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ORIGINAL ARTICLE

Energy Analysis and Economy Performance of a Hybrid Solar Dryer for Drying Coffee

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ABSTRACT – This work studies the effect of the drying temperature on the profile of the water content, drying rate, drying efficiency, economic performance, and the quality of robusta and arabica coffee beans using the hybrid solar dryer. The drying instrument, with the help of liquefied petroleum gas (LPG) heating, is used in this research at a specified temperature of 40°C, 50°C, and 60°C. The research is conducted on a sunny day for 1 day for each temperature and coffee beans. The temperature profile shows that the lowest water content in the study is 60°C. The drying rates for both 50°C and 60°C are similar, and the highest average efficiency of the instrument is at 50°C for both robusta and arabica beans. The dominant peak in the gas chromatography-mass spectrometry (GCMS) analysis result of coffee samples was caffeine, with a total area percentage of 30.89%. The description of the coffee bean structure using SEM test resulted in a hole size of 5–10 μm, the obtained fat content was 1.6%, the obtained protein content 17.3%. A hybrid solar dryer is an environmentally friendly solution that enables faster coffee drying, with a payback period of 1.5 years for both coffee bean types.

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INTRODUCTION

Coffee is a very popular drink with a rich and bitter taste. The types of commercially popular coffee are arabica and robusta coffee. In recent years, coffee has attracted the attention of people around the world because of its aroma, bitter taste, and health benefits that can reduce the risk of cancer, diabetes, gallstones, and various heart diseases [1]. Indonesia is the 4th largest coffee producer and exporter in the world. One of the largest coffee-producing regions in Indonesia is located in Temanggung Coffee Cluster, Central Java. Temanggung Coffee Cluster faces a major obstacle in drying, which is the main cause of the decline in the capacity and quality of coffee produced.

Drying will reduce the moisture content of the material to an extent where the development of microorganisms and enzyme activity that can cause spoilage is inhibited or stopped. Thus, the dried material can have a longer storage time [2]. Besides that, the results can reduce the moisture content of the product so that it is safe for storage or to the level required to proceed to other processing operations. Conventionally, farmers dry coffee beans using the conventional direct drying process in sunlight. This method is very dependent on the intensity of the sunlight. The traditional long-term drying can cause contamination and damage to the coffee beans. This method is not optimal because the material can be contaminated at ambient temperature and high relative humidity. This process results in adding new variables such as humidity and types of micro-organisms that can develop on the skin of the fruit (*Fusarium* sp., *Colletotricum coffeanum*) and fruit's surface (*Aspergillus niger, Penicillium sp*., and *Rhizopus sp*.) [3]. Therefore, drying with a hybrid solar drying instrument could be a good solution.

A hybrid solar dryer consists of three main components: a solar panel to capture solar energy, electrical resistance or an accumulation of energy, and a drying chamber [4]. The difference with solar drying is that the temperature in a hybrid solar dryer can be adjusted to the desired conditions using liquefied petroleum gas (LPG). Ratnasari [5] studied a bath-type dryer with a heat source of coffee husk furnace and solar collector and found that the temperature inside the drying chamber is higher than the ambient temperature, while the relative humidity in the dryer is lower than in the environment. This causes the drying process to take place quickly. Fauzi [6] studied the source of solar energy with the help of solar collectors and gas fuel energy and found that the evaporation rate of water content is high, and the time required for drying is shorter. Therefore, this research will apply another drying alternative: a hybrid solar dryer. The urgency of this research is to find, obtain, and apply drying technology that is inexpensive, applicable, easy to operate, inventory costs, environmentally friendly operation, and can be applied in the commercial industry and easily transferred to farmers in Temanggung.

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EXPERIMENTAL METHOD

Raw Material

Robusta and arabica coffee cherries are bought from the Temanggung Coffee Cluster. Raw coffee cherries are washed in water to remove dirt and grit, followed by blotting to remove excess water. Before the coffee is dried, it is necessary to find the total moisture content by drying a small amount of coffee in the dryer at a set temperature until it is constant and calculating the initial moisture content as a standard.

