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RESEARCH ARTICLE
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Comprehensive Characterization of Sugar Palm Fruit (*Arenga pinnata*) from Three Production Centers in West Sumatra: A Comparative Study of South Solok, Maninjau, and Pasaman

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ABSTRACT

Sugar palm fruit is the endosperm of palm tree fruit seeds processed by boiling. Palm trees (*Arenga pinnata*) thrive in West Sumatra and produce sugar palm fruits as the main horticultural product. This study aims to analyze the quality of sugar palm from various regions in West Sumatra, Indonesia. This study focuses on LC-MS/MS QTOF testing to identify the chemical components present in sugar palm fruit from South Solok (KS), Maninjau (KM), and Pasaman (KP). The results of this study indicate that there are differences in the chemical component analysis of sugar palm fruit. Each *Arenga pinnata* fruit has several compounds that distinguish it from other *Arenga pinnata* fruits from different regions. KS has 7 compounds, KP has 5 compounds, and KM contains 17 different compounds. Each sugar palm fruit contains the same compounds, specifically Arecatannin A1 and procyanidin B4. The study also examined the properties of color, moisture content, ash content, fat content, crude fiber, dietary fiber, protein, pH, and total polyphenols content. KS contained higher total polyphenols (fresh), protein, and ash content (fresh). KM samples had the highest moisture and dietary fiber content, and KP samples contained higher total polyphenols (dry), crude fiber, and fat content than the other samples. These findings indicate that the quality of sugar palm fruit in West Sumatra varies.

Keywords: *Arenga pinnata*, LC-MS/MS QTOF, Quality, Sugar palm fruit, *Fiber*.

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INTRODUCTION

Sugar Palm (*Arenga pinnata*) is a valuable commodity that supports the livelihoods of local farmers. *Arenga pinnata* is recognized as an important non-timber forest product (NTFP) with substantial commercial and socio-economic value (Latifah et al., 2025). It is known as a versatile plant, with nearly all parts of the tree that can be utilized (Anggraini et al., 2025a), including the sap for brown sugar and fermented beverages, the fibers for broom production, the leaves for traditional roofing materials, and the fruit for producing sugar palm fruit, locally known in West Sumatra as *kolang kaling* (Iskandar et al., 2023). Sugar palm fruit is rich in dietary fiber, predominantly galactomannan, a polysaccharide with well-documented prebiotic properties. Dietary fiber plays an important role in maintaining intestinal health by modulating gut microbiota and improving digestive function (Liu et al., 2024). In addition, fiber intake has been shown to regulate postprandial blood glucose levels by delaying glucose absorption (Xiong et al., 2023) and to reduce serum cholesterol through bile acid binding and enhanced fecal excretion (Chen et al., 2025). The high fiber content of sugar palm fruit may also contribute to obesity prevention by increasing satiety and limiting lipid absorption (Liu et al., 2024) and increase volume in conditions of excess water, thereby increasing satiety (Doria et al., 2025). Beyond its physiological benefits, dietary fiber from sugar palm fruit is also valuable for food processing applications (Xiong et al., 2023).

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In addition to its high fiber content, sugar palm fruit contains several compounds that are beneficial to the body. In 100g of sugar palm fruit, it includes 27kcal calories, 6g of carbohydrates, 1.6g of fiber, 24.3mg of phosphorus, and 9.1mg of calcium (Rahayu et al., 2025), galactomanan which ranges 61%, mannan 26%, and cellulose 12%, iron 0.25mg, moisture content reaches 93.6%, ash content 0.26%, and pH 5.53. The starch content in sugar palm fruit is approximately 84.58%, which provides a feeling of fullness to consumers, thereby helping to prevent obesity (Rahayu et al., 2025). Calcium, phosphorus, and iron are micronutrients essential for the body, whose benefits play a crucial role in building body tissues and regulating physiological processes, such as blood clotting, oxygen transport, and energy metabolism (Martiniakova et al., 2022). Previous studies have reported the presence of vitamin C in *Arenga pinnata* fruit, although its level may vary depending on conditions (Rianghepat et al., 2021). Antioxidants play a role in fighting and preventing the formation of free radicals in the body. Antioxidants can also prevent chronic diseases (Dixit et al., 2023).

Beyond its macro and micronutrient content, sugar palm fruit (*Arenga pinnata*) demonstrates substantial phytochemical diversity that enhances its functional value. A 70% ethanolic extract of the fruit was reported to contain structurally diverse secondary metabolites, including two terpenoids, sixteen phenylpropanoids, and eight known terpenoids, characterized using HR-ESI-MS and one- and two-dimensional NMR analyses (Wu et al., 2022). Additional screenings have identified flavonoids, triterpenoids, saponins, and tannins (Adelvia, 2020), while earlier studies also reported flavonoids, alkaloids, and quinones associated with antioxidant, anti-inflammatory, and analgesic activities (Sovia & Anggraeny, 2019). Collectively, the coexistence of essential nutrients and multiple classes of secondary metabolites underscores the multifaceted functional properties of sugar palm fruit and supports its classification as a functional food with potential health-promoting relevance. Several studies have demonstrated that environmental and biological factors significantly influence plant nutritional quality and metabolite composition, including in sugar palm fruit. Variables such as harvest age, species, seasonal variation, and exposure to biotic and abiotic stresses can alter both yield and chemical composition. In particular, nutrient deficiencies, strong winds, and low rainfall have been associated with reduced production quality (Salam et al., 2023; Singh et al., 2025), whereas higher rainfall and favorable growing conditions tend to support improved fruit quality and nutrient (Sarkar et al., 2023).

Because of the many benefits of sugar palm fruit, this research is very important, considering that the Arenga pinnata plant grows wild in West Sumatra. This research is expected to provide information regarding the compounds contained in sugar palm fruit and their benefits as a functional food. This research was conducted as a continuation of previous studies that evaluated the quality of sugar palm sap from various regions in West Sumatra. According to the results of prior research, the areas of South Solok, Maninjau, and Pasaman produce the highest quality of palm sap compared to other regions (Anggraini et al., 2025b). Therefore, in this study, sugar palm fruit was selected from South Solok (KS), Maninjau (KM), and Pasaman (KP), considering that the sugar palm fruit came from the best sugar palm sap-producing areas in West Sumatra. Although sugar palm (*Arenga pinnata*) is widely cultivated in West Sumatra, research has mainly focused on agronomic, physicochemical, and basic nutritional aspects. Comparative metabolite profiling of sugar palm fruit from different production centers remains limited, and advanced metabolomics approaches have not yet been applied to assess regional variation. This study addresses this gap by using comparative metabolomics to reveal geographical differences in metabolite composition, providing a basis for origin authentication, quality differentiation, and future valorization of sugar palm products.

This study used liquid chromatography–tandem mass spectrometry coupled with quadrupole time-of-flight (LC–MS/MS QTOF) to profile the metabolite composition of sugar palm fruit. The untargeted, high-resolution, accurate-mass capability of LC–MS/MS QTOF enables broad detection of metabolites without prior compound selection and improves discrimination of closely related compounds through accurate *m/z* measurements and MS/MS fragmentation information. This method is commonly used for metabolit profiling in plant materials, food products, biological fluids, microorganisms samples (Alseekh et al., 2021; Liden et al., 2023). Thus, it allows an understanding of how environmental factors, varieties, and processing can affect the presence of compounds in sugar palm fruit. Based on this description, it is necessary to conduct further research to determine the quality of sugar palm fruit obtained from several regions in West Sumatra. Therefore, this study aims to determine the chemical profile of sugar palm fruit by analyzing LC-MS/MS QTOF from the different areas in West Sumatra.

MATERIALS & METHODS

Sample Collection

Sugar palm fruit (*Arenga pinnata*) samples were collected from three major production centers in West Sumatra, Indonesia: South Solok (KS), Maninjau (KM), and Pasaman (KP) (Fig. 1). These regions were selected based on previous studies identifying them as high-quality sugar palm and palm sap production areas. No preservatives were added to the samples. All samples were processed immediately after collection.

