smell of cassava peels and fermentation. Although this aroma is acceptable, it would be preferable if it were absent to avoid interference with the overall flavour. The organoleptic quality of the aroma of cassava peel glucose syrup requires further improvement because a pleasant and appealing aroma can increase consumer preference for a food product, indicating that aroma is an important aspect to consider (Ege et al., 2023). Furthermore, consumers can assess the appeal of a food material based on its aroma, even from a distance (Tutuhatunewa, 2021).

Criteria/Sub-criteria Weighting Results

Respondents 1 and 2, experts in food chemistry and nutrition and food technology, respectively, provided the input for the pairwise comparison of criteria and sub-criteria. The consistency ratio (CR) value of pairwise comparisons must be less than 10% to ensure that the pairwise comparisons are consistent. The results of the pairwise comparisons of the combined criteria are presented in Table 5.

Table 5.

Pairwise comparison of combination criteria

Criteria	Ash content	Moisture content	Reducing sugar content	Organoleptic
Ash content	1	3.873	0.333	1
Moisture content	0.258	1	0.169	0.2
Reducing sugar content	3	5.916	1	3.873
Organoleptic	1	5	0.258	1

The normalization matrix and the average value of each row in the normalization matrix represent the weights of the criteria in that row (Table 6).

Table 6.

Eigen vector of criteria

Criteria	Ash content	Moisture content	Reducing sugar content	Organoleptic	Weight
Ash content	0.190	0.245	0.189	0.165	0.197
Moisture content	0.049	0.063	0.096	0.033	0.060
Reducing sugar content	0.571	0.375	0.568	0.638	0.538
Organoleptic	0.190	0.317	0.147	0.165	0.205

Subsequently, the weights of the organoleptic sub-criteria, including colour, taste, and aroma, were determined. The combination matrices are listed in Table 7.

Table 7.
Pairwise comparison of organoleptic sub-criteria combinations

	Aroma	Taste	Colour
Aroma	1	0.707	3
Taste	1.414	1	5
Colour	0.333	0.200	1

The normalization matrix and the average value of each row in the normalization matrix represent the weights of the organoleptic sub-criteria in that row (Table 8).

Table 8.
Eigen vectors of organoleptic sub-criteria

	Aroma	Taste	Colour	Weight
Aroma	0.364	0.371	0.333	0.356
Taste	0.515	0.524	0.556	0.532
Colour	0.121	0.105	0.111	0.112

The priority weights obtained based on the determination of the weights for the criteria and sub-criteria using the AHP method are listed in Table 9.

Table 9.
Priority weight

Criteria/sub-criteria	Weight
Reducing sugar content	0.538
Moisture content	0.060
Ash content	0.197
Organoleptic	0.205
- Taste	0.532
- Aroma	0.356
- Colour	0.112

Selection criteria and sub-criteria were established by referring to the Indonesian National Standard to determine the optimal combination of compositions that produces the best cassava peel glucose syrup, selection criteria and sub-criteria were established by referring to SNI (Indonesian National Standard). The criteria include the reducing sugar content, moisture content, ash content, and organoleptic properties, which consist of the following sub-criteria: colour, taste, and aroma. The criteria and sub-criteria were weighted using the analytical hierarchy process (AHP) method. The pairwise comparison in AHP was conducted by two expert respondents: the first respondent was an expert from the Laboratory of Food Engineering and Agricultural Products, and the second respondent was a lecturer from the

Department of Food Technology with expertise in food chemistry and microbiology. From the results of the consistency index and consistency ratio calculations using Equations 1 and 2, with a maximum value of 4.129 and n of 4, a CI of 0.043 and CR of 0.048 were obtained. Because the consistency ratio (CR) was less than 10%, the combined pairwise comparison was considered consistent.

Based on pairwise comparisons, the calculated weights for the criteria were as follows: reducing sugar content (0.538), ash content (0.197), moisture content (0.060), and organoleptic properties (0.205). The reducing sugar content received the highest weight because a higher reducing sugar content results in a sweeter taste. Cassava peel glucose syrup is expected to have a sweet flavour and can be used as an alternative sugar substitute. The next highest weighting criterion was organoleptic properties (0.205). Organoleptic properties, including taste, colour, and aroma, are the second highest after reducing sugar content because organoleptic testing or tests conducted directly using human senses demonstrate consumer acceptance of a food product. Therefore, organoleptic properties are an important criterion to prioritize as they are related to future consumer acceptance.

The organoleptic criteria consisted of three sub-criteria: colour, taste, and aroma. Experts' pairwise comparisons yielded the following sub-criteria priority weights: colour, 0.112; taste, 0.532; and aroma, 0.356. Taste had the highest priority weight because taste is the determining factor for whether consumers like a food product and greatly influences consumer acceptance (Ege et al., 2023). The next highest priority among the organoleptic sub-criteria was aroma. Aromas have a high weight because the aroma or smell of a food product determines its palatability. A pleasant and appealing aroma can make a food product more favourable to consumers, making it an important aspect to consider (Ege et al., 2023).