Hybrid Solar Dryer

Set up a hybrid solar dryer with an liquefied petroleum gas (LPG) burner (Figure 1). The burner is turned on with the dryer and is placed in direct contact with sunlight; set the burner until the inner ambiance temperature is reached according to the drying temperature (40°C, 50°C, and 60°C). Place 350 grams in each tray; the solar intensity, the weight change of coffee beans, and the LPG of each hour are recorded. The dried coffee beans are stored in a desiccator for a day to achieve a constant water-weight balance in the beans. Furthermore, coffee beans are roasted and stored in a plastic bag at 4°C to maintain their quality before product analysis.

(a) (b)

Figure 1. Hybrid solar dryer: (a) image (b) illustration

Analytical Determinations

Determination of Moisture Content and Drying Rate

Water content is one of the material's physical properties, indicating the amount of water contained in the material. The water content of dried coffee beans can be calculated by following the following steps. Calculate the estimated moisture content of dry coffee beans using Equation (1) and Equation (2).

$$MC = \frac{m_i - m_d}{m_i} \times 100 \quad (1)$$

$$DR = \frac{m_i - m_d}{t} \quad (2)$$

Where X is the moisture content (%), m_i is the initial mass of coffee (g), and m_d is the mass of coffee at any given time (g), t is the amount of time (minute) [7].

Dryer Efficiency Analysis

Drying efficiency is calculated based on the ratio between the amount of energy to heat and evaporate the water contained in the material with the energy produced by the fuel in the drying process [8]. Therefore, efficiency can be equated with Equation (3).

$$\eta_c = \frac{Q_{out}}{Q_{in}} = \frac{m_w \times L}{(I \times A) + P_b + (m_{LPG} \times LCV)} \quad (3)$$

Where m_w is the mass of water evaporated, L is the water latent heat, I is the solar intensity, A (area of solar), P_b is power used by the burner's blower, m_{LPG} is the mass of LPG used, and LCV is the lower caloric value of dryer.

Fourier-Transform Infrared Spectroscopy (FTIR)

The test was carried out with sample preparation so that it wasn't too thick when tested by mixing the sample with distilled water. The wavelength range used is 400-4000 nm [9]. Samples that have been allowed to stand overnight will appear as sediment. The solution separated from the precipitate is the sample that will be tested by FTIR to determine the functional groups present in the sample after treatment with the Liquid-Solid Extraction (LSE) method with Perkin Elmer IR 10.6.1.

Scanning Electron Microscopy (SEM)

The powder samples were analyzed for the microstructure by scanning electron microscopy (SEM-EDX JEOL JSM-6510LA), carried out at the University of Diponegoro (UNDIP) integrated laboratory. The dried coffee grounds were placed on a metal strip and coated with gold powder to make the sample analyzed. The surface of the prepared sample was visualized by SEM.

The 2,2-Diphenyl-1-Picrylhydrazyl (DPPH) Antioxidants Activity

The DPPH test is used to state the ability of antioxidants to scavenge stable DPPH radicals. This test was carried out as described by Dong, with minor modifications [10]. The sample extract was diluted five times with 80% ethanol. Then, 0.1 mL of the diluted extract was added to 0.5 mL of a mixture of 0.6 mM DPPH in methanol and shaken. The mixture was combined with 4.4 mL of 80% methanol and incubated in the dark for 30 minutes. The absorbance of the samples was determined at 515 nm, and the DPPH test was expressed in g Trolox/100 g DW [10].

Total Protein Content Analysis

More than 100 mg of coffee grounds are accurately measured in tin foil and analyzed using a Dumas analyzer with ethylenediaminetetraacetic acid as standard. Protein content was determined using the Dumas burning method and adaptation of the Association of Official Agricultural Chemists (AOAC) official method [11] using the Dumas analyzer.

Total Protein Content Analysis

Fat content was analyzed using the Soxhlet extraction apparatus [11]. The total fat extracted was carried out at 50°C for 16–18 hours until the petroleum ether was colorless. All analyses were carried out three times.

