

Characteristics of liquid sugar from old oil palm trunk sap as affected by processing methods

[Karakteristik gula cair dari nira batang kelapa sawit tua berdasarkan metode pengolahan]

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ABSTRACT

The sap of old oil palm trunks contains appreciable sugar, but it has not been considered a potential sugar source. This study aimed to find the best method for producing oil palm liquid sugar that complies with the Indonesian National Standard (SNI) The non-factorial experiment was arranged in a Completely Randomized Block Design (CRBD) with 6 replications. The treatments were a combination of lime-rotary vacuum evaporation (P1), without lime-vacuum rotary evaporation (P2), lime-atmospheric evaporation (P3); without lime-atmospheric evaporation (P4). The parameters observed were pH, °brix, reducing sugar, color, aroma, and overall acceptance. The data were subjected to ANOVA to determine the treatments' effect. Then, continued testing using HSD at α 0,05 for means separation. The best treatment was found on liquid sugar processed using lime, and atmospheric evaporation with °brix of 68.75%, pH of 5.4, moisture content of 17.74%, ash content of 0.86%, reducing sugar of 44.31%, sensory score of color, aroma, and overall acceptance were 3.42 (brownies yellow), 4.4 (like), and 4.04 (like).

Keywords: lime, liquid sugar, old oil palm trunk, sensory, vacuum rotary evaporator

ABSTRAK

Nira batang kelapa sawit tua mengandung gula dalam jumlah yang cukup besar, namun belum banyak dimanfaatkan sebagai sumber gula yang potensial. Penelitian ini bertujuan untuk mendapatkan metode terbaik dalam memproduksi gula cair nira batang kelapa sawit tua yang sesuai dengan Standar Nasional Indonesia (SNI). Percobaan disusun secara non faktorial dalam Rancangan Acak Kelompok (RAK) dengan 6 kali ulangan. Perlakuan yang dicobakan adalah kombinasi kapur Ca(OH)_2 -penguapan vakum putar (P1), tanpa kapur-penguapan vakum putar (P2), kapur-penguapan atmosfer (P3), tanpa kapur-penguapan atmosfer (P4). Parameter yang diamati adalah pH, °brix, dan gula reduksi, warna, aroma, dan penerimaan keseluruhan. Data yang diperoleh kemudian diolah dengan ANOVA untuk mengetahui pengaruh perlakuan, kemudian dilanjutkan dengan uji lanjut HSD pada α 0,05 untuk mengetahui perbedaan antar perlakuan. Perlakuan terbaik terdapat pada gula cair yang diproses menggunakan kapur dan penguapan atmosferik dengan °brix 68,75%, pH 5,4, kadar air 17,74%, kadar abu 0,86%, gula reduksi 44,31%, skor sensori warna, aroma, dan daya terima secara keseluruhan berturut-turut adalah 3,42 (kuning kecoklatan), 4,4 (agak suka), dan 4,04 (suka).

Kata kunci: batang kelapa sawit tua, penguapan vakum putar, gula cair, Ca(OH)_2 , sifat sensori

Introduction

Oil palm is a plantation crop with high economic value. Oil palm plants start to be productive (have fruit that can be harvested) at the age of 3 to 4 years. The productive period of oil palm plants

is around 25 years and after that is considered to be unproductive (Dirkes et al., 2021). Oil palm plants that are older than 25 years old produce low quality fruit (Sulaiman et al., 2020). Overtaking Malaysia and Thailand, which are ranked second and third, Indonesia is the nation that produces the most palm fruit globally. Based on The Central Bureau of Statistics of Indonesia, the area and the production of palm oil in 2021 reached more than 15 million hectares (BPS, 2021). Oil palm planting activities are usually carried out simultaneously on a huge area, so that when the plants are not productive many oil palm plants must be felled and replanted. Therefore, large number of old oil palm trunks to be cut down at the same time may cause a problem. In practice, these trunks are left on the plantation and affect the environment because the process of degradation of oil palm trunks takes several years (Dirkes et al., 2021). Furthermore, they will gradually affect oil palm plants that are still productive, and cause fungi (*Ganoderma*) (Gorea et al., 2020), beetles (*Oryctes*) (Rahayuwati et al., 2020), or other pests to grow.