Chemicals, Reagents and Instruments

The chemicals used for the analysis are distilled water, pH buffer solution, DPPH (1,1-diphenyl-2-pyrcylhydrazil), Folin-Ciocalteu, 95% ethanol, methanol, H_2SO_4 0.225 N, NaOH 0.313 N, K_2SO_4 10%, HCl 0.02 N, boric acid, methylene red: methylene blue indicator, and Na_2CO_3. Equipment used in this study included aluminum dishes, drying oven, muffle furnace, desiccator, analytical balance, Whatman filter paper, crucible tongs, and Kjeldahl digestion

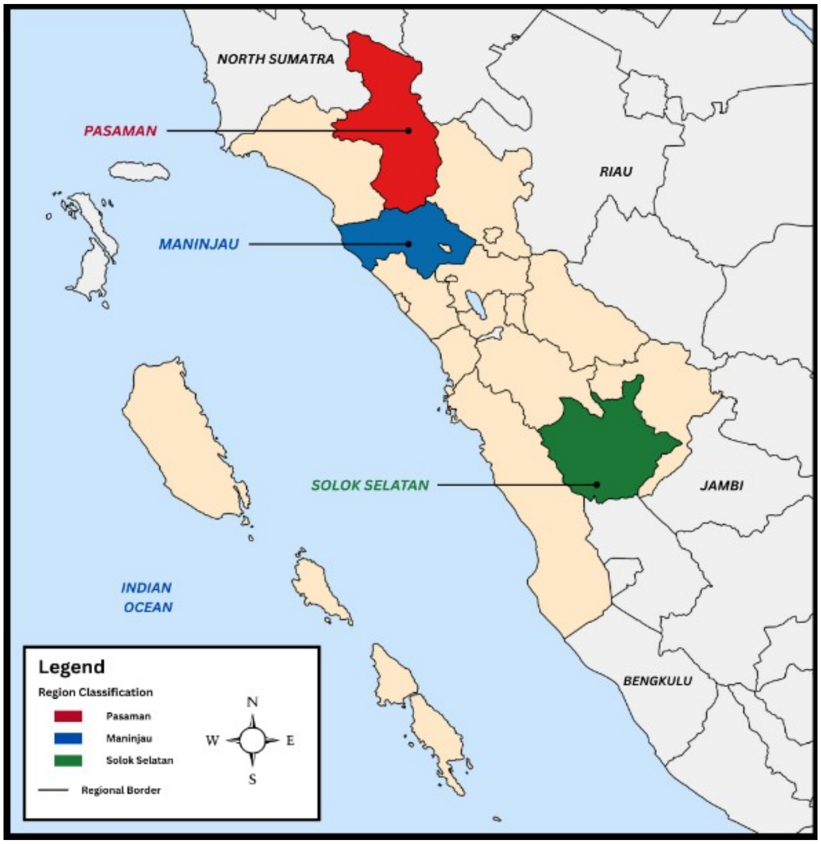


Fig. 1: Geographic Locations of Sampling Sites in South Solok, Maninjau (Agam), and Pasaman, West Sumatra, Indonesia**.**

flasks, digestion block unit, kjeldahl distillation unit, soxhlet extraction apparatus, fat flasks, erlenmeyer flasks, test tubes, micropipettes, Colorimeter ColorFlex EZ (Reston, Virginia, USA), UV–Vis spectrophotometer Shimadzu UV-1800 (Kyoto, Japan), and LC–MS/MS QTOF Waters Xevog2-XS (Waters, USA).

Sugar Palm Fruit Processing

Sugar palm fruit was prepared from semi-ripe palm fruits selected based on their characteristic freshgreen outer skin. The fruits were manually separated from the stalk and boiled in water for 3h to remove irritant sap compounds. After boiling, the fruits were opened to extract the endosperm using a traditional tong. The extracted seeds were thoroughly washed and subsequently soaked in lime water for 48h to facilitate the removal and precipitation of residual sap and mucilaginous substances. Following soaking, the seeds became translucent in appearance and were then designated as processed sugar palm fruit.

Sugar Palm Fruit Analysis

LC-MS/MS QTOF Analysis

A standard solution of biotin and chloramphenicol was made as a verification system instrument. Then weigh the test sample into a 10 mL measuring flask, add methanol, and sonicate the mixture. Add methanol to the impression mark and homogenize. Next, filter with agHP/PTFE filter membrane. After that, it is injected into the LC-MS/MS QTOF system. The column used is HSS T3, with motions A (0.1% formic acid in water) and B (0.1% formic acid in acetonitrile). Flow rate of 0.6 mL/min, and the pump system *gradient.* MS method with *Mode of Operation,* great MSE then *ionization* ESI (-) and/or ESI (+).

Color Measurement

Color measurement used a colorimeter (HunterLab) to measure the values of L*, a*, and b*. Before testing, the sample surface is cleaned of contamination. The sample is placed in a transparent container and then positioned appropriately on the measurement port, where it is secured to prevent shifting. The L* value indicates a brightness level between 0 (black) and 100 (white), a* indicates a red-green gradation, and b* indicates a yellow-blue gradient. Furthermore, the value of a* and value b* are used to calculate the value of Hue based on the formula:

$$^{o}\text{Hue arc} = \tan^{-1}(b^*/a^*)$$

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}}$$

Moisture Content

The moisture content test is performed by heating an empty aluminium dish in an oven at 105°C for 30 minutes. Then, it cools in the desiccant for about 15 minutes. Weigh empty aluminium dish and record as W0. The sugar palm fruit sample, which weighed up to 3g, was placed into a dish (W1). It is then placed in an oven at 105°C for 3 to 4 hours. After that, it is cooled in a desiccant for 30 minutes, then weighed. Reheat for 1h for a constant weight (weight difference ± 0.2g) and record it as W2.

$$\text{Moisture Content (\%)} = \frac{W1 - (W2 - W0)g}{W1\,g} x100\%$$

Ash Content

The ash content test is done by heating the ash cups in the oven at 105°C for 30 minutes. Then it is cooled in a desiccant for 15 minutes. The ash cup is weighed as (W0). Put a sample of 3g into an ash cup as (W1). Next, the cup and the sample are heated on an electric stove until they smoke. After it is smokeless, the cups are put in the oven for 6 hours at a temperature of 550°C. After forming a white ash, the cup is inserted into a desiccator for approximately 30 minutes. The cup is weighed and recorded as (W2).

$$\text{Ash Content (\%)} = \frac{(W2 - W0)g}{W1\ g}\ x100\%$$

Crude Fiber Analysis

Weighing 3g of sugar palm fruit (W1), samples were put into a 250 mL Erlenmeyer flask. 100 mL of H_2SO_4 0.225 N was added and refluxed for 30 minutes. Filter the solution using Whatman paper. The residue left behind is washed off with a hot aqueous solution of up to 100 mL. Place the residue in a 250 mL Erlenmeyer flask and add 0.313 N NaOH, which is then refluxed for 15 minutes. The solution was re-filtered with Whatman paper that had been weighed (W0), then 15 mL of 10% K_2SO_4 was added. Reflow the residue with 10 mL of boiling deionized water and 15 mL of 95% ethanol. Filter paper with residue is dried in the oven at 105°C for ± 2h. The filter paper is then transferred to the desiccant and refrigerated for 1h. Filter paper with weighed residue (W2).

$$\text{Crude Fiber (\%)} = \frac{(W2 - W0)g}{W1\ g}\ x100\%$$

Dietary Fiber Analysis

The sample was weighed into 50 mL Falcon tubes, then transferred into a 400 mL cup. Add the MES-TRIS buffer solution and stir until no clumps form. Add the enzyme α-amylase and stir until the mixture is homogeneous. Then the cup is covered with aluminum foil. It is further incubated in *a shaking waterbath* at 100°C for 30 minutes. The solution is cooled to 60°C, the aluminum foil is opened, the dispersion is formed, and the glass cup wall is rinsed with water. Add the protease enzymes and stir until no clumping occurs. Then cover it again with aluminum foil and incubate in a shaking water bath at 60°C for 30 minutes. Open the aluminum foil, and add 95% ethanol at 60°C. The solution is stirred and covered with aluminum foil. The solution is left to sit at room temperature for 1h. It is further filtered with ashless filter paper, and the residue is washed with 78% ethanol, 95% ethanol, and acetone. The filter paper is dried in the oven at a temperature of 103°C. Each filter paper containing residue is weighed and determined by the weight of ash in the first residue and the protein weight in the second residue.