Economic Performance Determinations

According to Hipple [12], explaining that the payback period value of a project can be said to be the initial investment is inversely proportional to the average cash flow per year. This can help us create equations to calculate the economy being carried out (Equation 4).

$$Payback\ Period = \frac{FCI}{\overline{CF}} \tag{4}$$

To get the average cash flow calculation, several things need to be obtained first, starting from the operating income and net income after taxes, which can be equated as shown by Equations (5) to Equations (12) below. Depreciation also occurs in this calculation, where the depreciation method used is the SOYD (sum of year digit) method.

$$SOYD = \frac{N}{2}(N+1) \tag{5}$$

$$D_i = \frac{N+1-i}{SOYD}(FCI+V) \tag{6}$$

$$S = P * S_p \tag{7}$$

$$O_E = (L_p + E_p + F_p) \times PS = P * S_p \tag{8}$$

$$O_I = S - O_E \tag{9}$$

$$NI_B = O_I - D_i \tag{10}$$

$$NI_T = NI_B \times T \tag{11}$$

$$NI_A = NI_B - NI_T \tag{12}$$

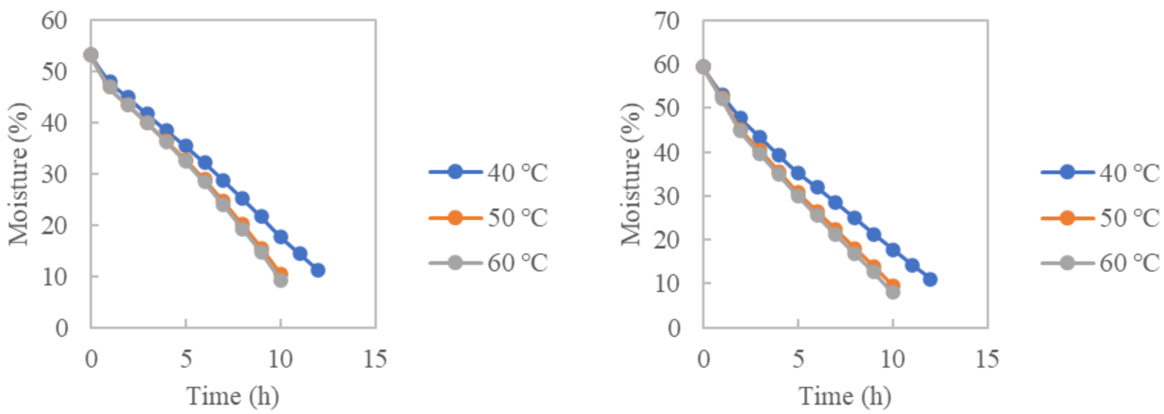
Where SOYD is the sum of year digit (years), N is years of instrument life (year), FCI is fixed capital investment, V is salvage value, D_i is depreciation, S is sales, P is the production of coffee, S_p is selling price, O_E is operating expenses, L_p is labor price per kilogram of coffee, E_p electrical price per kilogram of coffee, F_p is fuel price per kilogram of coffee, O_I is operating income, NI_B is net income before tax, NI_T is net income tax, T is national taxes, and NI_A is net income after tax.

RESULT AND DISCUSSION

The effects of temperature on moisture profile, drying rate, drying efficiency, economic analysis, antioxidants, functional groups, microstructure, total fat content, total protein content, and arabica and robusta coffee beans using a hybrid solar dryer were analyzed on a dry basis.

Drying Curve Analysis

Changes in moisture content in arabica and robusta coffee at 40°C, 50°C, and 60°C can be seen in Figure 2 (a) and Figure 2 (b). Both coffee beans' moisture content is below 2%, which is suitable for Indonesia's national standard. Both coffee beans experience a decrease in moisture content for 10–12 hours. However, the lowest content for both two types of coffee is at 60°C, where the water content in robusta bean is 9.27% and in arabica is 7.98%. According to Winarno, this phenomenon occurs due to higher temperatures, which results in faster evaporation and lower water content in the material [13].



