ANTHOR
Education and Learning Journal
https://anthor.org/index.php/anthor
Email. anthor.Jurnal@gmail.com
E-ISSN: 2963 –198X P-ISSN: 2963–2498 | Halaman: 1957 - 1964
Volume 5 Nomor 5 Tahun 2026

Potential of Mangsian (*Phyllanthus Reticulatus*) Chromophores as Basic Materials for Solar Cell Development

Manuscript Information

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Abstrak

Organic solar cell telah menjadi salah satu perhatian utama dalam upaya mengatasi krisis energi dunia. Keberadaan kromofor merupakan komponen penting dalam berbagai proses fotokimia pada solar cell. Penelitian ini bertujuan untuk mengkaji potensi senyawa bioaktif pada buah mangsian sebagai bahan baku pengembangan organic solar cell berdasarkan karakteristik kromofornya. Berdasarkan hasil spektrum UV-Vis, buah mangsian memiliki celah pita energi (band gap) sebesar 1,95 eV, yang menunjukkan bahwa zat warna pada buah mangsian berpotensi mengonversi energi dari sinar matahari. Hasil analisis LC-MS menunjukkan bahwa buah mangsian mengandung 121 senyawa bioaktif. Senyawa-senyawa yang teridentifikasi dari buah mangsian selanjutnya dikarakterisasi secara komputasi menggunakan perangkat lunak ORCA untuk menentukan tingkat energi HOMO dan LUMO dari setiap senyawa yang terkandung di dalamnya. Berdasarkan hasil komputasi terhadap seluruh senyawa tersebut, sebanyak 95 senyawa dalam buah mangsian teridentifikasi sebagai kromofor. Hal ini menunjukkan bahwa sebagian besar senyawa yang terkandung dalam buah mangsian berpotensi menjadi kromofor baru dalam pengembangan solar cell.

Kata Kunci:
Solar Cell, Kromofor, ORCA, Mangsian.

Abstract

Organic solar cell have become a major concern in overcoming the world's energy crisis. The presence of chromophores is a key component in many photochemical processes in solar cells. This study aims to examine the potential of bioactive compounds in mangsian as raw materials for the development of organic solar cells in terms of their chromophores. Based on the results of the UV-Vis spectrum, mangsian fruit has a band gap of 1.95 eV, which indicates that the dye in mangsian has the potential to convert energy from sunlight. The LC-MS results show that mangsian fruit contains 121 bioactive compounds. The compounds identified from mangsian were then computationally characterized with the help of ORCA software to determine the HOMO and LUMO energies of each compound contained. From the computational results of all these compounds, 95 compounds in mangsian are included in the chromophore. This indicates that most compounds in mangsian have the potential to become new chromophores in the development of solar cells.

Keyword:
Solar Cells, Chromophore, ORCA, Mangsian.

Information Production:
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INTRODUCTION

The energy crisis is one of the biggest challenges facing the world. The dramatic increase in energy demand is driven by rapid population growth, industrial development, and increasing living standards in terms of energy consumption. The increase in energy needs puts pressure on limited fossil energy resources. Currently, fossil fuels (coal, oil, and gas) account for 80% of the world's energy production. Countries emit a total of 36.8 billion tons of CO_2 from fossil fuels in 2023, an increase of 1.1 percent from last year. If added to the figures for the release and absorption of CO_2 emissions from land conversion aspects, such as deforestation and reforestation, it is estimated that human activities will emit 40.9 billion tons of CO_2 this year. In overcoming these problems, the development of renewable and environmentally friendly energy sources is needed.