The next step was to determine the best alternative using the WPM method based on the priority weights of the criteria and sub-criteria obtained from the WPM method. In the WPM, two types of variables influence decision-making: cost and benefit. A criterion is considered a cost variable if a lower value is preferable; it is considered a benefit variable if a higher value is preferable (Harmayani & Harahap, 2022). The weight exponent for cost variables is negative, whereas that for the benefit variables is positive. The classification of criteria and sub-criteria for selecting the best cassava peel glucose syrup is listed in Table 10.

Table 10.

Classification of criteria and sub-criteria

Criteria/Sub-criteria	Variable	Exponent Value
Reducing sugar content	Benefit	Positive
Moisture content	Cost	Negative
Ash content	Cost	Negative
Organoleptic	Benefit	Positive
- Colour	Benefit	Positive
- Taste	Benefit	Positive
- Aroma	Benefit	Positive

Based on the results of the organoleptic tests for colour, taste, and aroma, as well as the weight of each sub-criteria, the organoleptic S_i vector for each alternative was determined as the organoleptic value using Equation (2); the results are listed in Table 11.

Table 11.

 S_i Vector

Alternative	Reducing sugar content		Moisture content		Ash content		Organoleptic		S_i Value
	Criteria weight	Value	Criteria weight	Value	Criteria weight	Value	Criteria weight	Value	
T1	0.538	3	0.060	5	0.197	1	0.205	2.982	2.051
T2	0.538	4	0.060	5	0.197	1	0.205	3.121	2.417
T3	0.538	5	0.060	5	0.197	1	0.205	3.437	2.780
T4	0.538	5	0.060	5	0.197	1	0.205	2.483	2.600
T5	0.538	5	0.060	5	0.197	1	0.205	3.082	2.718
T6	0.538	4	0.060	5	0.197	1	0.205	3.249	2.437
T7	0.538	4	0.060	5	0.197	1	0.205	3.267	2.440
T8	0.538	4	0.060	5	0.197	1	0.205	3.454	2.468
T9	0.538	4	0.060	5	0.197	1	0.205	3.439	2.466

A recap of the S_i vector values is listed in Table 11. Subsequently, based on the S_i vector values in Table 17, the V_i vector values were determined and used to rank the alternatives using Equation (3). A recap of the V_i vector values (weights) and ranking of each alternative are listed in Table 12.

Table 12.

Weights and ranking

Alternative	Weight (V_i)	Ranking
T1	0.0917	9
T2	0.1080	8
T3	0.1242	1
T4	0.1162	3
T5	0.1214	2
T6	0.1089	7
T7	0.1090	6
T8	0.1103	4
T9	0.1102	5

The selection of the best alternative refers to the weights of the criteria and sub-criteria previously determined using the AHP method, and the ranking of the best alternatives is performed using the weighted product method. A combination of these two methods has been employed to produce a more stable ranking and reduce subjectivity (Harjanto et al., 2021b).

Based on the tests conducted and the weights of the criteria and sub-criteria obtained and processed using the weighted product method, the weights for each criterion were as follows: first treatment, 0.091; second treatment, 0.108; third treatment, 0.124; fourth treatment, 0.116; fifth treatment, 0.121; sixth treatment, 0.109; seventh treatment, 0.109; eighth treatment, 0.110; and ninth, 0.110. The greater the weight, the better the alternative. Therefore, the third treatment was the best alternative for cassava peel glucose syrup with a combination of 60 g of starch with 0.06 mL of glucoamylase and α -amylase (2 mL of α -amylase).

The glucose syrup produced in the third treatment had a reducing sugar content of 33.507%, moisture content of 64.516%, and ash content of 0.158%. In addition, based on the results of the organoleptic test, it is known that the cassava peel glucose syrup produced in the third treatment scored 3 for colour, which means it is still slightly cloudy (brownish); a taste score of 3.93, which means it is sweet; and a smell score of 2.93, indicating that the glucose syrup produced still had a slightly noticeable odour. According to the Indonesian National Standard (SNI), cassava peel glucose syrup produced from the composition combination in the third treatment met the standard for reducing sugar content, which is a minimum of 30%. The ash content also met the standard of less than 1%. However, the moisture content did not comply because it was still too high and did not exceed 20%. Additionally, based on the results of the organoleptic test, the glucose syrup produced had a sweet taste in line with the SNI quality requirements, but still had a slight odour and was somewhat cloudy or brownish in colour. According to SNI quality requirements, glucose syrup should be clear and odourless.

Based on the weights and rankings of each alternative, it was evident that the best glucose syrup was produced by treatment T3. This innovation not only reduces agro-industrial waste but also encourages the sustainable utilization of local resources and opens new economic opportunities, especially for the micro, small, and medium enterprise (MSME) sector and integrated agriculture. Moreover, local glucose production can serve as a substitute for imports needed by the food, beverage, and bioenergy industries, while also reducing greenhouse gas emissions from unmanaged waste decomposition. Thus, converting cassava peels into glucose syrup serves as a concrete example of circular economy implementation in support of sustainable development.

