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Preliminary Study on the Potential of Red Fruit Pigment (*Pandanus conoideus*) from West Papua as Dye-Sensitized Solar Cell (DSSC)

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Abstract

The red fruit (*Pandanus conoideus*) is an endemic plant from Papua, known for its distinctive color and shape. This fruit is recognized for its bioactive properties, such as antioxidant, anti-inflammatory, and antihyperglycemic effects. Its high pigment content is believed to have potential as a sensitizer in DSSC applications. However, research on this topic remains underexplored. Therefore, the aim of this preliminary study is to investigate the potential of red fruit pigments for DSSC. The characterization of red fruit pigments was conducted through phytochemical screening, FTIR and UV-Vis spectral analysis, as well as literature reviews. Pigment extraction was carried out using maceration without involving drying or grinding processes. Phytochemical screening results revealed that the macerate contains flavonoids, alkaloids, phenolics and terpenoids, compounds commonly used as natural pigments in DSSCs. FTIR analysis showed the presence of functional groups such as carboxyl (-COOH), carbonyl (C=O), and hydroxyl (-OH), which can act as effective anchoring groups when interacting with nanosemiconductor surfaces. Meanwhile, UV-Vis analysis showed absorption peaks in the UV region (wavelength 204–399 nm) and the visible region (wavelength 400–550 nm). Based on literature studies and research findings, it can be concluded that the pigments in red fruit have potential applications as DSSC sensitizers.

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INTRODUCTION

Based on electricity statistics data for the 2018-2022 period, there was a recorded increase in national electricity consumption of 16.29%, from 282,031.11 GWh (2018) to 322,336.67 GWh (2022) (ESDM, 2023). Specifically for the Papua region, the amount of electricity distributed to both Papua Province and West Papua Province also recorded an increase over this period. In Papua Province, energy consumption rose by 39.65%, from 916.96 GWh (2018) to 1,280.52 GWh (2022), while in West Papua Province there was a 9.22% increase, from 569.02 GWh (2018) to 621.46 GWh (2022) (BPS-Indonesia, 2024). Based on this data, a similar upward trend is predicted for the next five-year period, signaling the need for the government to accelerate the construction of power plants to ensure the future availability of electricity. On the other hand, researchers and academics must play an active role in contributing ideas and developing technologies to address this demand.

One form of technology that can contribute to long-term electricity supply is the Dye-Sensitized Solar Cell (DSSC), a solar cell that generates renewable energy based on solar power. DSSC was first introduced by O'Regan and Gratzel in 1991 as a new type of solar cell that utilizes pigment molecules and nano-semiconductor titanium dioxide (TiO_2) (O'Regan & Gratzel, 1991). The main components of this photoelectrochemical solar cell are the photoelectrode, dye, electrolyte, and counter electrode (Gong et al., 2017; Carella et al., 2018).

The function of pigments in DSSC is as a sensitizer, which absorbs sunlight and then converts solar energy into electrical energy through an electron transfer mechanism (Hagfeldt et al., 2010). The molecular structure characteristics of pigments are one of the key factors determining the effectiveness of DSSC prototype performance. In addition to natural pigments, the use of synthetic pigments (from metals and organic compounds) as sensitizers in DSSCs has also been widely researched, yielding relatively high efficiency results. However, a drawback of metal-containing synthetic sensitizers is their high production cost, considering the limited availability of metal materials. Unlike natural pigments, which are not only easily found in plants (in parts such as leaves, fruits, flowers, and even stems) but are also easy to extract with simple laboratory methods using readily available equipment and instruments. Furthermore, natural pigments are generally non-toxic and biodegradable (Pombeiro-Sponchiado et al., 2017; Orona-Navar et al., 2021). As a result, a major advantage of using natural pigments for DSSC fabrication is the relatively low production cost and the environmentally friendly profile (Jena et al., 2012).

The Land of Cenderawasih (Papua Island, from Merauke to Sorong) is recognized as having the highest biodiversity levels in the world. This is supported by research from Cámara-Leret et al. (2020), which reported that Papua Island hosts 13,634 plant species from 1,742 genera and 264 families, with an endemism rate of 68%. This indicates that Papua Island provides a rich source of flora with diverse pigment variations, which hold potential for use in DSSCs. However, research on DSSCs using natural pigments from Papua remains limited. Yet, DSSCs are capable of perform efficiently under low irradiance conditions (Hug et al., 2014; Lee et al., 2015). This presents both a challenge and an opportunity for researchers to explore and develop DSSC prototypes utilizing flora from Papua.