Protein Analysis

Protein analysis was carried out using the Kjeldahl method. First, a sample of 1g is put into the Kjedahl tube. Then, Kjedahl tablets were added, followed by 15 mL of H_2SO_4. Next, the flask is attached to the destruction device and destroyed for 3h. Pumpkin cooled. The sample solution in the Kjeldahl flask is transferred into a 100 mL measuring flask and diluted with deionized water. The kjeldahl pumpkin is cleaned, and then 10 mL of the sample solution is added. 30 mL of 50% NaOH was added to the Kjeldahl flask containing the solution, and a distillation device was fitted that had contained 10 mL of 3% boric acid and an indicator, metylen red: metylen blue (3:1). The tip of the distillate should be submerged in a solution of boric acid. The distillation is carried out for approximately 15 minutes, until the container solution changes color from a purplish red to green. The distillation results are titrated with 0.02 N HCl until the green color changes to a purplish red. The volume of HCl titration is used to calculate nitrogen levels. The percentage value of nitrogen obtained is converted into protein content.

$$\%N = \frac{(mL\ HCl\ sample - mL\ HCl\ blank)x\ N\ HCl\ x\ FP\ x\ 14{,}007}{W1\ (mg)}\ x100\%$$

% Protein =% N x Protein conversion factor

Fat Analysis

The fat content test was carried out using the Soxhlet method. The first step is to ensure the fat pumpkin is clean of contaminants. During the analysis process, the fat gourds should be clamped using clamping pliers. The fat gourd is weighed (W0), then solvent (hexane) is added to the capacity of the fat gourd. A socket tool is installed, and a thimble containing a sample is inserted (the thimble is made by folding filter paper, then a 3g (W1) sample is inserted and closed). The socket tool is heated for 15 minutes of circulation or approximately 4h. The thimble is lifted, and the solvent is vaporized and contained. The fat squash is heated in an oven at 100°C, then cooled in a desiccant for 30 minutes and weighed (W2).

$$\text{Fat Content} = \frac{(W2 - W0)g}{W1\ g}\ x100\%$$

pH Analysis

pH analysis was carried out using a pH meter. Turn on the pH meter and let it steady for about 15-30 minutes. Then the electrodes are rinsed with aquades and dried with tissue paper. Dip the sample electrode in the pH meter. The results of the pH reading of the sample, as recorded by the instrument, are noted.

Total Polyphenol Content (TPC)

1g of the sample was dissolved in 10 mL of methanol. The solution is vortex and extracted using *an ultrasonic bath* for 15 minutes. Next, 1 mL of supernatant, 2 mL of aquades, 1 mL of 50% Folin-Ciocalteu reagent, and 1 mL of 5% Na_2CO_3 solution were taken. The solution is vortexed until homogeneous, then let sit for 1 hour in a dark room. After that, the absorbency with a wavelength of 725nm was measured using the UV-Vis spectrophotometer. Total polyphenols were calculated by comparing the absorption value with acid standard and expressed in units of mgGAE/g of the sample.

Statistical Analysis

All quantitative analyses were conducted in triplicate (n = 3), and the results are presented as mean ± SD. Data processing and descriptive statistical calculations were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA) and Microsoft Excel (Microsoft Corp., USA). The present study was designed as a comparative and exploratory characterization of sugar palm fruit samples from different production centers, rather than hypothesis-driven experimentation. Therefore, the data were interpreted using descriptive statistics, and no formal inferential statistical analysis (e.g., ANOVA or regression modeling) was applied. No formal inferential statistical model was applied to the LC-MS/MS profiling results.

RESULTS & DISCUSSION

LC-MS/MS QTOF Analysis

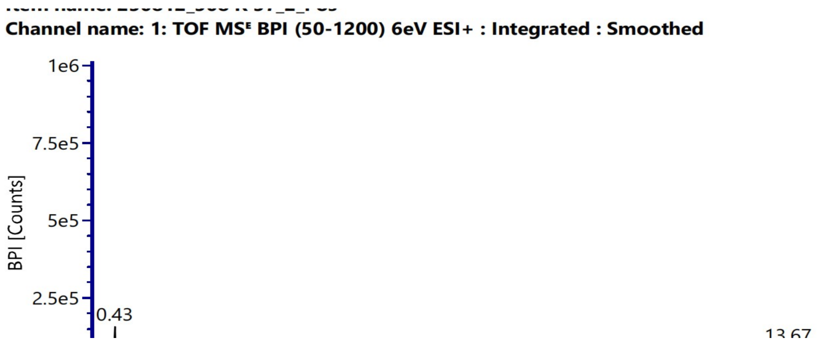
Untargeted LC–MS/MS QTOF profiling revealed clear differences in metabolite composition among sugar palm fruit from South Solok (KS), Maninjau (KM), and Pasaman (KP) (Table 1). A total of 16, 12, and 25 compounds were detected in KS, KM, and KP, respectively, indicating pronounced regional variation. Detected metabolites were classified as carbohydrates, flavonoids, and polyphenols (condensed tannins), with flavonoids dominating across all regions. The results of the LC-MS/MS QTOF chromatogram are shown in Fig. 2-4. The KS sample contained 16 metabolites, including carbohydrates, 10 flavonoids, and three polyphenols. Identified compounds included 3-β-D-glucopyranosyloxybutanol-2, which may contribute to carbohydrate availability, although its function remains poorly characterized. KS was also rich in bioactive flavonoids such as catechins, naringenin, tangeretin, odoratin-7-O-β-D-glucoside, and 5-hydroxy-6,4′-dimethoxyflavone-7-O-β-D-glucopyranoside. Catechins are known for strong antioxidant activity (Yuan et al., 2025), while naringenin exhibits anti-inflammatory and anti-infective properties (Cai et al., 2023).

The KM sample showed lower metabolite diversity (12 compounds), comprising five carbohydrates, six flavonoids, and one polyphenol. Key metabolites included sedoheptulose, phytolacca cerebroside, rhamnose, noririsflorentin, and 5-O-desmethylnobiletin. Sedoheptulose, a rare seven-carbon sugar, plays a role in the pentose phosphate pathway and inhibits C6 sugar metabolism (Palur et al., 2025). Phytolacca cerebroside is a glycosphingolipid involved in cell membrane structure (Zhang et al., 2020), while rhamnose has reported anti-inflammatory activity and stimulates collagen production (Novotná et al., 2023), Noririsflorentin and 5-O-desmethylnobiletin contribute antioxidant and polymethoxyflavone-related pharmacological effects, respectively (Mushtaq et al., 2023).

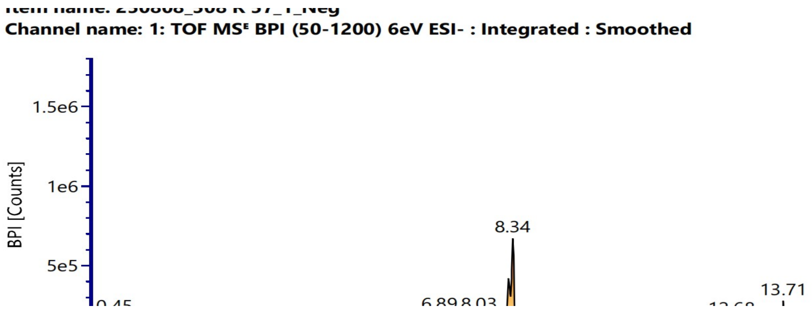
Table 1: LCMS/MS-QTOF Identified Compounds from KS, KM, KP