In addition to the starch fraction for glucose syrup production, cassava peels contain significant amounts of hemicellulose and cellulose, demonstrating their broader potential in integrated biorefinery systems. The hemicellulose fraction of lignocellulosic biomass can be enzymatically hydrolysed to produce xylooligosaccharides (XOS), high-value prebiotic compounds with significant functional food applications (Chen et al., 2021). Recent studies have highlighted that XOS production from lignocellulosic residues through controlled enzymatic hydrolysis is a promising strategy for biomass valorisation within a sustainable biorefinery framework (Santibáñez et al., 2021). Meanwhile, the cellulose fraction can be further converted into bioethanol or other bio-based products, thereby increasing the overall biomass utilization efficiency. Therefore, cassava peels should be considered not only as a source of

starch but also as a multifunctional lignocellulosic raw material, where integrated valorisation strategies can significantly increase its economic value and sustainability in line with the principles of a circular bioeconomy.

Analysis of Economic Added Value

To date, cassava peel waste from the production process lacks commercial value and is often discarded or used as animal feed by local residents. However, this waste can be economically valuable if processed into a raw material for glucose syrup production. Glucose syrup is extensively used in the pharmaceutical, chemical, and other agro-industries (Albaasith et al., 2014), and many food and beverage industries prefer it because it does not crystallize as easily as granulated sugar (Permanasari&Yulistiani, 2015). A patent for glucose syrup derived from kimpul starch reports a glycemic index approximately 31 points lower than that of granulated sugar (Rejeki et al., 2021), which is beneficial for managing blood glucose levels in individuals with type 2 diabetes (Momongan et al., 2019). Therefore, using cassava peel waste as a raw material for glucose syrup can add economic value to what was previously considered worthless. This is particularly significant given the large market potential of glucose syrup and the substantial amount of cassava peel waste produced during its manufacturing process. The experimental production of glucose syrup from cassava peel waste revealed that approximately 34 kg of clean peels and 30 kg of raw cassava peels yielded approximately 4 kg of cassava peel starch. In the experiment, 60 g of cassava peel starch was used to produce approximately 120 mL of cassava peel glucose syrup. According to the full costing method, the production cost of cassava peel glucose syrup was approximately IDR 2,850.31. Compared to similar liquid cassava sugar products, such as brand A, sold at IDR 29,500/350 mL (500 g), or brand B at IDR 39,665/600 g, the production cost of cassava peel glucose syrup was significantly lower. Given this low production cost, converting cassava peel waste into glucose syrup is highly feasible for micro-, small-, and medium-sized enterprises (MSMEs). From a waste material with no commercial value, if utilized as a raw material for glucose syrup and sold with a 20% profit margin, it would provide an added value of IDR 3,420.37 for every 60 g of cassava peel starch, derived from approximately 450 g of clean cassava peel or around 510 g of raw cassava peel. Thus, converting cassava peel waste into glucose syrup not only generates economic benefits, as demonstrated by Sari et al. (2024a), Sari et al. (2024b), and Wulan et al. (2025) for furniture industry waste, but also reduces the environmental impact caused by the waste, as evidenced by Sari et al. (2025) in furniture industry waste and Sari et al. (2024c) in electronic waste. Additionally, it offers social benefits from the recycling of electronic waste, as demonstrated by Sari et al. (2023).

Conclusions

The experimental results demonstrate that cassava peel starch can be effectively utilized as a raw material for glucose syrup production through enzymatic hydrolysis using glucoamylase and α -amylase. Among the nine treatments evaluated, the third treatment (60 g cassava peel starch, 0.06 mL glucoamylase, and 2 mL α -amylase) was identified as the best alterna-

tive based on the integrated AHP–WPM approach. This treatment achieved balanced performance across reducing sugar content, moisture content, ash content, and organoleptic attributes, making it the most preferable option under a multi-criteria evaluation.

The findings highlight the importance of applying multi-criteria decision-making methods to ensure that product optimization considers not only chemical characteristics but also sensory quality. By integrating AHP for weighting criteria and WPM for ranking alternatives, this study provides a systematic and transparent framework for selecting the most suitable treatment. Beyond technical optimization, this study underscores the potential of cassava peel valorisation as a strategy to enhance economic value while reducing agro-industrial waste, particularly for MSMEs. Overall, this work contributes to sustainable agro-industrial innovation by integrating process optimization and decision-making tools for waste valorisation.

Future research should focus on improving product clarity and aroma to enhance consumer acceptance. Further investigation into process refinement, enzyme concentration optimization, and post-processing techniques is recommended. In addition, market acceptance studies and the development of alternative product forms, such as powdered glucose syrup with an extended shelf life, would strengthen the commercial feasibility and scalability of cassava peel-based glucose syrup production.