One old tree trunk can yield up to six to seven liters of sap per day on average when it is tapped. Assuming that there are 100 trees per hectare of an oil palm plantation, a total of 600 to 700 liters of sap per day can be gathered in one hectare of oil palm plantation for roughly one month of tapping. The amount of Indonesian oil palm plantations that are prepared for replanting within a year is around 600.000 hectares or 60.000.000 palm trunks. The average oil palm trunk yields 6 L of sap per day, thus, 360.000.000 L of sap total will be generated daily, for 30 days. This amount is equal to 10.8 million m³ of oil palm sap in a year.

The USDA (2022) reported that national sugar (white crystal sugar) consumption reached 6.48 million tons consisting of 3.21 million tons and 3.27 million tons of refined crystal sugar. This is not adequately matched by domestic sugar production which is only 2.35 million tons, with details of private sugar companies reaching 1.29 million tons and state-owned sugar companies reaching 1.06 million tons in 2021. One way to meet the national sugar demand is by utilizing plants that have the potential to be used and processed into sugar, for example, *arenga pinnata*, coconut, and, oil palm. In several studies, old oil palm trunks contain a lot of water and chemical composition such as short-chain carbohydrates which have the potential as a source of sugar production (Hossain et al., 2018; Dirkes et al., 2021). Lately, oil palm sap has started to be used to produce brown sugar. However, to produce solid brown sugar, it may need up to 25% white crystal sugar to achieve a firm texture (Agustira et al., 2019), this white crystal sugar addition is not favorable because domestic production of white crystal sugar has not yet met the demand. An alternative that can be taken to be used as a substitute for white crystal sugar and firm brown sugar are liquid sugar. To the best of our knowledge, no prior paper has addressed aspects of processing method related to the qualities of liquid sugar produced from old oil palm trunks; therefore the purpose of this study was to find a suitable method to produce oil palm liquid sugar that has good chemical and sensory properties that meet National Indonesian Standard.

Materials and Methods

Materials

The sap was obtained from around 25-year-old oil palm trunk grown on oil palm plantation owned by PTPN VII Rejosari, Natar-South Lampung. Lime (Ca(OH)₂) (Sigma- Aldrich), phenol (Sigma-

Aldrich), and sulphuric acid (Merck) were bought from local suppliers. Equipment used included a vacuum rotary evaporator (Rotavapor® R-300 BUCHI), spectrophotometer (AquaMate 8100-Thermo Scientific), hand refractometer (ATAGO, Japan), pH meter (HI6221-01Advanced pH/ORP Benchtop Meter), electric stove and glass wares.

Methods

The experiment was non-factorial and arranged in a completely randomized block design (CRBD) with 6 replications. The treatments were designed as follows:

- P1: Oil palm liquid sugar processed with lime and evaporated using a vacuum rotary
- P2: Oil palm liquid sugar processed without lime and evaporated using a vacuum rotary
- P3: Oil palm liquid sugar processed with lime and evaporated at atmospheric condition
- P4: Oil palm liquid sugar processed without using lime and evaporated at atmospheric condition

Oil palm sap preparation

The old oil palm trunk was cut down, then the fronds were cleaned using an axe. The trunk of the oil palm tree was left for 1 day, then the top of trunk is scraped 0.5 - 1 cm thick per day using a sharp knife to initiate the sap to flow out. The sap water that comes out was collected in a concave tray that has been added Ca(OH)_2 and without the addition of Ca(OH)_2 . While tapping was carried out, the oil palm trunk was covered with a plastic sheet in order to protect the oil palm trunk from the rain, the sun, insects and farm animals that might affect the sap yield.

Liquid sugar preparation

1. Atmospheric evaporation

Oil palm sap (500 mL) according to the treatment (no lime or added lime) was poured into a 750 mL cooking pot to evaporate at a temperature of approximately 100°C, the temperature is monitored using a thermometer periodically, and the use of this temperature was based on previous observation and to minimize the Millard reaction. During the process of evaporation or cooking of the sap, constant stirring was carried out to keep the temperature evenly distributed for approximately 100 minutes with one of the parameters being observed was the volume and the brix level to comply with the standard of liquid sugar (minimum of 65% brix), if within that time the desired brix has not been reached, the cooking or evaporation was continued until a minimum quality standard of 65% brix was obtained. This method was modified from Asghar et al. (2020); and Julai et al. (2023).