Class Compound	Compound Name	Formula	Sugar Palm Fruit (Retention time *min)*		
			KS	KM	KP
Carbohydrate	3-β-D-Glucopyranosyloxybutanol-2	$C_{10}H_{20}O_7$	2.15	-	-
	Methyl-α-D-fructofuranoside	$C_7H_{14}O_6$	5.60	-	-
	Dulcitol	$C_6H_{14}O_6$	0.44	0.44	-
	Phytolacca cerebroside	$C_{48}H_{20}O_8$	-	18.53	-
	Rhamnose	$C_6H_{12}O_5$	-	0.44	-
	Polygalatenoside E	$C_{22}H_{32}O_{13}$	-	8.71	9.06
	Sedoheptulose	$C_7H_{14}O_7$	-	0.45	-
	2,7-Dihydroxy-4-methoxyphenanthrene-2,7-0-diglucoside	$C_{27}H_{32}O_{13}$	-	-	12.24
	Eugenylglucoside	$C_{16}H_{22}O_7$	-	-	11.25
	Suffruticoside E	$C_{26}H_{38}O_{17}$	-	-	7.21
	Tectoruside	$C_{21}H_{30}O_{13}$	-	-	8.84
	Sibiricaphenone	$C_{20}H_{28}O_{11}$	-	-	9.91
Flavonoid	(2S)-5,7-Dihydroxy-6-methoxy-flavanone-7-O-β-Dglucopyranoside	$C_{22}H_{24}O_{10}$	12.04	12.04	-
	3'-0-Methyltaxifolin	$C_{16}H_{14}O_7$	6.83	-	6.82
	5-o-Desmethylnobiletin	$C_{20}H_{20}O_8$	-	16.40	-
	Noririsflorentin	$C_{19}H_{16}O_8$	-	16.60	-
	Aloeresin	$C_{19}H_{22}0_9$	-	8.74	9.11
	Capillarisin	$C_{16}H_{12}O_7$	-	-	10.44
	Isobavachin	$C_{20}H_{20}O_4$	-	-	12.72
	Isorhamnetin	$C_{16}H_{12}O_7$	-	-	16.68
	Isorhamnetin-3-0-β-gentiobioside	$C_{28}H_{32}O_{17}$	-	-	10.68
	Kaempferol 3-a-L-dirhamnosyl-(1-4)- β-D-glucopyranoside	$C_{27}H_{30}O_{15}$	-	-	9.48
	Leucopelargonidin	$C_{15}H_{14}O_6$	-	-	5.92
	Quercetin-3-O-xyloside	$C_{20}H_{18}O_{11}$	-	-	10.23
	Shegansu A	$C_{32}H_{32}O_{16}$	6.87	-	7.16
	Sinencetin	$C_{20}H_{20}O_7$	-	-	16.65
	Catechin	$C_{15}H_{14}O_6$	6.90	-	-
	Cnidimol F	$C_{15}H_{14}O_6$	6.97	-	-
	Cnidimol E	$C_{15}H_{16}O_6$	-	-	7.35
	Naringenin	$C_{15}H_{12}O_5$	14.30	-	-
	Odoratin-7-O-β-D-glucoside	$C_{22}H_{24}O_9$	11.73	-	-
	Tangeritin	$C_{20}H_{20}O_7$	16.65	-	-
	Procyanidin B4	$C_{30}H_{26}O_{12}$	5.19	-	6.46
Polyphenol	Arecatannin A1	$C_{45}H_{38}O_{18}$	7.62	7.62	5.75
	Arecatannin A2	$C_{60}H_{50}O_{24}$	0.46	-	6.00
	Viscidulin Ⅰ	$C_{15}H_{10}O_7$	12.99	12.99	-

Remark: (-) indicates that the compound was not identified from the sample.

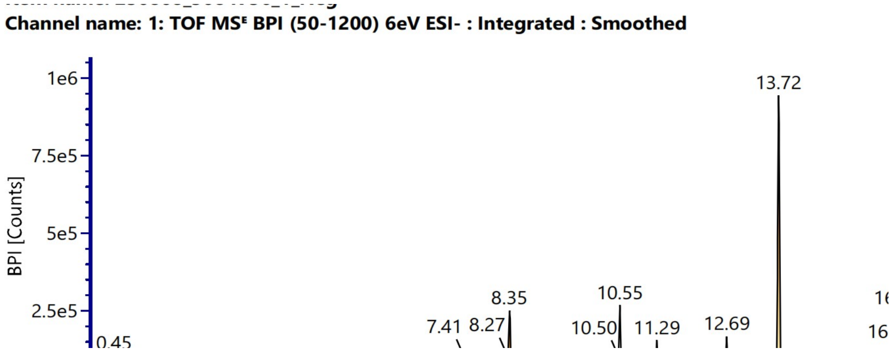


Chromatogram KS ESI +

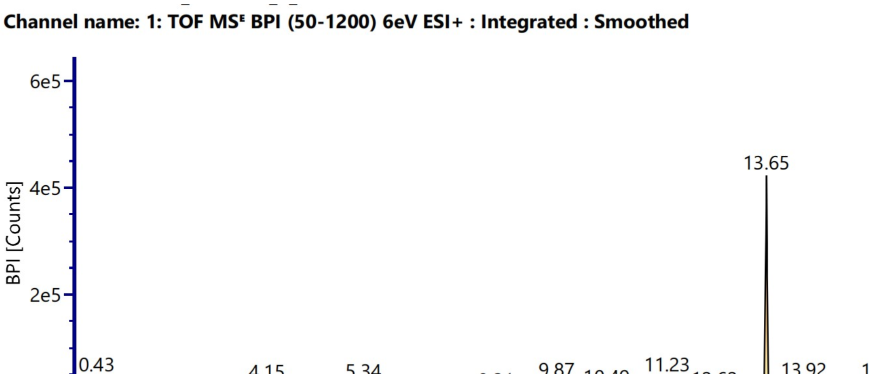


Chromatogram KS ESI –

Fig. 2: Chromatograms LC-MS/MS QTOF KS (South Solok) Sample.



Chromatogram KM ESI -



Chromatogram KM ESI +

Fig. 3: LC-MS/MS QTOF Chromatogram KM (Maninjau) Sample.

The KP sample exhibited the highest metabolite diversity, with 25 detected compounds, including six carbohydrates, two polyphenols, and 18 flavonoids. Carbohydrate-related compounds such as 2,7-dihydroxy-4-methoxyphenanthrene-2,7-O-diglucoside, eugenylglucoside, suffruticoside E, and tectoruside may contribute to satiety and potential anti-obesity effects. Eugenylglucoside, formed by glucosylation of eugenol, is also associated with aroma and flavor (Zhao et al., 2020). KP contained diverse flavonoids, including isorhamnetin, isobavachin, quercetin-3-O-xyloside, kaempferol derivatives, sinensetin, and capillarisin. Isorhamnetin has been linked to cardiovascular protection and anti-inflammatory effects (Gong et al., 2020) , while isobavachin shows notable pharmacological activity (Chung et al., 2024).

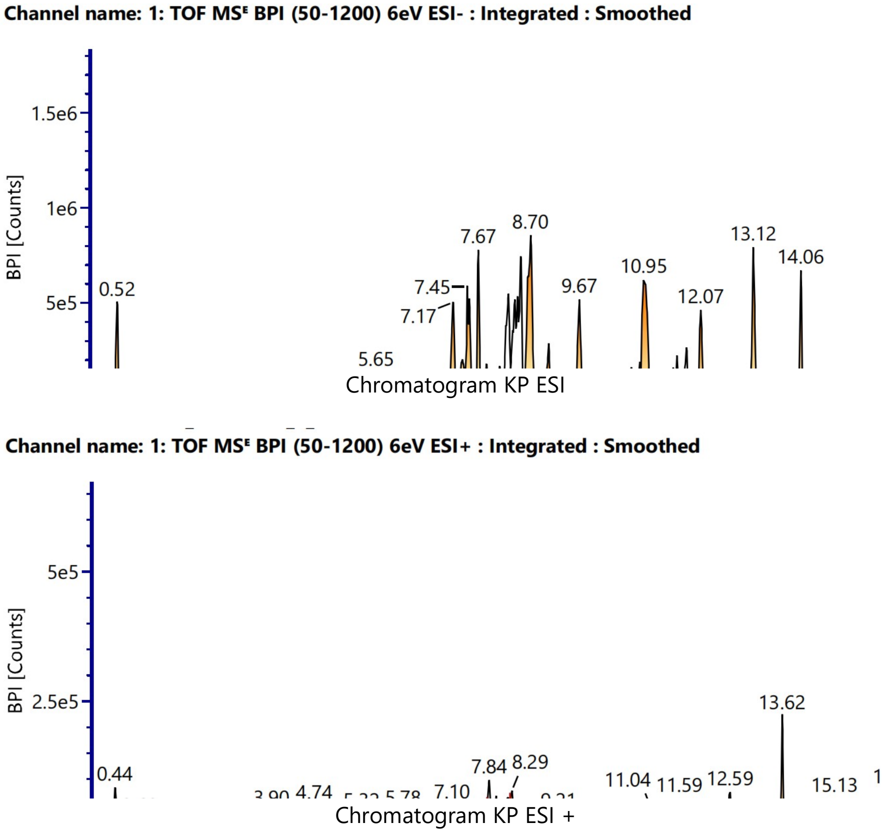


Fig. 4: LC-MS/MS QTOF Chromatogram of KP (Pasaman) Sample.