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References

- Akhadiarto, S. (2010). Pengaruh pemanfaatan limbah kulit singkong dalam pembuatan pelet ransum unggas. *Jurnal Teknologi Lingkungan*, 11(1), 127–138. <https://doi.org/10.29122/jtl.v11i1.1230>
- Albaasith, Z., Lubis, R. N., & Tambun, R. (2014). Pembuatan sirup glukosa dari kulit pisang kepok (*Musa acuminatabalbisianacolla*) secara enzimatis. *Jurnal Teknik Kimia USU*, 3(2), 15–18. <https://doi.org/https://doi.org/10.32734/jtk.v3i2.1607>
- Amadi, N., Yabrade, M., & Okubor, P. C. (2024). Impact of cassava peel on soil nutrient and microbial restoration of crude oil contaminated soil in Rivers State, Nigeria. *Scientia Africana*, 23(4), 141–156. <https://doi.org/10.4314/sa.v23i4.13>
- Aminudin, N., Sundari, E., Shankar, K., Deepalakshmi, P., Fauzi, R. I., & Maseleno, A. (2018). Weighted Product and its application to measure employee performance. *International Journal of Engineering & Technology*, 7(2.26), 102–108. <https://doi.org/http://dx.doi.org/10.14419/ijet.v7i2.26.14362>

- Annas, M., Erhan, T. P., & Sulaeman, S. (2020). Reverse and Green Logistics Cost Simulation Using Analytical Hierarchy Process. *Holistica*, 11(3), 46–58. <https://doi.org/10.2478/hjbpa-2020-0031>
- Ardiansyah, Nurlansi, & Musta, R. (2018). Waktu Optimum Hidrolisis Pati Limbah Hasil Olahan Ubi Kayu (*Manihot esculenta* Crantz var. Lahumbu) Menjadi Gula Cair Menggunakan Enzim α -Amilase dan Glukoamilase. *Indonesian Journal of Chemical Research*, 5(2), 86–95. <https://doi.org/10.30598/ijcr.2018.5-ard>
- Artati, A., Risky, R., Rafika, R., Armah, Z., Djasang, S., Ridwan, A., & Anwar, A. Y. (2023). Potential of Cassava Peel as an Alternative Growth Media of *Aspergillus niger* and *Rhizopus oryzae* with Concentration Modification. *Jurnal Media Analis Kesehatan*, 14(2), 179–188. <https://doi.org/10.32382/jmak.v14i2.251>
- Ben, F. (2024). Valorization of *Manihot esculenta* peel from environmental pollutant to sustainable engineering solutions for a cleaner future. *Environmental Science and Pollution Research*, 1–27. <https://doi.org/10.1007/s11356-024-35621-8>
- Benezzine, G., Zouhri, A., & Koulali, Y. (2021). AHP and GIS-based site selection for a sanitary landfill: Case of Settat province, Morocco. *Journal of Ecological Engineering*, 23(1), 1–13. <https://doi.org/10.12911/22998993/143865>
- Chen, J., Vercambre, G., Kang, S., Bertin, N., Gautier, H., & Génard, M. (2020). Fruit water content as an indication of sugar metabolism improves simulation of carbohydrate accumulation in tomato fruit. *Journal of Experimental Botany*, 71(16), 5010–5026. <https://doi.org/10.1093/jxb/eraa225>
- Chete, O. B. (2022). Utilisation of cassava waste among processors in Akoko Southwest, Ondo State, Nigeria. *Agricultura Tropica et Subtropica*, 55, 185–190. <https://doi.org/10.2478/ats-2022-0019>
- Chinnasami, S., RajKumar, S., Ramachandran, M., & Selvam, M. (2023). Evaluation of Drinking Water Quality for Salem District Using Weighted Product Method. *Mater Charact*, 2, 1–9.
- Coelho, C. R. V., Peters, G., Zhang, J., Hong, B., Abdollahi, M., & Undeland, I. (2022). A comparative life cycle assessment of cross-processing herring side streams with fruit pomace or seaweed into a stable food protein ingredient. *Future Foods*, 6(October), 100194. <https://doi.org/10.1016/j.fufo.2022.100194>
- Cooper, D. R., & Schindler, P. (2014). *Business research methods*. McGraw-hill.
- Cucurachi, S., Scherer, L., Guinée, J., & Tukker, A. (2019). Life Cycle Assessment of Food Systems. *One Earth*, 1(3), 292–297. <https://doi.org/10.1016/j.oneear.2019.10.014>
- Dasumiati, Saridewi, N., & Malik, M. (2019). Food packaging development of bioplastic from basic waste of cassava peel (*manihot utilisima*) and shrimp shell. *IOP Conference Series: Materials Science and Engineering*, 602(1), 12053. <https://doi.org/10.1088/1757-899X/602/1/012053>
- Dinulescu, R., & Dobrin, C. (2022). Applying the fuzzy analytical hierarchy process for classifying and prioritizing healthcare quality attributes. *Management & Marketing*, 17(1), 15–40. <https://doi.org/10.2478/mmcks-2022-0002>
- Dwitama, R. S. (2019). Pemilihan Metode Multi Criteria Decision Making (MCDM) Menggunakan Pendekatan Rank Similarity Simulation (RSS). *Prosiding Seminar Nasional Darmajaya*, 1, 27–37.
- Ege, K., Adu, A. A., & Aspatia, U. (2023). Organoleptic differences of biscuits made from yellow pumpkin flour as a substitution of wheat flour. *Journal of Public Health for Tropical and Coastal Region*, 6(3), 83–90.
- Ergun, R., Lietha, R., & Hartel, R. W. (2010). Moisture and Shelf Life in Sugar Confections. *Critical Reviews in Food Science and Nutrition*, 50(2), 162–192. <https://doi.org/10.1080/10408390802248833>
- Fadhallah, E. G., Juwita, N., Assa'diyah, I. N., Tullaila, S., Putri, S. A. N., Prayoga, R. A., & Iswahyudi, B. A. (2022). A review of potency of cassava peel waste and seaweed carrageenan as environmentally friendly bioplastic. *International Journal of Hydrological and Environmental for Sustainability*, 1(3), 146–159. <https://doi.org/10.58524/ijhes.v1i3.150>