In recent decades, the need for renewable energy sources has become a major focus worldwide. In facing this challenge, humans need energy sources in very large quantities and are sustainable. Therefore, solar cells are present as a promising solution to answer the challenges that occur in the world. Solar cells are power plants with the ability to convert sunlight into electric current. Solar cells are divided into 4 generations: the first and second-generation solar cells are silicon-based, the third-generation solar cells are organic-based, and the fourth-generation solar cells are organic-inorganic combination solar cells.

e-ISSN: 2963 – 198X
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Silicon-based solar cells have dominated the market and are used worldwide because they have an optimum band gap and standard operational efficiency of up to 25%. However, the high efficiency of silicon-based solar cells is also directly proportional to the high production costs and potential environmental pollution. Therefore, organic solar cells are now receiving more attention in the context of developing solar cells that are cheap, environmentally friendly, simple, and easy to produce. In choosing organic materials for solar cells, one important factor that must be considered is the band gap energy. The energy band gap chosen for solar cells is the mask in the conductor or semiconductor range. The material has a chromophore which is a key component in the photochemical process in solar cells.

Organic solar cells generally obtain raw materials from plants that have color in their parts, such as fruit, stems, leaves, or roots. One of the plants that has the potential to be used as raw material for making organic solar cells because it has a strong color and is easy to obtain, is the mangsian fruit. Color is a priority in organic solar cells, because the stronger the color obtained, the higher the efficiency in solar cells. Mangsian with the Latin name *Phyllanthus reticulatus* has the potential to be used as raw material in organic solar cells because the fruit has a strong color and its growth is easy to find in various locations. The results of Liquid Chromatography Mass Spectrometry (LC-MS) of mangsian showed that there were 121 compounds detected and the majority of compounds had conjugated double bonds indicating chromophores.

This study was conducted to examine the chromophores contained in mangsian fruit which have the potential as basic materials in the development of solar cells. Because the compounds have the potential to be important in the development of third and fourth-generation solar cells, namely organic and organic-inorganic combinations. The research was conducted in silico using ORCA software and ab initio electronic structure methods based on Density Functional Theory (DFT). Calculation methods such as B3LYP and the 6-31G basis set have proven useful in predicting material properties relevant to solar cells.

METHODS

Materials

The materials used in this study were mangsian fruit obtained on the side of the road in the Ketintang Timur PTT V area, Gayungan, Surabaya, East Java, Indonesia, and aquadest.

Instruments

Shimadzu LCMS – 8040 LC/MS, Shimadzu UV-Vis 1800 spectrophotometer, vials, Dell Inspiron 3670 PC hardware with Intel(R) Core(TM) i7-9700 CPU 3.00 GHz, 8 GB RAM, 64-bit Windows 11 Pro with Avogadro software to create input files and virtualize molecules and ORCA 6.0, Command Prompt, and Notepad for chemical calculations.

Identification of Compounds in Mangsian

Mangsian fruit was cleaned of impurities. Then the clean fruit was squeezed to obtain the juice. The extract obtained was then identified for the compounds contained therein using Shimadzu LCMS – 8040 LC/MS.

UV-Visible Spectrophotometry Analysis

Analysis using a UV-Vis spectrophotometer was carried out to determine the sample band gap. The wavelength absorption used in the UV-Vis spectrophotometer analysis is in the range of 490-560 nm.

Determination of chromophores in mangsian that have the potential to be raw materials for solar cells

The structure of the compound detected by LC-MS was then modeled in 3D molecules using Avogadro software. After the structure was drawn in 3D, geometry optimization was carried out. Then the input file that produced the structure coordinates in Avogadro carried out chemical calculations with ORCA software on each molecular structure. After the output file was obtained, it was then visualized using Avogadro software to see the HOMO and LUMO energies of each structure. The results obtained were then compared with the TiO_2 conduction band energy and the LUMO redox couple I^-/I^{3-}.

RESULTS AND DISCUSSION

Results

Identification of chromophores in mangsian was carried out by analyzing the results of the LC-MS test of mangsian. The obtained mangsian fruit was extracted by squeezing it, results of the mangsian fruit extract are shown in Figure 1.

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(a) (b)

Figure 1 Mangsian fruit before being squeezed (a) and Mangsian fruit juice (b)

Then the Mangsian fruit juice was tested by LC-MS. Figure 2 shows the graphic data of the compounds that were successfully analyzed.