Comparative analysis (Table 1) showed partial metabolite overlap among regions, with three shared compounds between KS–KM and KS–KP, and two between KM–KP. Dulcitol, detected in KS and KM, is a natural sweetener with antioxidant, anti-inflammatory, and anticancer activities (Ge et al., 2025). Aloeresin, identified in KM and KP, has anti-inflammatory properties and is commonly used in dietary supplements (Hicks et al., 2022). Aracetannin A2, detected only in KS, further supports the presence of bioactive polyphenols (Chung et al., 2024),

Notably, arecatannin A1 and procyanidin B4 were detected in all samples, suggesting that these condensed tannins represent core antioxidant constituents of sugar palm fruit. Condensed tannins exhibit strong radical-scavenging activity and protective effects against oxidative stress and lipid peroxidation (Chung et al., 2024). Procyanidin B4, a dimeric proanthocyanidin composed of catechin and epicatechin units, has demonstrated significant antioxidant activity (Fischer et al., 2025), indicating a fundamental contribution to antioxidant potential.

Consistent with reports on date palm and other fiber-rich tropical fruits, metabolomic profiles appear strongly influenced by cultivar and geographical origin (Alam et al., 2024; Alsuhaymi et al., 2023). Comparable metabolomic patterns have been observed in other fiber-rich tropical fruits. In jackfruit pulp, LC–QTOF–MS/MS analysis revealed diverse phenolic compounds with clear cultivar-related variation and links to antioxidant capacity (Cheng et al., 2025). Together, these results support the classification of sugar palm fruit as a functional fruit matrix enriched with bioactive polyphenols, rather than solely a dietary fiber source (Hou et al., 2025).

Several compound classes identified in this study have established biological relevance. Flavan-3-ols, procyanidins, catechins, naringenin, and polymethoxyflavones such as tangeretin and isorhamnetin derivatives have been linked to antioxidant, anti-inflammatory, metabolic, neuroprotective, and anti-obesity effects (González-Arceo et al., 2022; Cai et al., 2023; Sheng et al., 2023; Shoji et al., 2024; Wani et al., 2024). The regional variation observed in these metabolites suggests differences in functional potential among KS, KM, and KP samples.

Regional variation in metabolite composition likely reflects differences in rainfall, temperature, soil nutrients, and harvest maturity, which influence flavonoid and phenylpropanoid biosynthesis (Salam et al., 2023; Singh et al., 2025), contributing to the distinct metabolite fingerprints observed across the three regions.

Sugar Palm Fruit Color Analysis

Color is a key quality attribute in food, influencing identification, visual appeal, and consumer acceptance (Bureau et al., 2025). The appearance of sugar palm fruit sample is shown in Fig. 5.

Based on Table 2, fresh sugar palm fruit showed pH values of 6.52–7.75 and L* values of 9.42–43.27, with the highest brightness in Pasaman and the lowest in South Solok. Low chroma values (0.95–1.58) indicate weak color intensity, and the combination of relatively high L* and low c* values suggests a pale appearance. This is likely related to the low pigment content of the fruit, which is rich in water and colorless polysaccharides such as galactomannan, as well as pigment loss during soaking

Table 2: Color Analysis of Sugar Palm Fruit

	Treatment	^{0}Hue ± SD	c* ± SD	L* ± SD	Color
Fresh	KS	235.75 ± 0.77	0.95 ± 0.77	29.42 ± 0.01	Blue; colorless; dark
	KM	222.52 ± 0.94	1.09 ± 0.94	32.96 ± 0.04	Greenish-blue; colorless; Dark
	KP	162.53 ± 0.73	1.58 ± 0.01	43.27 ± 0.01	Green; colorless; Slightly bright
Dry	KS	76.22 ± 0.04	8.84 ± 0.01	40.91 ± 0.00	Reddish-yellow; less concentrated; Slightly bright
	KM	99.36 ± 0.00	8.06 ± 0.00	74.09 ± 0.00	Yellow; less concentrated; Bright
	KP	11.49 ± 0.05	11.49 ± 0.01	75.62 ± 0.00	Purplish red; less concentrated; bright

Remark: SD = Standard Deviation, C* = *Chroma*, L* = *Lightness index.*


(a) (b) (c)

Fig. 5: Sugar Palm Fruit; (a). South Solok (KS), (b), Maninjau (KM), (c), Pasaman (KP).

and boiling. In dried samples, hue angles ranged from 11.49° to 99.36°, reflecting variation in color tone, while higher c* values (8.06–11.49) and L* values (40.91–75.62) indicate increased color clarity compared with fresh fruit. Overall, sugar palm fruit powder exhibited a light but subdued color, consistent with the effects of plant age, variety, and processing conditions on food color (Bureau et al., 2025).

Chemical Analysis of Sugar Palm Fruit

Chemical composition analysis of sugar palm fruit included moisture, ash, fat, fiber, protein, dietary fiber, pH, polyphenols, and antioxidant activity (Fig. 6).

Moisture Content

Fresh sugar palm fruit exhibited very high moisture content (95.70–96.31%), with the highest value in KP and the lowest in KM (Fig. 6a). Drying substantially reduced moisture to 9.26–13.65%, with KS showing the highest and KM the lowest values. These differences may be linked to environmental temperature and climate, as heat stress is known to reduce fruit water content (Mesejo et al., 2024).

Ash Content

Ash content, which reflects total mineral content (Doria et al., 2025), ranged from 0.04% to 1.32% in fresh samples and from 0.30% to 1.23% in dried samples (Fig. 6b). The highest ash content was observed in KS (fresh) and KP (dry), while the lowest values occurred in KP (fresh) and KM (dry). Higher ash values indicate greater mineral content (Rizal et al., 2022). Variation may be related to fruit ripeness and growing conditions, as mineral redistribution during ripening can reduce ash levels in mature fruits (Yermia et al., 2025). Sugar palm fruit contains essential minerals, including calcium, phosphorus, and iron, which support structural, neuromuscular, and metabolic function

Fat Content

Fat content in fresh sugar palm fruit was low (0.08–0.17%), increasing to 0.41–0.58% after drying (Fig. 6c). The highest values were observed in KS (fresh) and KP (dry), while KM consistently showed the lowest levels. Fat content may also be influenced by endosperm hardness (Tarigan et al., 2020). Despite its low concentration, lipid content contributes to structural and metabolic functions, supporting the suitability of sugar palm fruit for low-fat dietary patterns (Doria et al., 2025; Martiniakova et al., 2022).

Fiber Content

Dietary fiber content was high, ranging from 78.72% to 97.67%, with the highest value in KM and the lowest in KS (Fig. 6d). Crude fiber levels were lower, reaching 1.97% in fresh samples and increasing to 26.45–27.45% in dried samples, with KM showing the highest value (Fig. 6e). Differences in fiber content may be influenced by fruit maturity, plant species, and tissue origin (Doria et al., 2025). Dietary fiber, composed mainly of cellulose, pectin, and lignin, is associated with reduced risks of cardiovascular disease, stroke, cancer, and weight gain, and supports gastrointestinal function through delayed gastric emptying and increased fecal bulk (Dixit et al., 2023; Liu et al., 2021; Pérez-Jiménez 2024).

Protein Content

Protein content, determined by the Kjeldahl method (Fig. 6f), ranged from 0.31–0.42% in fresh samples and increased to 2.50–3.10% after drying, with KS consistently showing the highest values and KP the lowest. Variations may reflect biological and environmental growing conditions. As an essential macronutrient, protein supports nitrogen balance, structural integrity, growth, and metabolic functions (Sá et al., 2020).

pH

pH values ranged from 3.41 to 5.53 (Fig. 6g), with the highest acidity in KP and the lowest in KM. Samples from South Solok and Pasaman showed lower pH values than previously reported (5.23 and 5.04) (Cena & Calder, 2020; Jalukhu et al., 2021). Differences in acidity may be influenced by soil conditions and climate, which affect organic acid metabolism and accumulation during fruit development (Dong et al., 2024; Wu et al., 2024).