- Fitriyano, G., Ismiyati, I., Purnawan, I., Othman, R., & Ramadhan, R. F. (2023). Mini Review: Potential Utilization of Cassava Peel Waste as Raw Material for Bio Briquettes Production in Indonesia. *E3S Web of Conferences*, 432, 11. <https://doi.org/10.1051/e3sconf/202343200011>
- Goswami, S. S., Behera, D. K., & Mitra, S. (2020). A comprehensive study of weighted product model for selecting the best product in our daily life. *Brazilian Journal of Operations & Production Management*, 17(2), 1–18. <https://doi.org/10.14488/BJOPM.2020.017>
- Gowen, A. A. (2012). Water and food quality. *Contemp. Mater*, 1(3), 31–37.
- Hardiani, T., Firdonsyah, A., & Afifah, A. N. (2022). the Use of the Weighted Product Method in a Food Choice Decision Support System for Patients With Type 2 Diabetes Mellitus. *Transmisi: Jurnal Ilmiah Teknik Elektro*, 24(3), 92–97. <https://doi.org/10.14710/transmisi.24.3.92-97>
- Harjanto, S., Setiyowati, S., & Vlandari, R. T. (2021a). Application of analytic hierarchy process and weighted product methods in determining the best employees. *Indonesian Journal of Applied Statistics*, 4(2), 103–113.
- Harjanto, S., Setiyowati, S., & Vlandari, R. T. (2021b). Application of analytic hierarchy process and weighted product methods in determining the best employees. *Indonesian Journal of Applied Statistics*, 4(2), 103–113.
- Harni, M., Putri, S. K., Gusmalini, & Handayani, T. D. (2021). Characteristics Of Glucose Syrup From Various Sources Of Starch. *IOP Conference Series: Earth and Environmental Science*, 757(1), 012064. <https://doi.org/10.1088/1755-1315/757/1/012064>
- Hasibuan, R., Hidayati, J., Misran, E., Samosir, R. N., Sitohang, A. J., Pramananda, V., & Fazillah, R. (2025). Characteristics of bio-briquettes from candlenut shells as a renewable energy: Selection of adhesive type, adhesive concentration, and bio-char particle size. *Journal of Ecological Engineering*, 26(10), 316–327. <https://doi.org/10.12911/22998993/204924>
- Hull, P. (2010). *Glucose syrups: technology and applications*. John Wiley & Sons.
- Iragaba, P., Hamba, S., Nuwamanya, E., Kanaabi, M., Nanyonjo, R. A., Mpamire, D., Muhumuza, N., Khakasa, E., Tufan, H. A., & Kawuki, R. S. (2021). Identification of cassava quality attributes preferred by Ugandan users along the food chain. *International Journal of Food Science & Technology*, 56(3), 1184–1192. <https://doi.org/10.1111/ijfs.14878>
- Ismail, B. P. (2017). Ash Content Determination. In *Food Analysis Laboratory Manual* (pp. 117–119). https://doi.org/10.1007/978-3-319-44127-6_11
- Kamble, A. G. (2024). Selection of two-wheelers using analytical hierarchy process. *Materials Today: Proceedings*, 102, 65–68. <https://doi.org/10.1016/j.matpr.2023.03.234>
- Kholis, N., Annisa, N., Khotimah, K., Prameswari, D. A., Pangesti, I. T., & Rohmadi, M. (2023). Pemanfaatan Limbah Kulit Singkong untuk Meningkatkan UMKM di Desa Palingkau Jaya. *Madaniya*, 4(4), 2070–2075. <https://doi.org/10.53696/27214834.675>
- Kisnawaty, S. W., Pertiwi, M. A., Ariyani, I., & Mustikaningrum, F. (2023). Education on preventing diabetes mellitus for prolanis through the introduction of high-fiber foods and glycemic index variations. *Community Empowerment*, 8(11), 1776–1784. <https://doi.org/10.31603/ce.10245>
- Kristiandi, K., Rozana, R., Junardi, J., & Maryam, A. (2021). Analisis kadar air, abu, serat dan lemak pada minuman sirop jeruk siam (citrus nobilis var. microcarpa). *Journal of Tropical Agricultural Engineering and Biosystems-Jurnal Keteknik Pertanian Tropis Dan Biosistem*, 9(2), 165–171. <https://doi.org/10.21776/ub.jkptb.2021.009.02.07>
- Kulakowski, K. (2020). *Understanding the analytic hierarchy process*. CRC Press.
- Latifah, R. N., & Martiyana, N. R. (2023). Utilization of cassava peel waste (Manihot esculenta L.) with concentration variations of α -amylase and glucoamylase enzymes for liquid sugar. *Jurnal Litbang Industri*, 13(2), 107. <https://doi.org/10.24960/jli.v13i2.7876.107-113>
- Lee, K.-H., & Vachon, S. (2016). Supply chain sustainability risk. In *Business value and sustainability: An integrated supply network perspective* (pp. 245–280). Springer.