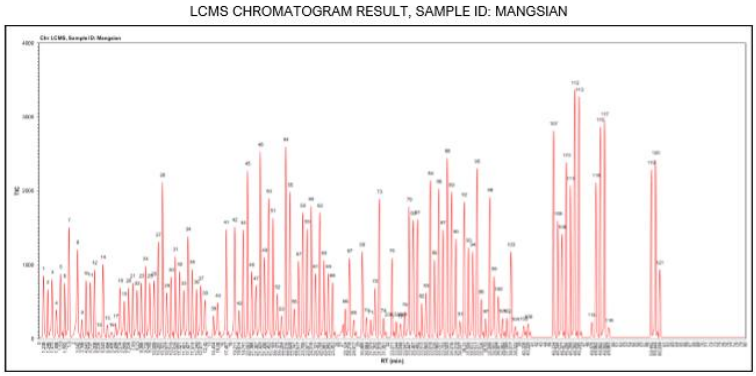


Figure 2 Graph of LC-MS test results of mangsian

The results of the mangsian fruit extract were then measured for light absorption using a UV-Vis spectrophotometer. Figure 3 shows the results of the mangsian fruit spectrum.

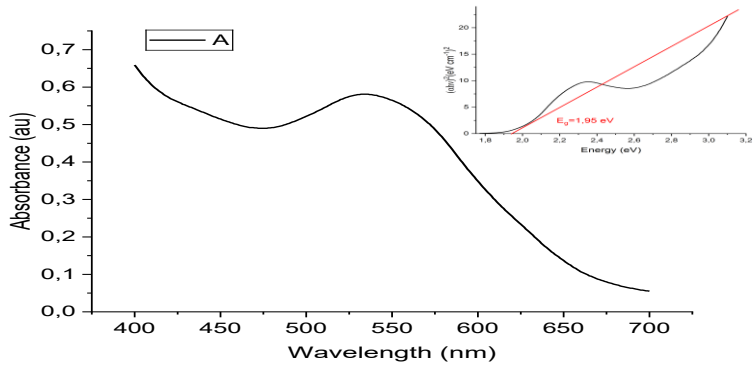


Figure 3 Absorption wavelength of mangsian fruit extract

Table 1 shows the results of HOMO and LUMO energy computations of each compound identified by LC-MS chromatogram with the DFT method and 6-31G basis set.

There are 5 main compounds in mangsian, namely alkaloids, carboxylic acids, phenols, terpenoids, and flavonoids. Table 1 shows the results of HOMO and LUMO energy computations, and energy band gaps of compounds contained in mangsian fruit with the DFT method and 6-31G basis set.

Table 1. Computed results of HOMO and LUMO energies for compounds containing mangsian

Classification of Compounds	Compounds	HOMO Energy (eV)	LUMO Energy (eV)	Band Gap Energy (eV)	Color
Alkaloid	phyllurine	-5,581	-1,495	4,086	Colorless
	phyllantidine	-5,949	-1,698	4,251	
	phyllalbine	-5,578	-0,708	4,870	