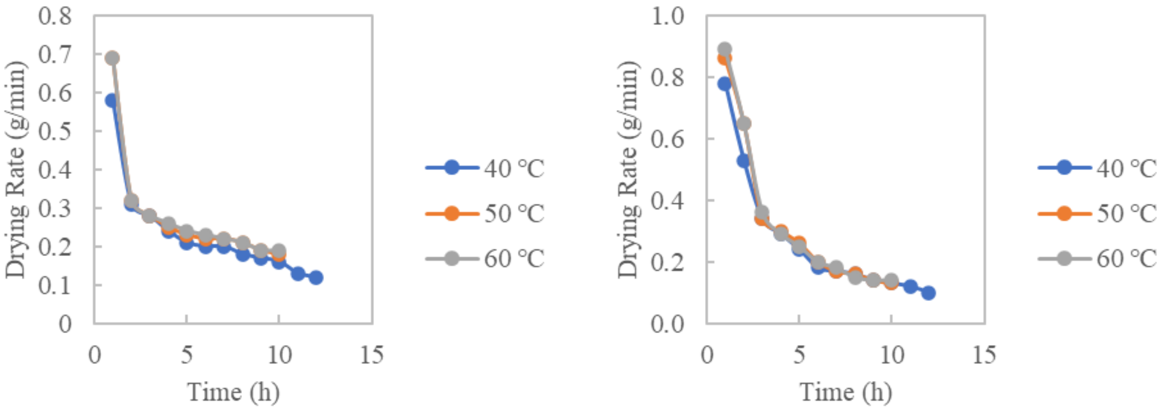
(a) (b)

Figure 2. Profile moisture of (a) robusta beans and (b) arabica beans

Drying Curve Analysis

The rate of drying for both coffee beans from time to time using a hybrid solar dryer with different temperatures of 40°C, 50°C, and 60°C can be seen in Figure 3 (a) and Fig 3 (b). From Figure 3 (a), it can be seen that the drying rate of robusta coffee at 60°C has a drying rate greater or equal to a temperature of 50°C, but for a temperature of 40°C, it is smaller than the two others. Figure 3 (b) shows that the drying rate of arabica coffee at 50°C and 60°C tends to be the same, while for a temperature of 40°C, it is below.

In the two figures, it can be observed that the drying rate of the two coffee beans starts with a high drying rate and slowly slows down to a constant. This is due to the drying phenomenon where water on the surface of the coffee beans easily moves from the coffee surface to the environment, which causes a higher drying rate. However, as the drying progresses, the drying rate will decrease due to water movement from the inside of the coffee core to the surface. The phenomenon that occurs is following the profiles of the two types of coffee at each temperature where the drying rate is the highest in the first hour, which over time will decline to approach constant [14].



(a) (b)