One of the well-known endemic plants from Papua is red fruit (*Pandanus conoideus*). Previous research reported that red fruit contain compounds such as α-cryptoxanthin, β-cryptoxanthin, α-carotene, β-carotene (Sarungallo et al., 2015a), fatty acids, triacylglycerol, phenols and tocopherol (Sarungallo et al., 2015b). Research has shown that red fruit exhibits bioactivity as an antioxidant (Rohman et al., 2010), anti-inflammatory (Khiong et al., 2009) and antihyperglycemic agent (Khairani et al., 2023). However, studies on the utilization of red fruit pigments as a source for DSSCs are still very limited and less explored. Therefore, the aim of this preliminary study is to investigate and evaluate the potential of red fruit as a source for DSSCs based on phytochemical screening, FTIR spectra, UV-Vis spectra and literature reviews. The findings of this preliminary study can serve as a reference for developing a DSSC prototype based on red fruit pigments.

METHOD

Materials

The materials used consist of red fruit samples, technical-grade methanol (CH_3OH) at 95%, filter paper, 10% NaOH, HCl, Mg powder, Dragendorff's reagent, Mayer's reagent, Wagner's reagent, Liebermann–Burchard reagent, 5% FeCl, aluminum foil, and distilled water.

Equipment and Instruments

The equipment used includes general laboratory glassware, dropper pipettes, test tube racks, vial bottles, oven, digital balance, magnetic stirrer, rotary evaporator, FTIR spectroscope (Shimadzu IRPrestige-21) and UV-Vis spectrophotometer (Thermoscientific Genesys 150).

Sample Preparation

The initial step in sample preparation involves cleaning the surface of the red fruit to remove dirt, followed by rinsing with methanol solvent. Next, the fruit flesh (outer part) is separated from the pith (inner part) using a knife, as shown in **Figure 1(b)**, while the seeds which is inside the fruit flesh are not removed. The separated fruit flesh, as seen in **Figure 1(c)**, is neither dried nor ground and is ready for extraction.

(a) (b) (c)

Figure 1. (a) Red fruit (b) Red fruit separated from the cob/pith (c) Red fruit seen from a close distance

Moisture Content

The moisture content of the red fruit sample was determined using the thermogravimetric (drying) method, referring to SNI 2354.2:2015 (BSN, 2015). A 10 g sample was heated in an oven at a temperature of 105 °C until a constant weight was obtained. The procedure was repeated for triplicate measurements. The moisture content value was calculated using **Equation (1)**.

$$\text{Moisture content (\%)} = \frac{A - B}{A} \times 100\% \qquad (1)$$

A – Initial weight (g)
B – Final weight (g)

Maceration and Evaporation

Pigment was extracted from 200 g of red fruit samples using maceration (3 x 24 hours at room temperature) with 750 mL of 95% technical-grade methanol solvent. Stirring for approximately 10 minutes was performed every 12 hours during the 3 x 24-hour maceration period using a

(a) (b) (c)

Figure 2. (a) Stirring with a magnetic stirrer (b) Macerate and red fruit residue (c) Macerate evaporation process

magnetic stirrer. During the maceration process, the macerate was kept in a dark room to prevent oxidation of the pigment molecules, which are sensitive to light (Groeneveld et al., 2022). The macerate was then filtered and stored in a brown glass bottle. Subsequently, the macerate was evaporated at a temperature of < 40°C using a rotary evaporator to prevent pigment color degradation due to high-temperature heating (Yusoff et al., 2014; Abdollahi et al., 2021). Before phytochemical, UV-Vis and FTIR test, the macerate was placed back in the dark room.

Phytochemical Screening

The identification of secondary metabolite compounds (flavonoids, alkaloids, saponins, phenolics, terpenoids, and steroids) is carried out through qualitative testing (Harborne, 1998; Banu & Cathrine, 2015).

Infrared (IR) Spectrum Analysis

The IR testing was conducted using an FTIR spectroscopy device (Shimadzu IRPrestige-21 model). The purpose of the IR spectrum analysis is to identify functional groups in the compounds present in the red fruit methanol extract.

Ultra-Violet Visible (UV-Vis) Spectrum Analysis

UV-Vis testing (screening) was conducted using a UV-Vis spectrophotometer (Thermo Scientific Genesys 150) over a wavelength range of 200-800 nm. The purpose of the UV-Vis spectrum analysis is to determine the wavelength at maximum absorbance.

RESULTS AND DISCUSSION

Moisture Content

Table 1. Moisture content percentage

	Moisture content (%)			
	I	II	III	mean ± SD
Triplicate measurements	61,7	62,0	61,3	61,67 ± 0,35

*SD= Standard Deviation

Table 1 shows the moisture content values of the red fruit, which were relatively high at 61.67 ± 0.35 (mean ± SD). Besides water, red fruit also contains volatile chemical components, including 1,3-dimethylbenzene, N-glycyl-L-alanine, trichloromethane, and ethane (Rohman & Windarsih, 2018).