2. Vacuum rotary evaporation

Oil palm sap (500 mL) based on the type treatment (no lime or added lime) was poured into a 1000 mL round flask and reinstalled in the vacuum rotary evaporator unit then the water chamber was filled with water and the temperature was set at 70°C and the water bath was activated. The use of these temperatures was chosen based on previous trials. Then, the round flask position was lowered until immersed in the water bath. The rotary speed was adjusted and the vacuum was activated to lower the pressure in the flask. This condition was kept for 40 minutes. (Asghar et al., 2020; and Julai et al., 2023 with slight modification).

Observed variables

1. Chemical composition

The chemical content of the liquid sugar samples was analyzed based on the AOAC official method (AOAC, 2019). The parameters observed included the degree of brix (hand refractometer, ATAGO Tokyo Japan), moisture content was determined using the gravimetric method (AOAC 945.62), pH (AOAC method 943.02), ash content (AOAC 945.28), total reducing sugar content (Dubois et al., 1956).

2. Sensory analysis

Sensory evaluation was conducted by 30 semi-trained panelists, selected from students who have passed the sensory evaluation subject, a mandatory subject in The Department of Agriculture Product Technology, to ensure that they have the same background knowledge of how to do the evaluation properly. Liquid sugar samples (5 g) were put in clear plastic cups covered with lids and labeled with 3-digit random numbers. Panelists were asked to give scores on the color and aroma of the samples at room temperature. Each sample was evaluated for, color using a 5-point scoring scale (5 = opaque white, 4 = yellow, 3 = brownish yellow, 2 = brown, 1 = dark brown); aroma, and overall acceptance using a 5-point hedonic scale (5 = like extremely, 3 = neither like nor dislike and 1 = dislike extremely). Panelists were asked to rinse their mouths with bottled drinking water between samples (Poste et al., 1991).

Data analysis

The data were subjected to analysis of variance (ANOVA) using a statistical software program (SPSS for Windows version 11.0). and the differences between means were distinguished using an honest significant difference (HSD) Test at $p < 0.05$.

Results and Discussion

1. Chemical content of oil palm liquid sugar

The results of °Brix, moisture content, pH, ash, and total reducing sugar of oil palm liquid sugar are shown in Table 1. The treatments applied on processing oil palm liquid sugar did not significantly affect the °brix, ash, and reducing sugar levels; however, pH and moisture content were significantly affected (Table 1).

Table1. Effect of different treatments on brix, pH, moisture, ash, and reducing sugar

Treatment	°Brix	Moisture (%)	pH	Ash (%)	Reducing sugar (%)
P1	70.17 ^a ± 3.72	15.95 ^b ± 0.89	5.45 ^a ± 0.09	0.94 ^a ± 0.04	42.75 ^a ± 1.17
P2	66.83 ^a ± 0.94	15.76 ^b ± 0.94	4.07 ^b ± 0.04	0.91 ^a ± 0.06	41.91 ^a ± 1.67
P3	68.75 ^a ± 2.91	17.74 ^a ± 0.80	5.40 ^a ± 0.04	0.86 ^a ± 0.08	44.31 ^a ± 2.33
P4	70.58 ^a ± 2.95	16.80 ^{ab} ± 1.00	4.62 ^b ± 0.12	0.92 ^a ± 0.07	42.75 ^a ± 2.59

Note: The average value followed by different letter superscripts in the same column shows a significant difference based on the HSD test ($P < 0.05$).

The degree of Brix (°Brix) represents the total soluble solids content in liquid sugar. Thus the °Brix value obtained using the refractometer also reflects the percentage of sugars in the sample because the dominant soluble solid is sugar (Magwazaa & Opara, 2015; Elewa et al., 2022; Elisanti et al., 2023).

The degree of Brix was not significantly different for treatment because the evaporation process was stopped at a designated level of concentration (65 ± 5 °Brix).

Moisture content was affected significantly by the treatment. Oil palm sap added with lime and evaporated at atmospheric conditions had the highest moisture content but this was not different from the one without lime. Processing coconut sap into liquid sugar using a rotary evaporator is more effective and quicker due to faster water molecular movements than an open heat evaporator (Asghar et al., 2020; Yuwono et al., 2020; Wiyono et al., 2022). All samples in this study met the SNI 01-2978-1992 concerning the maximum quality requirements for sugar syrup, which is below the maximum of 20%.