Figure 3. Drying rate profile of (a) robusta beans and (b) arabica beans

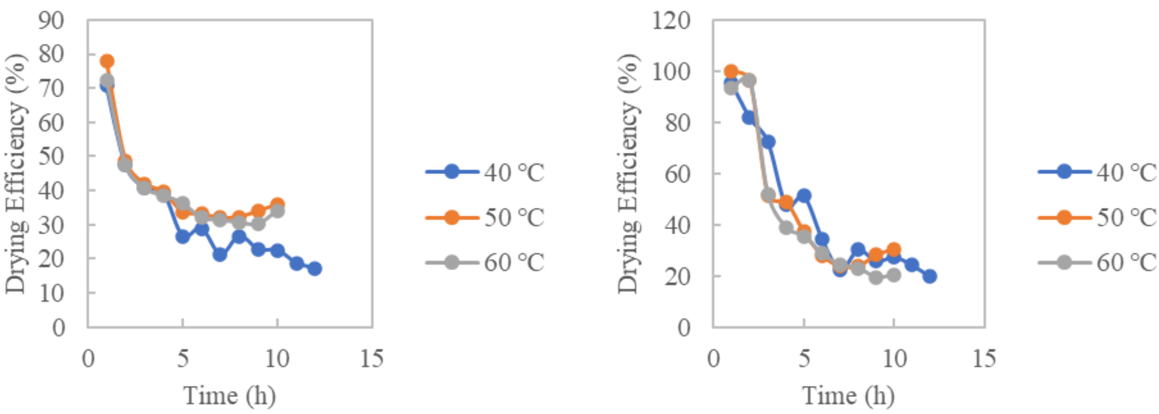
Drying Curve Analysis

The efficiency of the forced-circulated solar dryer depends on the amount of water vapor released into the environment in proportion to the amount of energy used. The research data results for the two coffee types presented can be seen in Figures 4 (a) and Figure 4 (b).

If it is observed that the efficiency data obtained during the research fluctuates and tends to decrease, this is because more and more water has been drained. Therefore, the efficiency decreases each time, but the energy used is relatively the same. This follows the efficiency calculation formula used, whereas the efficiency is calculated based on the ratio between the amount of energy to heat and evaporate the water contained in the material, and the energy produced by the fuel in the drying process [7]. From Table 1, the average efficiency for both coffee beans is shown, where for both types of coffee, the most efficient temperature for drying is 50°C; this can be caused by the amount of usage energy used to achieve a temperature of 60°C. The use of more energy can affect the average efficiency, with the drying rate and the amount of water vapor released into the environment for both temperatures not much different; this can cause the efficiency value of 50°C to be greater than 60°C.

Table 1. The average efficiency of arabica and robusta beans

Coffee Bean	Average Efficiency (%)		
	40°C	50°C	60°C
Arabica	44.40 ± 2.46	46.84 ± 2.72	43.12 ± 2.75
Robusta	32.14 ± 1.48	40.94 ± 1.34	39.34 ± 1.22



(a) (b)

Figure 4. Drying efficiency profile of (a) robusta beans and (b) arabica beans

Gas Chromatography-Mass Spectrometry (GCMS) Analysis

In chromatography gas analysis mass spectrometry spectra for coffee samples from Temanggung, Central Java, drying temperature of 50°C is used. There are volatile compounds in coffee consisting of several groups, namely hydrocarbons, alcohols, aldehydes, ketones, carboxylic acids, esters, pyrazines, pyrrole, pyridine, sulfur compounds, furans, phenols, and oxazoles [15]. Not all compounds detected by GCMS are determinants of coffee aroma. Based on the test results, Table 2 consists of 20 compounds detected by GCMS in coffee samples (Figure 5).