- Mardina, P., Irawan, C., Putra, M. D., Priscilla, S. B., Misnawati, M., & Nata, I. F. (2021). Bioethanol production from cassava peel treated with sulfonated carbon catalyzed hydrolysis. *Jurnal Kimia Sains Dan Aplikasi*, 24(1), 1–8. <https://doi.org/10.14710/jksa.24.1.1-8>
- Mohammed, R. J., & Suliman, A. A. (2023). land suitability assessment for wheat production using analytical hierarchy process and parametric method in Babylon Province. *Journal of Ecological Engineering*, 24(7), 75–87. <https://doi.org/10.12911/22998993/163349>
- Momongan, N. R., Kereh, P. S., & Sriwartini, S. (2019). Indeks Glikemik Bahan Makanan Dengan Kadar Glukosa Darah Pada Penderita Diabetes Mellitus Tipe 2 Di Puskesmas Ranotana Weru. *Jurnal GIZIDO*, 11(01), 36–41. <https://doi.org/10.22373/pbio.v8i1.9648>
- Nahrisah, C. P., Hidayat, M., & Taib, E. N. (2020). Pemanfaatan Limbah Kulit Singkong Menjadi Pupuk Organik Cair Terhadap Pertumbuhan Tanaman Sawi. *Prosiding Seminar Nasional Biologi, Teknologi Dan Kependidikan*, 8(1).
- Ntelok, Z. R. E. (2017). Limbah kulit singkong (manihot esculenta l.): alternatif olahan makanan sehat. *JIPD (Jurnal Inovasi Pendidikan Dasar)*, 1(1), 115–121.
- Nwalo, N. F., & Cynthia, A. O. (2014). Glucose syrup production from cassava peels and cassava pulp. *International Journal of Current Microbiology and Applied Sciences*, 3(12), 781–787.
- Ogbonna, C., Mbadike, E., & Alaneme, G. U. (2020). Characterisation and use of Cassava peel ash in concrete production. *Computational Engineering and Physical Modeling*, 3(2), 12–28. <https://doi.org/10.22115/cepm.2020.223035.1091>
- Oghenejoboh, K. M., Otuagoma, S. O., & Ohimor, E. O. (2016). Application of cassava peels activated carbon in the treatment of oil refinery wastewater—a comparative analysis. *Journal of Ecological Engineering*, 17(2). <https://doi.org/10.12911/22998993/62290>
- Ogundahunsi, O. E., Akpan, G. E., Shittu, T. D., & Umani, K. C. (2024). Biofuel production from cassava processing by-products and processing wastes. In *Sustainable Cassava* (pp. 311–328). Elsevier. <https://doi.org/10.1016/B978-0-443-21747-0.00017-5>
- Okike, I., Wigboldus, S., Samireddipalle, A., Naziri, D., Adeshinwa, A. O. K., Adejoh, V. A., Amole, T., Bordoloi, S., & Kulakow, P. (2022). Turning waste to wealth: harnessing the potential of cassava peels for nutritious animal feed. In *Root, Tuber and Banana Food System Innovations: Value Creation for Inclusive Outcomes* (pp. 173–206). Springer International Publishing Cham.
- Osorio, L. L. D. R., & Grande-Tovar, C. D. (2021). Valorización de residuos industriales en la producción de almidón de yuca Valorization of industrial waste in the production of cassava starch. *Prospevita*, 19(2). <https://doi.org/10.15665/rp.v19i2.2556>
- Permanasari, A. R., & Yulistiani, F. (2015). Pembuatan gula cair dari pati singkong dengan menggunakan hidrolisis enzimatis. *Fluida*, 11(2), 9–14. <https://doi.org/10.35313/fluida.v11i2.81>
- Permanasari, A. R., Yulistiani, F., Purnama, R. W., Widjaja, T., & Gunawan, S. (2018). The effect of substrate and enzyme concentration on the glucose syrup production from red sorghum starch by enzymatic hydrolysis. *IOP Conference Series: Earth and Environmental Science*, 160. <https://doi.org/10.1088/1755-1315/160/1/012002>
- Permatasari, N. U., Dali, S., & Wahyuni, E. S. (2023). Potential Cassava Peel Waste (Manihot esculenta Crantz) in The Production of Bioethanol by Enzymatic Hydrolysis and Fermentation Using *Zymomonas mobilis* Bacteria. *Journal of Pure & Applied Chemistry Research*, 12(2).
- Pojić, M., Kravić, S., Stojanović, Z., Nollet, L., & Toldra, F. (2015). Analytical methods for determination of moisture and ash in foodstuffs. *Handbook of Food Analysis*, 1, 275–296.
- Pontoh, J., & Low, N. H. (1995a). Glucose syrup production from Indonesian palm and cassava starch. *Food Research International*, 28(4), 379–385.
- Pontoh, J., & Low, N. H. (1995b). Glucose syrup production from Indonesian palm and cassava starch. *Food Research International*, 28(4), 379–385. [https://doi.org/10.1016/0963-9969\(95\)00010-J](https://doi.org/10.1016/0963-9969(95)00010-J)
- Ray, S. (2021). Sensory properties of foods and their measurement methods. In *Techniques to Measure Food Safety and Quality: Microbial, Chemical, and Sensory* (pp. 345–381). Springer.