Phytochemical Screening Results

Table 2. Phytochemical screening results

Test		Before	After	Observation	Result
Flavonoid	NaOH 10%			Before: Red color After: Reddish-brown color After being left ± 30 minutes, oil clumps were observed. The color remains reddish-brown	Positive (+)

Test		Before	After	Observation	Result
	HCl + Mg			Before: Red color After + Mg: Brownish red color and foam is observed	Positive (+)
Alkaloid	Dragendroff			Before: Red color After: Orange red color and oil clumps observed	Positive (+)
	Wagner			Before: Red color After: Brownish red color and oil lumps observed	Positive (+)
	Mayer			Before: Red color After: Brownish red color and oil lumps observed	Positive (+)
Saponin	Add 10 mL of distilled water and stir			Before: Red color After being left for ± 10 minutes, two layers were observed. The top layer consists of oil clumps, while the bottom layer is a pale/bright yellow color. No foam was observed	Negative (-)
Phenolic	Add 2-3 drops of 5% FeCl.			Before: Red color After: Dark green color	Positive (+)

Test		Before	After	Observation	Result
Terpenoid /Steroid	Add 2-3 drops of Liebermann Burchardt reagent			Before: Red color After: Brownish red color and oil lumps observed	Positive (+) Terpenoid

Table 2 contains the results of phytochemical screening for red fruit macerate. Through this qualitative test, positive results were obtained for the secondary metabolite content of flavonoids, alkaloids, phenolics and terpenoids. On the other hand, it gives negative results for the saponin test. Flavonoid, alkaloid, phenolic and terpenoid compound derivatives have been widely used as natural pigments in DSSC research, some examples are listed in Table 3.

Table 3. Natural pigment in DSSC

Secondary Metabolites	Compound	Reference
Flavonoid	Antosianin, Quercetin, Morin, Fisetin, Luteolin	Zdyb & Krawczyk, 2019; Woldu et al., 2020
Alkaloid	Betalain, Betasianin, Betanin, Betaxanthin, Indole	Zhang et al., 2008; Qian et al., 2017; Patni et al., 2020
Phenolic	Gallic acid, Catechol, Coumarin, α-Mangostin, β-Mangostin,	Tennakone et al., 1996; Sánchez-De-Armas et al., 2012; Kumara et al., 2017
Terpenoid	Carotenoid, β-carotene	Yamazaki et al., 2007; Prakash et al., 2023