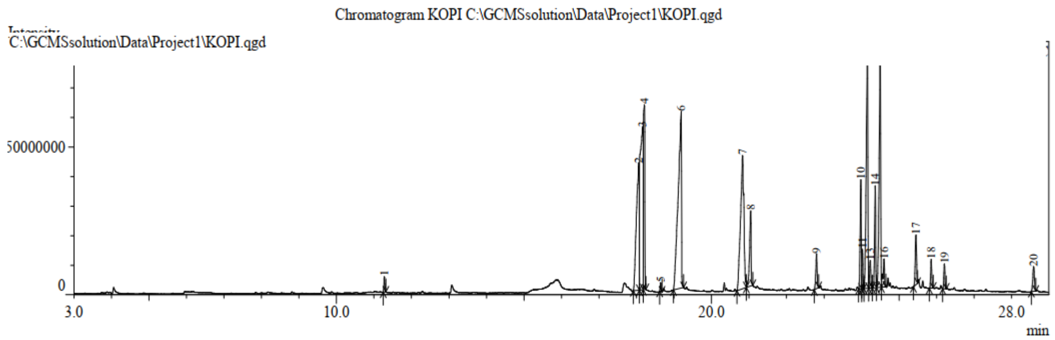


Figure 5. GCMS spectrum results

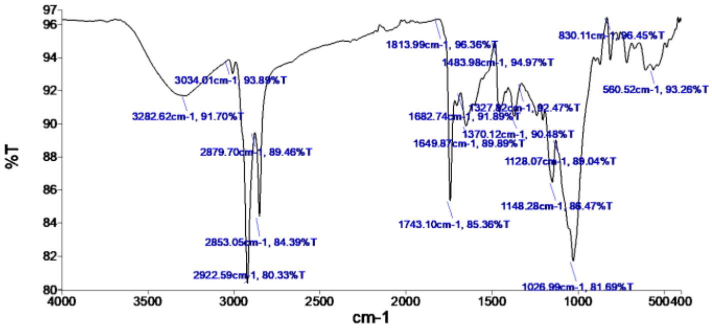
Table 2. Aromatic compounds and dominant compounds detected by GCMS in samples.

Peak	Percentage	Compound
1	0.40	2-Methoxy-4-vinylphenol
2	10.04	Caffeine
3	13.99	Caffeine (CAS)
4	6.86	Caffeine (CAS)
5	0.23	Hexadecanoic acid, methyl ester (CAS)
6	16.24	n-Hexadecanoic acid
7	12.22	9,12-Octadecadienoic acid
8	3.24	Octadecanoic acid
9	1.24	Eicosanoic acid (CAS)
10	3.43	2,3-Dimethylbenzofuran
11	1.02	Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester
12	10.98	Naphthalene, 1,2,3,4-tetrahydro-5-methyl- (CAS)
13	0.99	2,3-Dimethylbenzofuran
14	3.12	Pregn-5-en-20-one, 3-(acetyloxy)-, (3.beta.)-
15	10.27	5.beta.-Pregn-16-en-20-one, 3.beta.-hydroxy- (CAS)
16	1.20	Pregn-5-en-20-one, 3-(acetyloxy)-, (3.beta.)-
17	1.80	9,12-Octadecadienoic acid (Z, Z)-, 2,3-dihydroxypropyl ester (CAS)
18	0.89	2,3-Dimethylbenzofuran
19	0.75	Methyl communate
20	1.08	Tocopherol

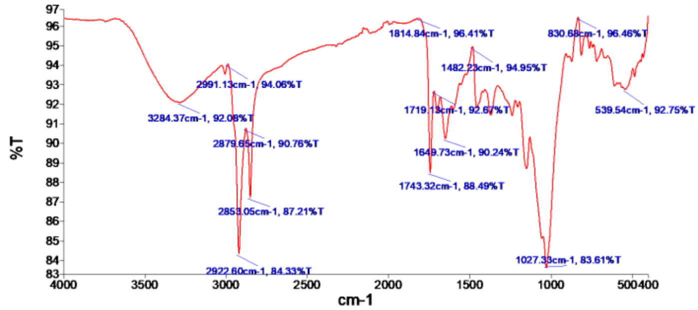
In the analysis, it was found that the dominant peak on the GCMS results of the coffee sample showed a caffeine compound. Caffeine compounds are shown by the peak spectrum numbers 2, 3, and 4 in coffee samples with contents of 10.04%, 13.99%, and 6.86%. The area under the peak is related to the concentration of the compound in the sample. Percent area is obtained by dividing the area of a particular compound by the total area of the peaks of all compounds detected. Based on the data presented in Table 2, caffeine compounds appear in the coffee sample. This compound is one of the compounds that determine the taste of coffee, with a total area percentage of 30.89%. This caffeine compound describes the distinctive taste of coffee beans [16]. Apart from caffeine, several other aromatic compounds were also detected from the ester group, the phenol group, and the furan group.

Fourier-Transform Infrared (FTIR) Analysis

Janzen mentioned that coffee has specific components, and these main components of coffee give out the distinct taste of bitterness and acidity of a cup of coffee. The chemical composition is common, such as caffeine, trigonelline, and carbohydrates, chlorogenic acids, lipids, amino acids, melanoidins, volatile aroma, and ash (minerals) [17]. FTIR analysis of the two coffee beans (Figure 6) is to ensure that our drying instrument and method did not cause any hindrance to the chemical components that are present in coffee.