- Rejeki, F. S., Puspitasari, D., & Wedowati, E. R. (2021). *Paten Proses Pembuatan Gula Cair Kimpul dengan Indeks Glikemik Rendah* (Patent IDPP000077542).
- Rudiyanto, B., Ulma, Z., Prasetyo, D. A., & Piluharto, B. (2023). Utilization of cassava peel (Manihot utilissima) waste as an adhesive in the manufacture of coconut shell (Cocos nucifera) charcoal briquettes. *International Journal of Renewable Engineering Development*, 12(2), 270–276. <https://doi.org/10.14710/ijred.2023.48432>
- Saaty, T. L. (1990). How to make a decision: the analytic hierarchy process. *European Journal of Operational Research*, 48(1), 9–26. <https://doi.org/10.13128/Aestimium-7138>
- Sari, D. P., Hartini, S., Azzahra, F., Arsiwi, P., & Prayoga, R. G. (2024). *Modular-Based Multifunctional Product Design Made from Furniture Waste Toward the Circular Economy: Case in Indonesia*. 32(3), 303–316. <https://doi.org/10.2478/mspe-2024-0029>
- Sari, D. P., Hartini, S., Azzahra, F., Hamdi, M., & Arsiwi, P. (2024). Designing a bedside table of wood furniture waste based on TRIZEE methodology. *Production Engineering Archives*, 30(4), 551–564. <https://doi.org/10.30657/pea.2024.30.51>
- Sari, D. P., Mahdiyah, A. S. A. A., & Purwaningsih, R. (2025). Assessing environmental impact and eco-efficiency of wood waste gallon holders using life cycle assessment. *Journal of Ecological Engineering*, 26(3). <https://doi.org/10.12911/22998993/199727>
- Sari, D. P., Masruroh, N. A., & Asih, A. M. S. (2024). Economic and Environmental Benefits of E-Waste Management Networks Design in Yogyakarta Province, Indonesia. *Journal of Industrial Engineering and Management*, 17(1), 292–320. <https://doi.org/10.3926/jiem.6651>
- Shariffifar, A., Ghorbani, H., & Karimi, H. (2013). Integrated Land Evaluation for Sustainable Agricultural Production by Using Analytical Hierarchy Process. *Agriculture*, 59(3), 131–140. <https://doi.org/10.2478/agri-2013-0012>
- Situmorang, E., Supriyanto, A., Surtono, A., & Junaidi, J. (2024). Utilization of Cassava Peel Waste for Renewable Electrical Energy Production Using Joule Thief Series with Microbial Fuel Cell Technology (Addition of Yeast and Acetate). *Journal of Energy, Material, and Instrumentation Technology*, 5(3), 81–92.
- Soesilo, D., Santoso, R. E., & Diyatri, I. (2006). Peranan sorbitol dalam mempertahankan kestabilan pH saliva pada proses pencegahan karies (The role of sorbitol in maintaining saliva's pH to prevent caries process). *Dental Journal (Majalah Kedokteran Gigi)*, 38(1), 25–28. <https://doi.org/10.20473/j.djmk.v38.i1.p25-28>
- Sulistiyowati, L., Pangaribuan, N., Idrus, O., & Rachman, A. (2023). Utilization of cassava peel waste as an organic fertilizer to build a sustainable cassava production center. *Jurnal Pengelolaan Sumberdaya Alam Dan Lingkungan (Journal of Natural Resources and Environmental Management)*, 13(4), 528–537. <https://doi.org/10.29244/jpsl.13.4.528-537>
- Syadiah, E. A., Adelina, F., Sudarmin, S., Handayani, F., & Bulawan, J. A. (2022). The potency of Mentega Cassava (Manihot esculenta) Variety Peels Waste as Raw Material for Bioethanol by Enzymatic Hydrolysis. *EDUFORTECH*, 7(2), 138–146. <https://doi.org/10.17509/edufortech.v7i2.50966>
- Tambunan, T. (2013). *A survey of business models for agricultural investment in Indonesia*. International Institute for Sustainable Development.
- Tanone, R., & Prasetya, H. (2019). Designing and Implementing an Organoleptic Test Application for Food Products Using Android Based Decision Tree Algorithm. *International Journal of Interactive Mobile Technologies (IJIM)*, 13(10), 134. <https://doi.org/10.3991/ijim.v13i10.9669>
- Tavana, M., Soltanifar, M., & Santos-Arteaga, F. J. (2023). Analytical hierarchy process: Revolution and evolution. *Annals of Operations Research*, 326(2), 879–907. <https://doi.org/10.1007/s10479-021-04432-2>
- Tutuhatunewa, A. (2020). Analisis Kualitas Produk Abon Ikan Dengan Pendekatan Logika Fuzzy. *ALE Proceeding*, 3, 24–32.