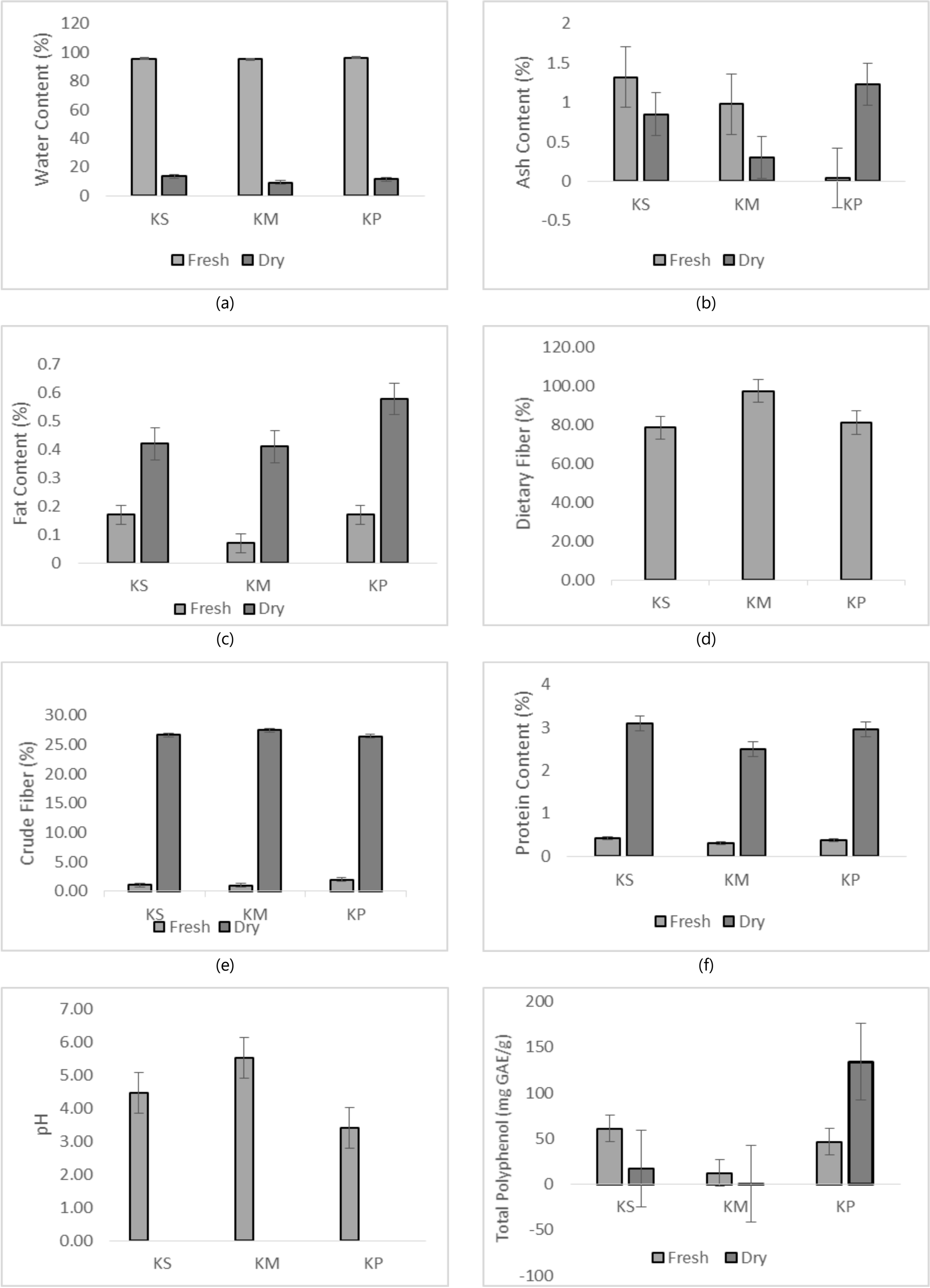


Fig. 6: Chemical Analysis: (a) moisture content, (b) ash content, (c) fat content, (d) dietary fiber content, (e) crude fiber content, (f) protein content, (g) pH, (h) total polyphenols content.

Total Polyphenol Content

Total polyphenol content (Fig. 6h) ranged from 12.41–61.04mgGAE/g in fresh samples and 0.58–133.91mgGAE/g in dried samples, with KS highest in fresh fruit and KP highest after drying. Increased values in powdered samples may reflect enhanced extraction efficiency due to reduced particle size (Horablaga et al., 2023). Polyphenol levels are also influenced by geographical origin, variety, and fruit maturity (Abioye et al., 2022; Sarkar et al., 2023). Polyphenols are bioactive compounds known for antioxidant, anti-inflammatory, anticancer, and antibacterial activities (Dixit et al., 2023; Martiniakova et al., 2022). The predominant polyphenols identified, arecatannin A1 and procyanidin B4, likely contribute significantly to the antioxidant capacity of sugar palm fruit by neutralizing free radicals and reducing oxidative stress (Chung et al., 2024; Silaban et al., 2024).

Conclusion

This study examines the distribution of chemical content contained in sugar palm fruit with variations in plant growth locations. The LC-MS/MS QTOF analysis reveals that sugar palm fruit from different regions exhibits distinct chemical components. In addition, the water content, ash content, fat content, fiber content, protein content, pH, and total polyphenols of each sugar palm fruit are different. The KS sample contains higher total polyphenols (fresh), protein, and ash content (fresh). The water content and dietary fiber content in the KM sample have the best values, and the KP sample contains higher total polyphenols (dry), crude fiber, and fat than the other samples. The results of this study indicate that variations in environmental conditions, climate, varieties, soil fertility, and harvest agegreatly influence the chemical components and quality of the resulting sugar palm fruit.

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Data Availability: All the data is available in the article.

Ethics Statement: This study did not involve live animals or humans; thus, it did not require any such statement.

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REFERENCES

Abioye, V.F., Babarinde, G.O., Ogunlakin, G.O., Adejuyitan, J.A., Olatunde, S.J., & Abioye, A.O. (2022). Varietal and processing influence on nutritional and phytochemical properties of finger millet: A review. *Heliyon*, *8*(12), e12310. https://doi.org/10.1016/j.heliyon.2022.e12310

Adelvia, A. (2020). Pengaruh Ekstrak Buah Aren (Arenga pinnata M) terhadap Tingkat Mortalitas Larva Aedes aegypti. *Jurnal ABDI (Sosial, Budaya Dan Sains)*, *2*(1), 22.

Alam, M.Z., Fristedt, R., Landberg, R., & Kamal-Eldin, A. (2024). Soluble and hydrolyzable phenolic compounds in date fruits (Phoenix dactylifera L.) by UPLC-QTOF-MS/MS and UPLC-DAD. *Journal of Food Composition and Analysis*, *132*, 106354. https://doi.org/10.1016/j.jfca.2024.106354

Alseekh, S., Aharoni, A., Brotman, Y., Contrepois, K., D'Auria, J., Ewald, J., Ewald, J.C., Fraser, P.D., Giavalisco, P., & Hall, R.D. (2021). Mass spectrometry-based metabolomics: a guide for annotation, quantification and best reporting practices. *Nature Methods*, *18*(7), 747–756. https://doi.org/10.1038/s41592-021-01197-1

Alsuhaymi, S., Singh, U., Al-Younis, I., Kharbatia, N.M., Haneef, A., Chandra, K., Dhahri, M., Assiri, M.A., Emwas, A.-H., & Jaremko, M. (2023). Untargeted metabolomics analysis of four date palm (Phoenix dactylifera L.) cultivars using MS and NMR. *Natural Products and Bioprospecting*, *13*(1), 44. https://doi.org/10.1007/s13659-023-00406-y

Anggraini, T., Anwar, A., Hervani, D., Suhendra, D., Wisnubroto, M.P., Noflindawati, N., & Nasution, I.H. (2025a). Quality of sugar palm sap (Arenga pinnata) from various production centers in West Sumatra, Indonesia. *Biodiversitas Journal of Biological Diversity*, *26*(2), 859-860. https://doi.org/10.13057/biodiv/d260234

Anggraini, T., Azima, F., Anwar, A., Hervani, D., & Suhendra, D. (2025b). *Characteristics of Sugar Palm Sap Powder (Arenga pinnata Merr) Produced using the Foam-mat Drying Method with Various Encapsulant Agents*. 20, 1–7. https://doi.org/10.18805/ajdfr.DRF-490.Submitted

Bureau, S., Leca, A., Gouble, B., Garcia, C., Danelski, W., Hallmann, E., Kazimierczak, R., Średnicka-Tober, D., Rembiałkowska, E., & Le Bourvellec, C. (2025). Impact of conventional and innovative processing conditions on organoleptic and nutritional properties of applesauce from organic and conventional production systems. *Food Chemistry*, *467*, 142346. https://doi.org/10.1016/j.foodchem.2024.142346