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Carboxylic Acid	cinnamic acid	-6,399	-1,658	4,741	Colorless
	fumaric acid	-7,511	-2,032	5,479	
	ascorbic acid	-6,065	-0,439	5,626	
	glucuronic acid	-6,837	-1,098	5,739	
	citric acid	-7,422	-0,376	7,046	
	malic acid	-7,372	-0,306	7,066	
	tartaric acid	-7,562	-0,443	7,119	
	succinic acid	-7,429	0,044	7,473	
Terpenoid	cryptoxanthin	-4,496	-1,831	2,665	Red, Orange, Yellow
	zeaxanthin	-4,557	-1,820	2,737	
	lutein	-4,585	-1,705	2,880	
	β-carotene	-4,646	-1,376	3,270	
	phytofluene	-4,600	-1,226	3,374	
	β-ionone	-6,007	-1,347	4,660	
	3-friedelanone	-6,141	-0,218	5,923	
	betulinic acid	-6,182	0,173	6,355	
	β-chamigrene	-5,852	0,830	6,682	
	β-caryophyllene	-6,163	0,536	6,699	
	β-caryophyllene epoxide	-6,163	0,536	6,699	
	limonene	-6,029	0,912	6,941	
	β-sitosterol	-5,948	1,013	6,961	
	lupeol	-6,133	0,903	7,036	
	betulin	-6,170	0,870	7,040	
	β-selinene	-6,324	0,827	7,151	
Phenol	anethole	-5,767	-2,050	3,717	Pale yellow to light brown
	sinapic acid	-5,298	-1,253	4,045	
	caffeic acid	-5,743	-1,478	4,265	
	phyllanthostatin A	-5,623	-1,328	4,295	
	phyllanthostatin 6	-5,632	-1,330	4,302	
	ferulic acid	-5,631	-1,326	4,305	
	phyllanthostatin 1	-5,643	-1,333	4,310	
	(+)-phyllanthostatin 2	-5,647	-1,335	4,312	
	(+)-phyllanthostatin 3	-5,647	-1,335	4,312	
	ellagic acid	-6,152	-1,835	4,317	
	isobiflorin	-6,085	-1,390	4,695	
	galic acid	-5,679	-0,893	4,786	
	biflorin	-6,329	-1,542	4,787	
	β-glucogallin	-6,098	-1,250	4,848	
	phyllanthusol B	-6,285	-1,362	4,923	
	phyllanthusol A	-6,275	-1,080	5,195	
	hypophyllanthin	-5,097	0,250	5,347	
	phyllanthin	-5,151	0,451	5,602	
Flavonoid	kaempferol-3-O-(6-malonylglucoside)	-6,387	-6,059	0,328	Red, Purple, Blue, Yellow
	delphinidin-3-caffeylglucoside	-3,608	-1,650	1,958	
	malvidin-3-(6"-p-caffeyglucoside)	-3,342	-1,383	1,959	
	malvidin-3-(6"-p-coumarylglucoside)	-3,414	-1,368	2,046	
	pelargonidin-3-p-coumarylglucoside	-3,617	-1,505	2,112	
	delphinidin-3-(6"-p-coumarylglucoside)	-3,699	-1,499	2,200	
	cyanidin-3-(6-O-p-coumarylglucoside)	-3,665	-1,297	2,368	
	petunidin-3-(6"-p-coumarylglucoside)	-3,782	-1,314	2,468	
	petunidin-3-(6"-p-coumarylglucoside)-5-glucoside	-4,015	-1,474	2,541	
	cryptoflavin	-4,544	-1,757	2,787	
	malvidin-3-glucoside	-3,328	-0,520	2,808	