The levels of pH were between 4.07 and 5.45. Despite evaporation methods, the lime-treated liquid sugar showed significantly higher compared to those without lime treatment. Lime treatment during processing can increase pH of liquid sugar (Saetear et al., 2021; Sariwahyuni et al., 2022; Dewi et al., 2024). In addition, the treatments did not significantly affect the ash and reducing sugar contents of oil palm liquid sugar. In addition, both comply with SNI 01-2978-1992 which sets an ash content maximum of 1% and reducing sugar content minimum of 30%.

2. Sensory properties

The results of the sensory properties can be seen in Table 2. The treatment significantly affected color, aroma, and overall acceptance. The lowest color score (the highest intensity of brown color) was found in the liquid sugar processed through atmospheric evaporation without lime addition, whereas the highest score (the lightest color) was found in the liquid sugar processed using a vacuum rotary evaporator without lime addition. Atmospheric heating needs a higher temperature to evaporate the sap. Evaporating a mixture of reducing sugar solution at high temperatures caused a Maillard reaction to occur, and as a result, regarding the color, the reducing sugars in the mixtures can change the sensory characteristics of the mixtures by producing melanoidins. The Maillard reaction affects various food quality parameters, including organoleptic properties, which include color, aroma, and taste. The specific aroma profile produced depends on the temperature-time profile used during food processing (Perez et al., 2023; Cappelletti et al., 2015; Tamanna et al, 2015).

The appearances of oil palm liquid sugar are presented in Figures 1-4. The results shown that the sensory score of brown color was also affected by pH and processing conditions. Oil palm sap with lime addition then evaporated through a vacuum rotary resulting in a darker color compared to that of without lime (Fig. 1-2). On the contrary, using atmospheric evaporation, the addition of lime resulted in liquid sugar with a lighter color (Fig. 3-4) This finding suggests that higher temperature applied at atmospheric pressure during processing has caused the color change to be darker, however, the brown color intensity depends on heating condition whether vacuum or atmospheric as well as pH applied. Julai et al. (2023); Fu et al.(2019); and Nie et al. (2013) reported that the brown color was formed mainly by the Maillard reaction and caramelization of sugar. The results of this study are in line with Naknean et al. (2009); Rao et al. (2009); and Marasinghege et al.(2022); who reported that the greater extent of browning reactions were caused by harsher open-heating conditions (higher temperature and longer duration), as well as oxygen exposure. Because more Maillard reaction products and caramelization products were produced when the syrups were heated

openly compared to when they were evaporated under vacuum, the open-heated syrups had a darker brown color.

The sensory evaluation on aroma showed that oil palm sap added with lime and evaporated through atmospheric condition was found to be the most preferred by panelists. The significant different in aroma of oil palm liquid sugar was presumably caused by Maillard reaction, defined as a chemical reaction between an amino acid and a reducing sugar mainly glucose and fructose in the exposure of heat. The reactions between the carbonyl group of sugar and the nucleophilic amino group of amino acid create a wide range of flavor, aroma, and/or noticeable browning color compounds in foods (Liu et al., 2022; Chen et al., 2023; Julai et al., 2023).

Table 2. Effects of different treatments on color, aroma and overall acceptance of oil palm liquid sugar

Treatment	Color	Aroma	Overall acceptance
P1	3.62 ^b ± 0.07	2.70 ^c ± 0.06	3.01 ^b ± 0.15
P2	5.00 ^a ± 0.00	1.73 ^d ± 0.07	1.37 ^c ± 0.05
P3	3.42 ^c ± 0.04	4.40 ^a ± 0.06	4.04 ^a ± 0.14
P4	1.67 ^d ± 0.07	3.58 ^b ± 0.04	3.81 ^a ± 0.20

Note: The average value followed by different letter superscripts in the same column shows a very significant difference (p<0.05).