Cai, J., Wen, H., Zhou, H., Zhang, D., Lan, D., Liu, S., Li, C., Dai, X., Song, T., Wang, X., He, Y., He, Z., Tan, J., & Zhang, J. (2023). Naringenin: A flavanone with anti-inflammatory and anti-infective properties. *Biomedicine and Pharmacotherapy*, *164*, 114990. https://doi.org/10.1016/j.biopha.2023.114990

Cena, H., & Calder, P.C. (2020). Defining a Healthy Diet: Evidence for the Role of Contemporary Dietary Patterns in Health and Disease. *Nutrients*, *12*(334), 1–15. Cena, H., & Calder, P. C. (2020). Defining a Healthy Diet: Evidence for The Role of Contemporary Dietary Patterns in Health and Disease. *Nutrients*, *12*(2), 334. https://doi.org/10.3390/nu12020334

Chen, H., Liu, X., Liu, J., Fan, H., Ren, J., Liu, H., & Liu, T. (2025). Study on the structure and adsorption characteristics of the complex of modified Lentinus edodes stalks dietary fiber and tea polyphenol. *Food Chemistry*, *468*, 142321. https://doi.org/10.1016/j.foodchem.2024.142321

Cheng, M., Liu, M., Tan, L., Li, C., Wu, G., Xu, B., Zhang, Y., & Zhu, K. (2025). Comparison of phenolic profiles and antioxidant activities in the pulps from 21 different *Artocarpus heterophyllus* Lam. cultivars. *Food Chemistry: X*, *29*, 102735. https://doi.org/10.1016/j.fochx.2025.102735

Chung, Y.C., Song, S.J., Lee, A., Jang, C.H., Kim, C.S., & Hwang, Y.H. (2024). Isobavachin, a main bioavailable compound in Psoralea corylifolia, alleviates lipopolysaccharide-induced inflammatory responses in macrophages and zebrafish by suppressing the MAPK and NF-κB signaling pathways. *Journal of Ethnopharmacology*, *321*, 117501. https://doi.org/10.1016/j.jep.2023.117501

Dixit, V., Joseph Kamal, S.W., Bajrang Chole, P., Dayal, D., Chaubey, K.K., Pal, A.K., Xavier, J., Manjunath, B.T., & Bachheti, R.K. (2023). Functional Foods: Exploring the Health Benefits of Bioactive Compounds from Plant and Animal Sources. *Journal of Food Quality, 20, 46753.* https://doi.org/10.1155/2023/5546753

Dong, Z., Chen, M., Srivastava, A.K., Mahmood, U.H., Ishfaq, M., Shi, X., Zhang, Y., Moussa, M.G., Li, X., & Hu, C. (2024). Climate changes altered the citrus fruit quality: A 9-year case study in China. *Science of The Total Environment*, *923*, 171406. https://doi.org/10.1016/j.scitotenv.2024.171406

Doria, C.M.M., Mejía, F.F.O., & Cifuentes, A.L.D. (2025). Characterization of the dietary fiber obtained from chayote Sechium edule (Jacq.) Sw. var. virens levis. *Food Chemistry Advances*, *8*, 101091. https://doi.org/10.1016/j.focha.2025.101091

Fischer, A., Keller, H., Droste, J., Gök, R., & Esatbeyoglu, T. (2025). Structure elucidation and antioxidant activity of the radical-induced oxidation products obtained from procyanidins B1 to B4. *Current Research in Food Science*, *11, 160*. https://doi.org/10.1016/j.crfs.2025.101160

Ge, R., Su, Q., Liang, J., Zheng, L., Li, Q. shan, & Tang, L. (2025). Dulcitol ameliorates LPS-induced acute lung injury (ALI) in mice by inhibiting TLR4/NF-κB activation. *Journal of Functional Foods*, *128*, 106797. https://doi.org/10.1016/j.jff.2025.106797

Gong, G., Guan, Y.Y., Zhang, Z.L., Rahman, K., Wang, S.J., Zhou, S., Luan, X., & Zhang, H. (2020). Isorhamnetin: A review of pharmacological effects. *Biomedicine and Pharmacotherapy*, *128*, 110301. https://doi.org/10.1016/j.biopha.2020.110301

González-Arceo, M., Gomez-Lopez, I., Carr-Ugarte, H., Eseberri, I., González, M., Cano, M.P., Portillo, M.P., & Gómez-Zorita, S. (2022). Anti-Obesity Effects of Isorhamnetin and Isorhamnetin Conjugates. *International Journal of Molecular Sciences*, *24*(1), 299. https://doi.org/10.3390/ijms24010299

Hicks, E.G., Kandel, S.E., & Lampe, J.N. (2022). Identification of Aloe-derived natural products as prospective lead scaffolds for SARS-CoV-2 main protease (Mpro) inhibitors. *Bioorganic and Medicinal Chemistry Letters*, *66*, 23–29. https://doi.org/10.1016/j.bmcl.2022.128732

Horablaga, N.M., Cozma, A., Alexa, E., Obistioiu, D., Cocan, I., Poiana, M.A., Lalescu, D., Pop, G., Imbrea, I.M., & Buzna, C. (2023). Influence of Sample Preparation/Extraction Method on the Phytochemical Profile and Antimicrobial Activities of 12 Commonly Consumed Medicinal Plants in Romania. *Applied Sciences (Switzerland)*, *13*(4), 2530. https://doi.org/10.3390/app13042530

Hou, C., Chen, Y., Zhang, W., Yu, J., Ji, M., Cai, S., Guo, W., Ji, X., Sun, L., Liu, X., & Wang, Y. (2025). An insight into the full aspects of bound polyphenols in dietary fiber: Interaction, composition, function and foundation as well as alteration in food processing. *Food Chemistry*, *485*, 144553. https://doi.org/10.1016/j.foodchem.2025.144553

Iskandar, A.M., Wirando, W., & eva Tavita, G. (2023). Potensi Dan Pemanfaatan Aren (Arenga Pinnata) Oleh Masyarakat Di Desa Gema Kecamatan Simpang Dua Kabupaten Ketapang. *Jurnal Hutan Lestari*, *11*(4), 854–866. https://doi.org/10.26418/jhl.v11i4.64258

Jalukhu, I.N., Johan, V.S., & Rahmayuni, R. (2021). Utilization of Sugar Palm Fruit and Red Dragon Fruit in Making of Velva. *Jurnal Sagu* 20(1), 16. https://doi.org/10.31258/sagu.v20i1.7914

Latifah, S., Fachrudin, K.A., Hartini, K.S., Syahputra, O.K.H., Ulum, Z., Doufan Sihombing, L.A., Amelia, M., Aziz, F., Nainggolan, J., & Hawari, M.R. (2025). Utilization of non-timber forest products Arenga pinnata as a natural food source. *IOP Conference Series: Earth and Environmental Science*, *1445*(1), 12008.

Liden, T., Wang, E., & Schug, K. (2023). An Overview of the Untargeted Analysis Using LC–MS (QTOF): Experimental Process and Design Considerations. *LCGC Supplements*, *41*, 8–12.

Liu, T., Zhen, X., Lei, H., Li, J., Wang, Y., Gou, D., & Zhao, J. (2024). Food Chemistry: X Investigating the physicochemical characteristics and importance of insoluble dietary fiber extracted from legumes: An in-depth study on its biological functions. *Food Chemistry: X*, *22*(8326), 101424. https://doi.org/10.1016/j.fochx.2024.101424

Liu, Y., Zhang, H., Yi, C., Quan, K., & Lin, B. (2021). Chemical composition, structure, physicochemical and functional properties of rice bran dietary fiber modified by cellulase treatment. *Food Chemistry*, *342*, 128352. https://doi.org/10.1016/j.foodchem.2020.128352

Martiniakova, M., Babikova, M., Mondockova, V., Blahova, J., Kovacova, V., & Omelka, R. (2022). The Role of Macronutrients, Micronutrients and Flavonoid Polyphenols in the Prevention and Treatment of Osteoporosis. *Nutrients*, *14*(3), 523. https://doi.org/10.3390/nu14030523

Mesejo, C., Martínez-Fuentes, A., Reig, C., El-Otmani, M., & Agustí, M. (2024). Examining the impact of dry climates temperature on citrus fruit internal ripening. *Scientia Horticulturae*, *337*(6), 113501. https://doi.org/10.1016/j.scienta.2024.113501