FTIR Spectrum Analysis

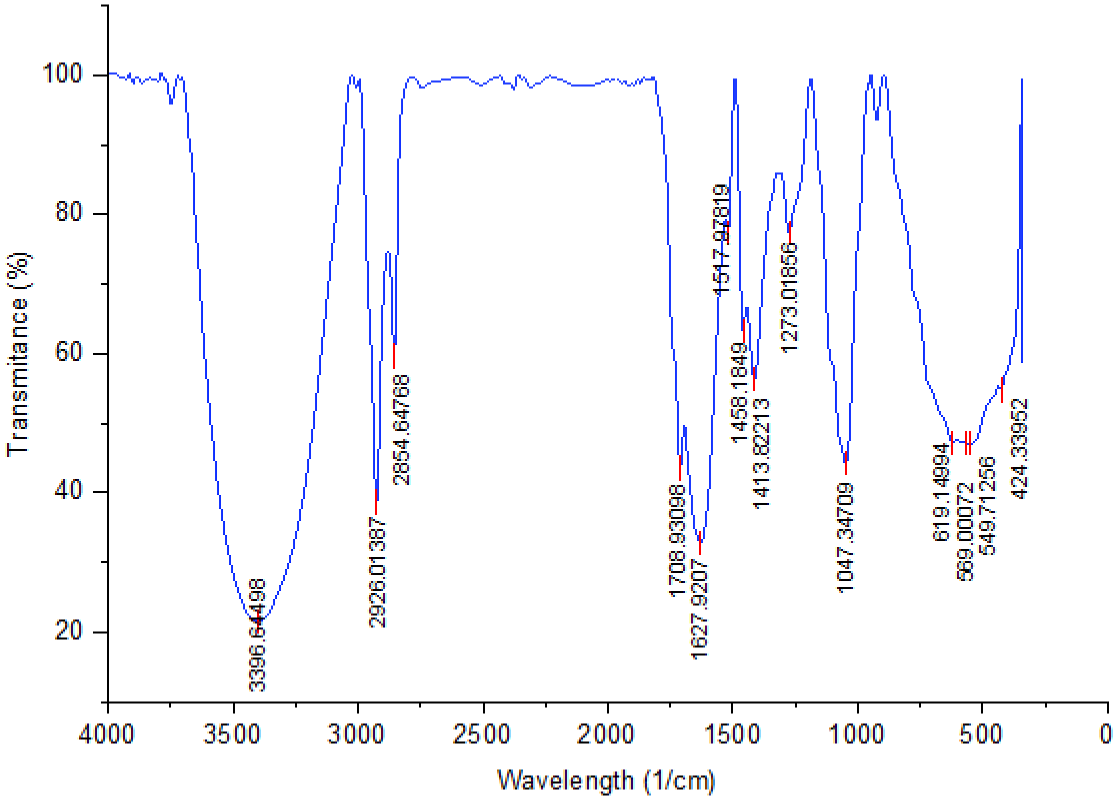

Figure 3. IR spectrum of red fruit extract (methanol solvent)

Figure 3 shows the IR spectrum of red fruit macerate. The absorption band (ν_{max}) at wavelenght 3396 cm^{-1} (O-H stretching) indicates the presence of an OH group. This is supported by the absorption of the CO group at 1047 cm^{-1} (C-O stretching). The absorption bands that appear at 2926 cm^{-1} and 2854 cm^{-1} (C-H_2 stretching) indicate the presence of an aliphatic CH group which is strengthened by the absorption at 1458 cm^{-1} and 1413 cm^{-1} (C-H_3 bending). Then, the absorption of 1708 cm^{-1} (C=O stretching) is the C=O carbonyl group with the absorption of 1273 cm^{-1} (C-O stretching) as the C-O group. Meanwhile, the aromatic C=C group is seen at an absorption of 1627 cm^{-1} (C=C stretching) (Rouessac & Rouessac, 2007; Silverstein et al., 2015).

Based on the results of IR spectrum analysis, it is known that the chemical components in red fruit maserate have a carboxylic functional group (-COOH), a carbonyl group (C=O) and a hydroxyl group (-OH), which are important functional groups for pigment molecules to be able to interact with nanosemiconductor surfaces, for example titanium oxide (Ti_2O) in DSSC. These functional groups can act as effective anchoring groups for electron transfer (Manoharan et al., 2016; Kumar & Wong, 2017; Hashimoto et al., 2022). Apart from carboxylic acid derivatives (COOH), phosphonate derivatives ($P(O)(OH_2)$) are also reported to play an effective role in binding to nanosemiconductor surfaces (Galoppini, 2004). Antocinin, chlorophyll (Yahya et al., 2021) and betalain (Hosseinnezhad et al., 2020) are several examples of pigment molecules with -COOH, C=O, -OH groups in their structures that have been the subject of previous DSSC research. Through the results of IR spectrum analysis, it is suspected that red fruit macerate contains pigment components that have -COOH, C=O, -OH groups as potential functional groups for DSSC.