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	malvidin-3,5-diglucoside	-3,467	-0,056	3,411
	cyanidin 3-O-glucoside	-3,812	-0,383	3,429
	delphinidin-3 glucoside	-3,848	-0,393	3,455
	petunidin-3,5-di-O-β-D-glucoside	-4,042	-0,577	3,465
	cyanidin-3,5-diglucoside	-3,774	-0,293	3,481
	delphinidin-3-(6"-acetylglucoside)	-3,719	-0,231	3,488
	malvidin-3-(6"-acetylglucoside)	-3,755	-0,240	3,515
	petunidin-3-(6"-acetylglucoside)	-3,770	-0,183	3,587
	malvidin 3-sophoroside-5-glucoside	-3,482	0,129	3,611
	petunidin-3-O-β-D-glucopyranoside	-3,688	-0,024	3,664
	cyanidin 3-(6"-acetylglucoside)	-3,916	-0,193	3,723
	4',6'-dihidroxy-3',5'-dimethyl-2'-methoxychalcone	-5,592	-1,824	3,768
	kaempferol-3-(6"-caffeoylglucoside)	-5,553	-1,707	3,846
	quercetin-3-(3"-p-coumarylglucoside)	-5,700	-1,757	3,943
	myricetin-3-(3"-galloylrhamnoside)	-5,717	-1,672	4,045
	kaempferol 3-(5"-feruloylapioside)	-5,605	-1,556	4,049
	apigenin-7-glucoside-4'-trans-caffeate	-5,786	-1,736	4,050
	kaempferol-7-rhamnoside-4'-glucoside	-5,784	-1,701	4,083
	kaempferol-4'-rhamnoside	-5,619	-1,515	4,104
	(2S)-5,7,3',4'-tetrahydroxyflavanone 7-(6-p-coumaroylglucoside)	-5,539	-1,414	4,125
	3-O-galloylepigallocatechin-(4β→8) epigallocatechin-3-O-gallate	-5,165	-1,040	4,125
	kaempferide	-5,594	-1,442	4,152
	quercetin-3-glucoside-7-rhamnoside	-5,772	-1,561	4,211
	isorhamnetin-3,4' diglucoside	-6,061	-1,837	4,224
	apigenin-7-rutinoside-4'-trans-caffeate	-5,711	-1,486	4,225
	apigenin-7-(6"-p-coumarylglucoside)	-5,853	-1,619	4,234
	4',4'"-di-O-methylcupressuflavone	-5,639	-1,402	4,237
	rutin	-5,316	-1,028	4,288
	isoquercitrin	-5,772	-1,482	4,290
	luteolin-7-O-rutinoside	-5,644	-1,338	4,306
	acacetin-7-rutinoside	-5,806	-1,463	4,343
	naringenin 7-O-(6"-O-galloyl)glucoside	-5,738	-1,392	4,346
	naringenin 7-O-(6"-O-trans-coumaroyl)glucoside	-5,789	-1,440	4,349
	quercetin-3-arabinoside	-6,041	-1,658	4,383

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	kaempferol-3-o-rhamnoside	-5,936	-1,549	4,387
	quercetin	-5,685	-1,296	4,389
	isorhamnetin-3-O-rutinoside	-5,473	-1,084	4,389
	myricetin	-5,662	-1,252	4,410
	kaempferol-3-glucoside-2"-rhamnoside-7-rhamnoside	-5,446	-1,026	4,420
	luteolin-7-glucoside	-5,996	-1,575	4,421
	kaempferol	-5,673	-1,247	4,426
	astragalin	-6,078	-1,650	4,428
	hirsutrin	-5,829	-1,401	4,428
	acacetin-7-galactoside	-5,899	-1,466	4,433
	luteolin	-5,850	-1,379	4,471
	isovitexin	-6,160	-1,689	4,471
	quercetin-3,7,4'-triglucoside	-6,569	-2,086	4,483
	acacetin	-6,049	-1,545	4,504
	apigenin	-5,892	-1,382	4,510
	naringin	-5,567	-1,022	4,545
	epigallocatechin-3-O-gallate	-5,443	-0,893	4,550
	vitexin	-6,124	-1,573	4,551
	quercetin-3-O-malonylglucoside	-6,069	-1,515	4,554
	kaempferol 3-(2"-acetylrhamnoside)	-5,851	-1,293	4,558
	apigenin-7-rhamnoside-4'-rutinoside	-6,051	-1,487	4,564
	dihydrokaempferol-3-o-alpha-l-rhamnopyranoside	-6,064	-1,483	4,581
	quercetin-3-o-rhamnoside	-5,843	-1,229	4,614
	3,5,7-trihydroxyflavone 3-glucoside-8-sulfate	-6,610	-1,933	4,677
	phyllanthoside	-6,336	-1,639	4,697
	epiafzelechin-3-o-gallate	-5,636	-0,839	4,797
	epigallocatechin-(4β8)-epigallocatechin-3-O-gallate ester	-5,438	-0,636	4,802
	7-hydroxy-5-methoxy-6,8-dimethylflavanone	-5,819	-0,988	4,831
	naringenin	-5,783	-0,882	4,901
	7-hydroxyflavanone	-6,193	-1,169	5,024
	epiafzelechin	-5,436	-0,242	5,194