Mushtaq, Z., Aslam, M., Imran, M., Abdelgawad, M.A., Saeed, F., Khursheed, T., Umar, M., Abdulmonem, W. Al, Ghorab, A.H. Al, & Alsagaby, S.A. (2023). Polymethoxyflavones: an updated review on pharmacological properties and underlying molecular mechanisms. *International Journal of Food Properties*, *26*(1), 866–893. https://doi.org/10.1080/10942912.2023.2189568

Novotná, R., Škařupová, D., Hanyk, J., Ulrichová, J., Křen, V., Bojarová, P., Brodsky, K., Vostálová, J., & Franková, J. (2023). Hesperidin, Hesperetin, Rutinose, and Rhamnose Act as Skin Anti-Aging Agents. *Molecules (Basel, Switzerland)*, *28*(4), 1728. https://doi.org/10.3390/molecules28041728

Palur, D.S.K., Luu, B., Taylor, J.E., Singhal, M., Didzbalis, J., Siegel, J.B., & Atsumi, S. (2025). Microbial production of D-mannose and D-sedoheptulose with tunable ratios. *Trends in Biotechnology, 43, 3154-3171.* https://doi.org/10.1016/j.tibtech.2025.07.017

Pérez-Jiménez, J. (2024). Dietary fiber: Still alive. *Food Chemistry*, *439, 138607*. https://doi.org/10.1016/j.foodchem.2023.138076

Rahayu, A.A.D., Leksono, B., Asmaliyah, Krisnawati, Rianawati, H., Umroni, A., Haryjanto, L., Widyatmoko, A.Y., Putri, A.I., Sudomo, A., Hani, A., Octavia, D., Andini, S., Khotimah, H., Mudhofir, M.R.T., Anggadhania, L., Winarni, I., Astarini, I.A., Artati, Y., & Baral, H. (2025). The potential of Arenga pinnata (Wurmb) Merr. for enhancing soil health, food, energy, and water security in Indonesia: A comprehensive review. *Trees, Forests and People* 20, 100808. https://doi.org/10.1016/j.tfp.2025.100808

Rianghepat, F.C.C., Rafael, A., & Ballo, A. (2021). Analisis kandungan vitamin c pada kandungan buah enau (a. pinnata) di desa nekmese. *Indigenous Biologi: Jurnal Pendidikan Dan Sains Biologi*, *4*(1), 1–6. https://doi.org/10.33323/indigenous.v4i1.92

Rizal, S., Kustyawati, M.E., Suharyono, A.S., & Suyarto, V.A. (2022). Changes of nutritional composition of tempeh during fermentation with the addition of Saccharomyces cerevisiae. *Biodiversitas*, *23*(3), 1553–1559. https://doi.org/10.13057/biodiv/d230345

Sá, A.G.A., Moreno, Y.M.F., & Carciofi, B.A.M. (2020). Plant proteins as high-quality nutritional source for human diet. *Trends in Food Science and Technology*, *97*(10), 170–184. https://doi.org/10.1016/j.tifs.2020.01.011

Salam, U., Ullah, S., Tang, Z. H., Elateeq, A.A., Khan, Y., Khan, J., Khan, A., & Ali, S. (2023). Plant Metabolomics: An Overview of the Role of Primary and Secondary Metabolites against Different Environmental Stress Factors. *Life (Basel, Switzerland)*, *13*(3), 706. https://doi.org/10.3390/life13030706

Sarkar, T., Mukherjee, M., Roy, S., & Chakraborty, R. (2023). Palm sap sugar an unconventional source of sugar exploration for bioactive compounds and its role on functional food development. *Heliyon*, *9*(4), e14788. https://doi.org/10.1016/j.heliyon.2023.e14788

Sheng, Y., Sun, Y., Tang, Y., Yu, Y., Wang, J., Zheng, F., Li, Y., & Sun, Y. (2023). Catechins: Protective mechanism of antioxidant stress in atherosclerosis. *Frontiers in Pharmacology*, *14*, 1144878. https://doi.org/10.3389/fphar.2023.1144878

Shoji, T., Masumoto, S., & Miura, T. (2024). Mechanism of procyanidins for health functionality by improving the intestinal environment. *Bioscience, Biotechnology, and Biochemistry*, *88*(4), 345–351.

Silaban, S., Nainggolan, B., Ikhwan, J., Harliananda, N., & Simorangkir, M. (2024). LC-MS/MS analysis and antioxidant activity of ethanol fraction of Aglaonema modestum leaves. *Biodiversitas*, *25*(12), 4756–4762. https://doi.org/10.13057/biodiv/d251211

Singh, S., Ikram, M., & Sharma, P.C. (2025). Influence of climatic conditions on metabolite production in some Himalayan plants: a literature review. *Metabolomics*, *21*(6), 172.

Sovia, E., & Anggraeny, D. (2019). Sugar palm fruits (Arenga pinnata) as potential analgesics and anti-inflammatory agent. *Molecular and Cellular Biomedical Sciences*, *3*(2), 107–114.

Tarigan, J.B., Barus, D.A., Dalimunthe, A., Angin, S.P., & Nguyen, T.T. (2020). Physicochemical properties of Arenga pinnata Merr. endosperm and its antidiabetic activity for nutraceutical application. *Journal of Advanced Pharmaceutical Technology & Research*, *11*(1), 1–5. https://doi.org/10.4103/japtr.japtr

Wani, I., Koppula, S., Balda, A., Thekkekkara, D., Jamadagni, A., Walse, P., Manjula, S.N., & Kopalli, S.R. (2024). An Update on the Potential of Tangeretin in the Management of Neuroinflammation-Mediated Neurodegenerative Disorders. *Life (Basel, Switzerland)*, *14*(4), 504. https://doi.org/10.3390/life14040504

Wu, J.-T., Algradi, A.M., Liu, Y., Huo, J.-H., Li, X.-M., Yang, B.-Y., & Wang, W.-M. (2022). Two new terpenoids with anti-inflammatory activity from the fruits of Arenga pinnata (Wurmb) Merr. *Natural Product Research*, *36*(22), 5753–5761. https://doi.org/https://doi.org/10.1080/14786419.2021.2023869

Wu, S., Gao, G., Du, Y., Mo, X., Tan, Q., Sun, X., Dong, Z., & Hu, C. (2024). Low soil pH enhances fruit acidity by inhibiting citric acid degradation in lemon (Citrus lemon L.). *Horticulture Advances*, *2*(1), 26. https://doi.org/10.1007/s44281-024-00044-5

Xiong, M., Feng, M., Chen, Y., Li, S., Fang, Z., Wang, L., Lin, D., Zhang, Q., Liu, Y., Luo, Y., & Chen, H. (2023). Comparison on structure, properties and functions of pomegranate peel soluble dietary fiber extracted by different methods. *Food Chemistry: X*, *19*, 100827. https://doi.org/10.1016/j.fochx.2023.100827

Yermia, Y., Rahayu, W.P., Suyatma, N.E., Muhandri, T., & Purnomo, E.H. (2025). Chemical and thermal properties of sugar palm fruits (Arenga pinnata) at different maturity levels. *BIO Web of Conferences*, *169*, 1012.

Yuan, T., Ye, T., Guo, H., Yang, Y., Song, G., Wang, D., Li, L., Cheng, Y., & Gong, J. (2025). Comparative analysis of β-lactoglobulin complexes with different catechins: formation, structure, functionality, and emulsion stability. *Lwt*, *224*, 117881. https://doi.org/10.1016/j.lwt.2025.117881

Zhang, X., Guo, S., Ho, C.T., & Bai, N. (2020). Phytochemical constituents and biological activities of longan (Dimocarpus longan Lour.) fruit: a review. *Food Science and Human Wellness*, *9*(2), 95–102. https://doi.org/10.1016/j.fshw.2020.03.001

Zhao, M., Cai, B., Jin, J., Zhang, N., Jing, T., Wang, J., Pan, Y., Zhou, Z., Zhao, Y., Feng, Y., Yu, F., Zhang, M., Li, Y., Liu, Z., & Song, C. (2020). Cold Stress-induced Glucosyltransferase CsUGT78A15 is Involved in the Formation of Eugenol Glucoside in Camellia sinensis. *Horticultural Plant Journal*, *6*(6), 439–449. https://doi.org/https://doi.org/10.1016/j.hpj.2020.11.005