UV-Vis Spectrum Analysis

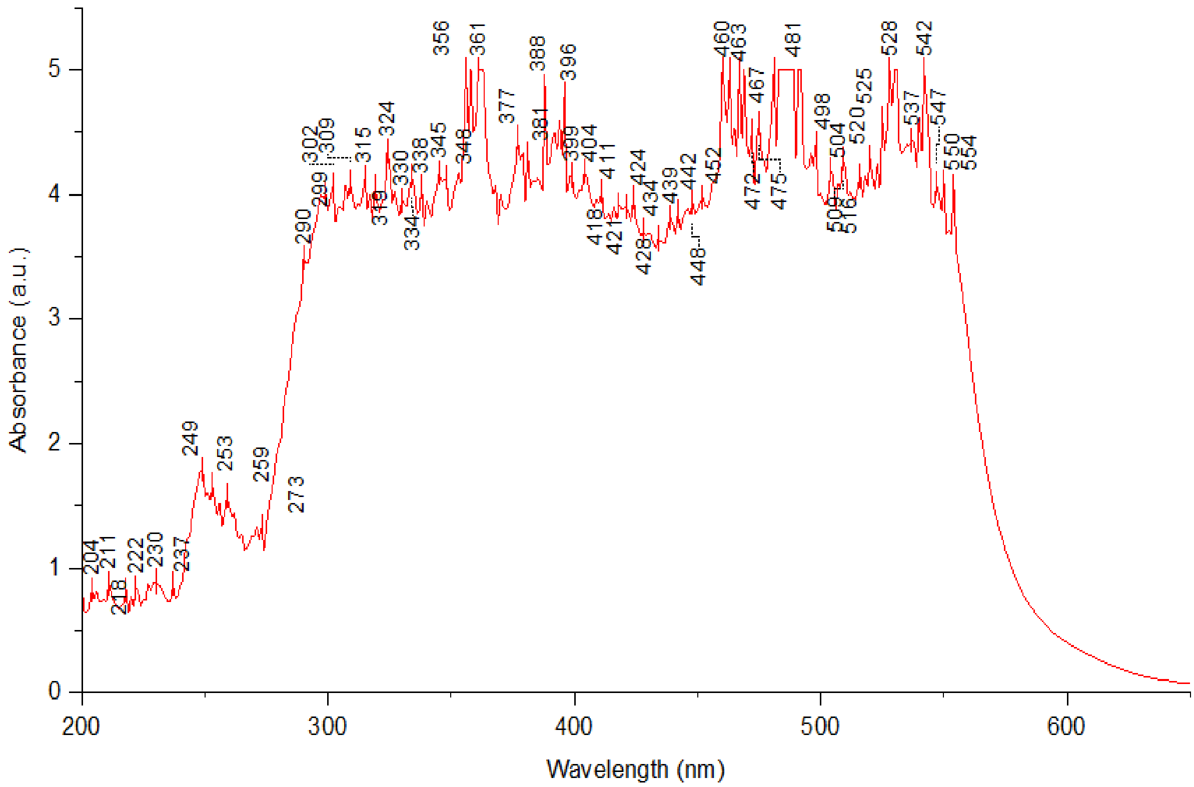

Figure 4. UV-Vis spectrum of red fruit extract (methanol solvent)

The UV-Vis spectrum of the red fruit macerate with methanol solvent can be seen in Figure 4. Absorption within the wavelength range of 200-400 nm corresponds to ultraviolet (UV) light, while absorption within the wavelength range of 400-800 nm corresponds to visible light

(Hollas, 2004; Pavia et al., 2013). In the spectrum, several absorption peaks in the UV region are observed within a wavelength range from 204 nm to 399 nm. A low absorption (< 2 a.u. , a.u.= absorbance units) is observed at wavelengths below 273 nm, which then rises (> ±3.5 a.u.) after a wavelength of 290 nm. In contrast, absorption peaks in the visible region, from 404 nm to 554 nm, show all peaks with absorption above ±3.5 a.u.. After 554 nm, no absorption peaks are observed.

The colors of visible light absorbed by chemical compound components for wavelengths from 400-550 nm consist of violet, blue, blue-green, yellow-green and yellow, whereas the colors of visible light observed in this wavelength range are yellow, orange , red, red-violet and violet (Worsfold, 2005; Pavia et al., 2013). This is in accordance with the visual appearance of the color of the red fruit macerate which consists of a mixture of yellow-orange-red. Several previous studies (Table 4) reported that natural pigments used as DSSC had maximum absorption in the 400-550 nm wavelength range (Shalini et al., 2015). Thus, based on the results of UV-Vis spectrum analysis, it can be indicated that the pigment components contained in red fruit macerate have the potential to act as DSSC.

Table 4. Pigment sources and maximum wavelength λ_{mak}

Pigment sources	λ_{mak} (nm)	Reference
Tangerine peel	446	Zhou et al., 2011
Rhododendron	540	
Fructus lycii	425, 447	
Marigold	487	
Yellow rose	487	
Flowery knotweed	435	
Lithospermum	520	
Erythrina variegata	451, 492	Hao et al., 2006
Capsicum	455	
Red *Bougainvillea glabra*	482, 535	Hernandez-Martinez et al., 2012
Red *Bougainvillea spectabilis*	480	
Spinach	437	Chang et al., 2010
Ipomea	410	
Turmeric	525	Moustafa et al., 2012
Lemon leaves	475	

CONCLUSION

Based on the research findings, it was discovered that red fruit maserate contains secondary metabolites such as flavonoids, alkaloids, phenolics and terpenoids, which are commonly used as natural pigments in DSSC. The FTIR spectrum analysis revealed the presence of functional groups such as carboxyl (-COOH), carbonyl (C=O), and hydroxyl (-OH), which can act as effective anchoring groups when interacting with the surface of nanosemiconductors. Furthermore, the UV-Vis spectrum analysis showed absorption peaks in the UV region (wavelength 204–399 nm) and the visible region (wavelength 400–550 nm). Based on the research findings and supported by a literature review, it can be inferred that red fruit pigment has potential for use in DSSC applications. Therefore, further research is needed to fabricate DSSC prototypes using red fruit pigment and evaluate their electrical performance.

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