- Tutuhatunewa, A. (2021). Analisis Kualitas Produk Abon Ikan dengan Pendekatan Logika Fuzzy. *ALE Proceeding*, 3, 24–32. <https://doi.org/10.30598/ale.3.2020.24-32>
- Utomo, P., Cahyono, S. D., & Tristono, T. (2019). Selection of talented archery athletes using weighted product method. *Journal of Physics: Conference Series*, 1211(1), 12037. <https://doi.org/10.1088/1742-6596/1211/1/012037>
- Widyastuti, P. (2019). Pengolahan limbah kulit singkong sebagai bahan bakar bioetanol melalui proses fermentasi. *Jurnal Kompetensi Teknik*, 11(1), 41–46.
- Wulan, T. C., Sari, D. P., Hartini, S., & Azzahra, F. (2025). Leveraging Integrated Quality Function Deployment (QFD) and Theory of Solving Problems Inventively, Eco-Efficiency (TRIZEE) Methodologies for Sustainable Innovation in Chair Design through Wood Waste to Enhance Eco-Efficiency. *Journal of the Korean Wood Science and Technology*, 53(3), 324–342. <https://doi.org/10.5658/WOOD.2025.53.3.324>
- Yi, S., & Jang, Y.-C. (2022). Analysis of recommended mobile selection using the weighted product method. *International Journal of Informatics and Information Systems*, 5(4), 167–174. <https://doi.org/10.47738/ijiis.v5i4.144>
- Zargaraan, A., Kamaliroosta, L., Yaghoubi, A. S., & Mirmoghtadaie, L. (2016). Effect of substitution of sugar by high fructose corn syrup on the physicochemical properties of bakery and dairy products: a review. *Nutrition and Food in Health and Disease*, 3(4), 3–11. <https://doi.org/10.1080/10408398.2022.2151560>

OPTIMALIZACJA SYROPU GLUKOZOWEGO Z ODPADÓW ZE SKÓREK MANIOKU: OKREŚLANIE OPTIMALNEGO SKŁADU Z UŻYCIEM METODY HIERARCHII ANALITYCZNEJ PRODUKTU WAŻONEGO PROCESEM

Streszczenie. Maniok jest jednym z największych produktów rolnych Indonezji. Obecnie jego wykorzystanie ogranicza się głównie do bulw, co skutkuje produkcją stałych odpadów z łupin manioku. Warto zauważyć, że łupiny manioku zawierają dużo węglowodanów, stanowiących do 50% węglowodanów znajdujących się w bulwach. Ponadto, wysoki koszt cukru granulowanego i niezdolność krajowego przemysłu cukrowniczego do zaspokojenia popytu na cukier w Indonezji stały się poważnymi problemami. W związku z tym, celem niniejszego badania było zbadanie wykorzystania odpadów z łupin manioku jako alternatywnego surowca do produkcji syropu glukozowego, który potencjalnie może służyć jako substytut cukru. Przetestowano dziewięć eksperymentalnych metod w celu określenia optymalnego syropu glukozowego. Najlepszy syrop glukozowy zidentyfikowano, stosując integrację procesu hierarchii analitycznej (AHP) i metody ważonego produktu (WPM). AHP wykorzystano do ustalenia ważonych priorytetów kryteriów i podkryteriów, a następnie WPM do określenia alternatywnych wag i uszeregowania opcji. Trzeci sposób obróbki okazał się najlepszą alternatywą, o masie 0,124, obejmujący 60 g skrobi z łupin manioku, 0,06 ml glukoamylazy i 2 ml α -amylazy. Wyniki testów syropu glukozowego z tego sposobu obróbki wykazały zawartość cukru redukującego 33,51%, wilgotność na poziomie 64,419%, zawartość popiołu 0,137%, barwę organoleptyczną 3 (lekko mętny), smak 3,93 (słodki) i aromat 2,93 (lekko pachnący). Oczekuje się, że wykorzystanie tych odpadów zwiększy ich wartość ekonomiczną, jednocześnie minimalizując ich wpływ na środowisko.

Słowa kluczowe: proces hierarchii analitycznej, odpady z obierek manioku, syrop glukozowy, metoda produktu ważonego