- Color:
- 1: dark brown
- 2: brown
- 3: brownish yellow
- 4: yellow
- 5: opaque white
- Aroma and overall acceptance:
- 1: dislike extremely
- 2: very dislike
- 3: neither like nor dislike
- 4: very like
- 5: like extremely



Figure 1. Oil palm liquid sugar processed using lime and evaporated using vacuum rotary



Figure 2. Oil palm liquid sugar processed without lime and evaporated using vacuum rotary



Figure 3. Oil palm liquid sugar processed with lime and evaporated at atmospheric condition



Figure 4. Oil palm liquid sugar processed without lime and evaporated at atmospheric condition

Processing methods significantly affected the overall acceptance of oil palm liquid sugar. The most preferred by panelists was sugar processed through atmospheric condition with or without lime (P3 and P4), whereas the lowest was found in P2 (sugar processed without lime evaporated using a vacuum rotary). This suggests that the panelists were more interested in darker liquid sugar, presenting more brownish yellow to brown pigments with a more preferable aroma. During heating of oil palm sap, Maillard reaction occurs and results in brown pigment which affects the color of the product, and simultaneously flavor substances are formed (Ge et al., 2021; Liu et al., 2022; Chen et al., 2023). Consumer acceptance of innovative products is based on their sensory similarity to the original product. Innovative products that have taste, color, and flavor that are similar to the original product will receive high value from consumers (Al-Amrani et al., 2020; Abdullah, 2023; Laureati et al., 2024).

Conclusion

This study exposed that processing of old oil palm trunk sap using atmospheric evaporation provides products that comply with national standards, and acceptable sensory properties. These results could prompt the food industry to valorize sap from old oil palm trunks. Further studies are needed to explore the bioactive compounds as well as functional properties and other compounds that contribute the consumer's demand for liquid sugar from old oil palm trunk sap.

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REFERENCES

- Abdullah, K. M. (2023). The determinants influencing consumer acceptance of innovative traditional food products: A systematic literature review. *Advances in Social Sciences Research Journal*, 10(6), 330–344. <https://doi.org/10.14738/assrj.106.2.15006>
- Agustira, M. A., Siahaan, D., & Hasibuan, H. A. (2019). Nilai ekonomi nira sawit sebagai potensi pembiayaan economic value of oil palm sap as potentially financing. *Jurnal Penelitian Kelapa Sawit*, 27(2), 115–126. <https://doi.org/10.22302/iopri.jur.jpks.v27i2.62>
- Al-Amrani, M., Al-Alawi, A., & Al-Marhobi, I. (2020). Assessment of enzymatic browning and evaluation of antibrowning methods on dates. *International Journal of Food Science*, 2020(8380461), 1–9. <https://doi.org/https://doi.org/10.1155/2020/8380461>
- AOAC. Official Methods of Analysis of AOAC, 21st ed.; AOAC International: Rockville, MD, USA, 2019
- Asghar, M. T., Yusof, Y. A., Mokhtar, M. N., Yaacob, M. E., Ghazali, H. M., Varith, J., Manaf, E., Changd, L. S., & Manaf, Y. N. (2020). Processing of coconut sap into sugar syrup using rotary evaporation, microwave, and open-heat evaporation techniques. *Journal of the Science of Food and Agriculture*, 100, 4012–4019. <https://doi.org/10.1002/jsfa.10446>
- BPS (2021). Statistik Perkebunan Kelapa Sawit Indonesia 2017-2021. <https://www.bps.go.id/id/publication/2022/11/30/254ee6bd32104c00437a4a61/statistik-kelapa-sawit-indonesia-2021.htmlf>