Discussion

The results of the mangsian fruit juice are shown in Figure 1, which produces a blackish-blue color. The analysis using a UV-Vis spectrophotometer shown in Figure 3 that the maximum wavelength of the mangsian fruit extract is at a wavelength absorption of 534 nm with an absorbance of 0.582. Meanwhile, the large band gap in mangsian is 1.95 eV, which is included in the band gap area that is efficient in converting energy from sunlight.

Table 1 shows the magnitude of the HOMO and LUMO energy values, as well as the number of band gaps for each compound that has been visualized using Avogadro software. Based on Table 1, it can be seen that the bioactive compounds in mangsian are generally semiconductors that have an energy band gap ranging from 0.328 eV - 7.473 eV. Based on the working principle of DSSC, during the redox process, the ability of molecules to capture and release electrons can be measured qualitatively based on the position of the HOMO and LUMO energy levels [16]. For DSSC to function efficiently, the LUMO energy of the chromophore must be suitable to inject electrons into the semiconductor (TiO_2), and the HOMO energy must allow the chromophore to reclaim electrons from the I^-/I^{3-} redox. The LUMO energy of the mangsian chromophore must be more positive than the TiO_2 conduction band which is -4.0 eV. This is to provide the power of electron

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injection from the excited state to the TiO_2 conduction band. Meanwhile, the HOMO energy of the mangsian chromophore must be more negative than the I^-/I^{3-} redox, which is -4.8 eV. This aims to allow regeneration by accepting electrons from the electrolyte. From the results of the computational calculations in Table 1, 95 compounds in mangsian fruit have the potential to be developed into chromophores in organic solar cells or organic-inorganic combinations.

CONCLUSION

An in silico study has been conducted to determine the potential of chromophores by looking at the magnitude of HOMO and LUMO energy contained in chemical compounds contained in mangsian fruit using ORCA software. The compounds contained in mangsian fruit were identified using LC-MS. The results of the UV-Vis spectrophotometer analysis showed that mangsian has a band gap of 1.95 eV, which is included in the optimal band gap area in converting energy from sunlight. The results of LC-MS showed that mangsian contains 121 bioactive compounds divided into 5 secondary metabolites, namely alkaloids (2.48%), carboxylic acids (6.61%), phenols (14.88%), terpenoids (13.22%), and flavonoids (62.81%). Of all these compounds contained, 95 compounds are chromophores that have the potential in the development of organic solar cells. Based on the results of band gap measurements and the majority of compounds that are chromophores, it shows that the compounds in mangsian have the potential to become new chromophores in the development of solar cells.

REFERENCES

Almosni, S., Delamarre, A., Jehla, Z., Suchet, D., Cojocaru, L., Giteau, M., & Guillemoles, J.-F. (2018). Material challenges for solar cells in the twenty-first century: Directions in emerging technologies. Science and Technology of Advanced Materials, 19, 336–369. https://doi.org/10.1080/14686996.2018.1433439

Ayalew, W. A., & Ayele, D. W. (2016). Dye-sensitized solar cells using natural dye as light-harvesting materials extracted from Acanthus sennii Chiovenda flower and Euphorbia cotinifolia leaf. Journal of Science: Advanced Materials and Devices, 1(4), 488–494. https://doi.org/10.1016/j.jsamd.2016.10.003

Gielen, D., Boshell, F., Saygin, D., Bazilian, M., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. Energy Strategy Reviews, 24, 38–50. https://doi.org/10.1016/j.esr.2019.01.006

Grażyna, J., Rafał, M., & Ryszard, S. (2020). Effect of band gap on power conversion efficiency of single-junction semiconductor photovoltaic cells under white light phosphor-based LED illumination. Materials Science in Semiconductor Processing, 107, Article 104812. https://doi.org/10.1016/j.mssp.2019.10812