- Cappelletti, M., Ferrentino, G., Endrizzi, I., Aprea, E., Betta, E., Corollaro, M. L., Charles, M., Gasperi, F., & Spilimbergo, S. (2015). High-pressure carbon dioxide pasteurization of coconut water: A sport drink with high nutritional and sensory quality. *J. Food Eng.*, 145, 73–81. <https://doi.org/10.1016/j.jfoodeng.2014.08.012>
- Chen, T., Wei, C.-K., Li, T., Zhang, H.-L., Ni, Z.-J., Khan, M. R., & Wei, Z.-J. (2023). Effects of reducing sugars on the structural and flavor properties of the Maillard reaction products of *Lycium barbarum* seed meal. *Foods*, 12(4346), 1–17. <https://doi.org/https://doi.org/10.3390/foods12234346>
- Dewi, E., Utami, A. S., & Junaidi, R. (2024). The effect of Ca(OH)₂ addition and cooking process to chemical characteristic of palm sap sugar (*Arenga pinnata*) produced by crystallisor. *Proceedings of the 7th FIRST 2023 International Conference on Global Innovations (FIRST-ESCSI 2023)*, 232, 532–538. https://doi.org/https://doi.org/10.2991/978-94-6463-386-3_54
- Dirkes, R., Neubauer, P. R., & Rabenhorst, J. (2021). Pressed sap from oil palm (*Elaeis guineensis*) trunks: a revolutionary growth medium for the biotechnological industry? *Biofuels, Bioprod. Bioref.*, 15, 931–944. <https://doi.org/10.1002/bbb.2201>
- Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry*, 28(3), 350–356. <https://doi.org/10.1021/ac60111a017>
- Elewa, M., El-Saady, G., Ibrahim, K., Tawfek, M., & Elhossieny, H. (2022). Evaluation of digital brixmeter performance for brix measurement in raw sugar solution. *Journal of Engineering Sciences*, 50(3), 1–10. <https://doi.org/https://doi.org/10.21608/JESAUN.2022.115375.1108>
- Elisanti, A. D., Ardianto, E. T., & Rindiani, R. (2023). Brix level on dragon fruit and *Moringa oleifera* soft candy to prevent children dental caries. *IOP Conf. Series: Earth and Environmental Science*, 1168, 1–8. <https://doi.org/doi:10.1088/1755-1315/1168/1/012038>
- Fu, Y., Zhang, Y., Soladoye, O. P., & Aluko, R. E. (2019). Maillard reaction products derived from food protein-derived peptides: insights into flavor and bioactivity. *Critical Reviews in Food Science and Nutrition*, 60(12), 1–14. <https://doi.org/https://doi.org/10.1080/10408398.2019.1691500>
- Ge, Y., Li, K., Xie, C., Xu, Y., Shi, C., Hang, F., & Doherty, W. O. S. (2021). Formation of Volatile and aroma compounds during the dehydration of membrane-clarified sugarcane juice to non-centrifugal sugar. *Foods*, 10(1561), 1–18. <https://doi.org/https://doi.org/10.3390/foods10071561>
- Gorea, E. A., Godwin, I. D., & Mudge, A. M. (2020). *Ganoderma* infection of oil palm – a persistent problem in Papua New Guinea and Solomon Islands. *Australasian Plant Pathology*, 49, 69–77. <https://doi.org/10.1007/s13313-019-00673-9>
- Hossain, N., Zaini, J., Jalil, R., & Mahlia, T. M. I. (2018). The efficacy of the period of saccharification on oil palm (*Elaeis guineensis*) trunk sap hydrolysis. *International Journal of Technology*, 9(4), 652–662. <https://doi.org/10.14716/ijtech.v9i4.1808>
- Julai, K., Sridonpai, P., Ngampeerapong, C., Tongdonpo, K., Suttisansanee, U., Kriengsinyos, W., Nattira, O.-N., & Tangsuphoom, N. (2023). Effects of extraction and evaporation methods on physico-chemical, functional, and nutritional properties of syrups from Barhi dates (*Phoenix dactylifera* L.). *Foods*, 12, 1268, 1-21. <https://doi.org/10.3390/foods12061268>
- Laureati, M., Boni, A. De, Saba, A., Lamy, E., Minervini, F., Delgado, A. M., & Sinesio, F. (2024). Determinants of consumers' acceptance and adoption of novel food in view of more resilient