International Energy Agency. (n.d.). Net zero by 2050: A roadmap for the global energy system. https://www.iea.org/events/net-zero-by-2050-a-roadmap-for-the-global-energy-system

Li, P., Cui, Y., Song, C., & Zhang, H. (2017). A systematic study of phenoxazine-based organic sensitizers for solar cells. Dyes and Pigments, 13, 12–23. https://doi.org/10.1016/j.dyepig.2016.09.060

Logayah, D. S., Mustikasari, B. R., Hindami, D. Z., & Rahmawati, R. P. (2023). The European Union's energy crisis: Challenges and opportunities in the face of limited energy supplies. Hasanuddin Journal of International Affairs, 3(2), 103–110. https://doi.org/10.31947/hjirs.v3i2.27052

Luceño-Sánchez, J. A., Díez-Pascual, A. M., & Capilla, R. P. (2019). Materials for photovoltaics: State of art and recent developments. International Journal of Molecular Sciences, 20, Article 976. https://doi.org/10.3390/ijms20040976

Pamungkas, G., & Sanjaya, I. G. M. (2013). Theoretical study to determine the energy gap of calcium metal conjugated porphyrin using density functional theory (DFT). Unesa Journal of Chemistry, 2(1), 54–61. https://doi.org/10.26740/ujc.v2n1.p%25p

Sanjay, P., Deepa, K., Madhavan, J., & Senthil, S. (2019). Natural dyes extracted from fruit of Phyllanthus reticulatus as sensitizers in ZnO nanorods-based dye-sensitized solar cells. Materials Today: Proceedings, 8(1), 284–293. https://doi.org/10.1016/j.matpr.2019.02.113

Sanjaya, I. G. M., & Setiarso, P. (n.d.). Study of chromophores potential in binahong leaf extracts for solar cell development. Journal of the Turkish Chemical Society Section A: Chemistry, 11(4), 1651–1658.

Thibaud, E., Chbibi, L., Michaux, C., Perpète, E., Assfeld, X., & Monari, A. (2014). All-organic chromophores for dye-sensitized solar cells: A theoretical study on aggregation. Dyes and Pigments, 101, 203–211. https://doi.org/10.1016/j.dyepig.2013.10.004

Tiedje, T., Yablonovitch, E., Cody, G. D., & Brooks, B. G. (1984). Limiting efficiency of silicon solar cells.

e-ISSN: 2963 – 198X
p-ISSN: 2963 – 2498

IEEE Transactions on Electron Devices, 31(5), 711. https://doi.org/10.1109/t-ed.1984.21594

Wazzan, N. A. (2019). A DFT/TDDFT investigation on the efficiency of novel dyes with ortho-fluorophenyl units (A1) and incorporating benzotriazole/benzothiadiazole/phthalimide units (A2) as organic photosensitizers with D–A2–π–A1 configuration for solar cell applications. Journal of Computational Electronics, 18, 375–395. https://doi.org/10.1007/s10825-019-01308-4

World fossil fuel pressure data. (n.d.). In Kementerian Energi dan Sumber Daya Mineral Republik Indonesia. https://www.esdm.go.id/id/media-center/arsip-berita/hingga-2030-permintaan-energi-dunia-meningkat-45-

Zamrani, R. A., & Prajitno, G. (2013). Making and characterizing a dye-sensitized solar cell (DSSC) prototype using mangosteen peel extraction as a dye sensitizer using the doctor blade method. Pomits Journal of Science and Arts, 1(2), 1–8. https://doi.org/10.24252/jft.v3i0.116823

Zsiborács, H., Baranyai, N. H., Vincze, A., Zentkó, L., Birkner, Z., Máté, K., & Pintér, G. (2019). Intermittent renewable energy sources: The role of energy storage in the European power system of 2040. Electronics, 8(7), Article 729. https://doi.org/10.3390/electronics8070729