- and sustainable food systems in the EU: A systematic literature review. *Foods*, 13(10), 1–23. <https://doi.org/10.3390/foods13101534>
- Liu, S., Sun, H., Ma, G., Zhang, T., Wang, L., Pei, H., Li, X., & Gao, L. (2022). Insights into flavor and key influencing factors of Maillard reaction products: A recent update. *Frontiers Nutrition*, 9, 1–18. <https://doi.org/10.3389/fnut.2022.973677>
- Magwazaa, L. S., & Opara, U. L. (2015). Analytical methods for determination of sugars and sweetness of horticultural products—A review. *Scientia Horticulturae*, 184, 179–192. <https://doi.org/10.1016/j.scienta.2015.01.001>
- Marasinghege, C., Broadfoot, R., Bottle, S., Bartley, J., Doherty, W. O. S., & Rackemann, D. W. (2022). Investigation on the effect of the heating surface temperature of 1st evaporator on sucrose loss and the degradation of sugarcane juice constituents. *Journal of Food Engineering*, 329, 1–12. <https://doi.org/10.1016/j.jfoodeng.2022.111074>
- Naknean, P., Meenune, M., & Roudaut, G. (2009). Changes in physical and chemical properties during the production of palm sugar syrup by open pan and vacuum evaporator. *Asian Journal of Food and Agro-Industry*, 2(04), 448–456. [http://ifrj.upm.edu.my/20%20\(05\)%202013/38%20IFRJ%2020%20\(05\)%202013%20Meeune%20214.pdf](http://ifrj.upm.edu.my/20%20(05)%202013/38%20IFRJ%2020%20(05)%202013%20Meeune%20214.pdf)
- Nie, S., Huang, J., Hu, J., Zhang, Y., Wang, S., Li, C., Xie, M., & Marcone, M. (2013). Effect of pH , temperature and heating time on the formation of furan in sugar – glycine model systems. *Food Science and Human Wellness*, 2(2), 87–92. <https://doi.org/10.1016/j.fshw.2013.05.001>
- Pérez, N.S.V., Ramírez-Sotelo, G., Yáñez-Fernández, J., & Castro-Rodríguez, D.C. (2023). Role of thermal process on the physicochemical and rheological properties and antioxidant capacity of a new functional beverage based on coconut water and rice flour. *ACS Omega*, 8, 26938–26947. <https://doi.org/10.1021/acsomega.3c01761>
- Poste, L. M., Mackie, D. A., Butler, G., & Larmond, E. (1991). *Laboratory Methods for Sensory Analysis of Food*. Canada Communication Group—Publishing Centre Ottawa, Canada K1A, 104p.
- Rahayuwati, S., Kusuma, Y. M., Prawirosukarto, S., Dadang, & Santoso, T. (2020). The status of *Oryctes rhinoceros* Nudivirus (OrNV) invection in *Oryctes rhinoceros* (Coleoptera: Scaradaeidae) in Indonesia. *Journal of Oil Palm Research*, 32(4), 582–589. <https://doi.org/10.21894/jopr.2020.0041>
- Rao, P. V. K. J., Das, M., & Das, S. K. (2009). Changes in physical and thermo-physical properties of sugarcane , palmyra-palm and date-palm juices at different concentration of sugar. *Journal of Food Engineering*, 90(4), 559–566. <https://doi.org/10.1016/j.jfoodeng.2008.07.024>
- Saetear, P., Saechua, N., & Sreenonchai, K. (2021). Sequential injection system for analysis of degree brix, orthophosphate and ph in raw sugarcane juice applicable to sugar industry. *Molecules*, 26(21), 6484, 1-16. <https://doi.org/10.3390/molecules26216484>
- Sariwahyuni, Amin, I., & Kurniawan. (2022). Optimasi penambahan susu kapur pada nira mentah terhadap ph dan volume endapan Ca₃(PO₄)₂ di PTPN XIV Unit Pabrik Gula Takalar. *Jurnal Teknologi Kimia Mineral*, 1(2), 86–89. <https://doi.org/10.61844/jtkm.v1i2.267>
- Sulaiman, S., Jafarzadeh, S., & Ariffin, F. (2020). Characterization of physico-chemical and antioxidant properties of oil palm trunk saps as affected by the storage time in comparison to nipa sap. *Journal of Oil Palm Research*, 32(1), 75–82. <https://doi.org/10.21894/jopr.2020.0014>

- Tamanna, N., & Mahmood, N. (2015). Food processing and Maillard reaction products: effect on human health and nutrition. *Int. J. Food Sci.*, 2015(526762). <https://dx.doi.org/10.1155/2015/526762>
- USDA. Foreign Agricultural Service (2022). *Sugar Annual Indonesia*. <https://fas.usda.gov/data/indonesia-sugar-annual-5>
- Wiyono, S., Fachry, M. S., Abdullah, S., Sidik, D., & Erwin. (2022). The effect of vacuum pressure on the quality of liquid palm sugar resulting from the vacuum evaporation process. *Conference on Broad Exposure to Science and Technology 2021*, 210, 453–455. <https://doi.org/10.2991/aer.k.220131.070>
- Yuwono, S. S., Istianah, N., Ali, D. Y., & Aghata, R. J. A. (2020). The properties of sweet sorghum syrup produced by combined vacuum falling film and rotary evaporation. *International Journal of Advance Tropical Food*, 2(1), 1–7. <http://dx.doi.org/10.26877/ijatf.v2i1.5811>