(a)



(b)

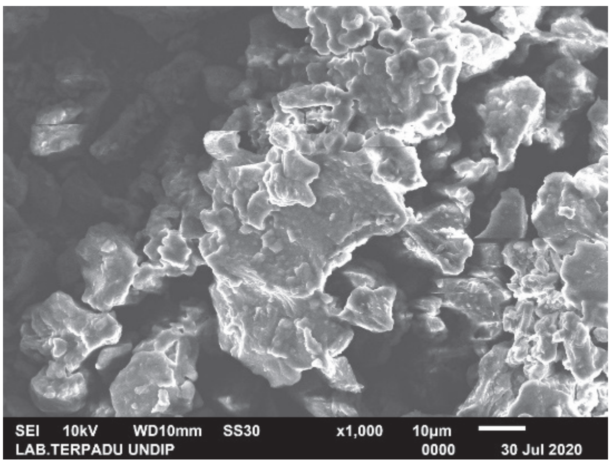
Figure 6. FTIR analysis of (a) robusta beans and (b) arabica beans

In robusta coffee beans, caffeine can be detected in our analyses in peak numbers 4, 8, and 9. Trigonelline traces can be found in peak numbers 3, 5, 8, 9, and 10. Chlorogenic acid traces can be found in peak numbers 1, 7, 8, 10, 11, and 12. Caffeine in coffee (1,3,7-Trimethylxanthine) is present in various wavelengths, which is present in both of our coffee beans, whereas in robusta on peaks number 4, 8, 9, and arabica is present on peaks 4, 8, and 9. Trigonelline in coffee is also present in both coffee beans, whereas on robusta, it is peak number 3, 5, 8, 9, and 10, respectively, and for arabica, respectively. Both lipid and amino can be noticed by peak number 9 in both coffee beans.

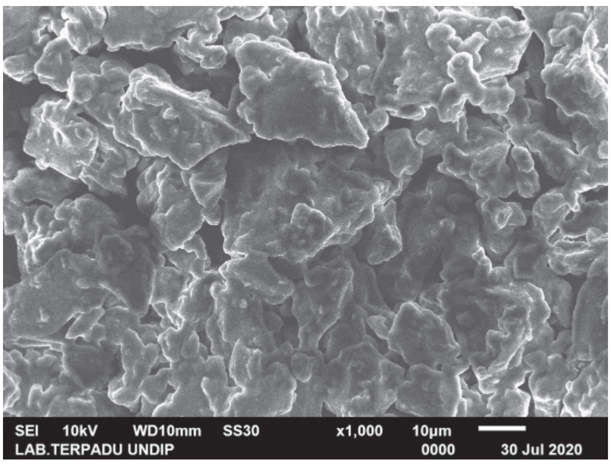
It is safe to conclude that our drying instrument did not do any significant removal of substances that are usually in coffee beans, where every specific component mentioned by Janzen was found in our FTIR reading.

Scanning Electron Microscope (SEM) Analysis

In the SEM test, the study aims to see the depiction of the layer structure. In the SEM, retrieval was carried out on a cross-section. Figure 7 shows the SEM test results.



(a)



(b)

Figure 7. SEM analysis of (a) robusta and (b) arabica beans

Figure 7 (a) and Figure 7 (b) show cross-sections of both coffee beans in the 1000-times magnification state. The hole size varies from 10 µm to 30 µm for arabica beans, while for robusta beans, it varies from 5 µm to 10 µm. Liu's research states that the size of the cross-sectional holes for Robusta ranges from 5 to 15 µm [18].

Proximate Analysis

According to Verma, the proximate test is a way to estimate the levels of certain components in coffee. This analysis was conducted to determine the protein and fat content [19].

Fat Content Analysis

According to Tarigan and Towaha, dried coffee contains 1.51–2.93% fat [20], while the fat content is 1.6% for robusta beans and 1.8% for arabica beans. The practical fat content obtained falls into the category of fat content that has been done by previous research. It can be concluded that drying using a hybrid solar dryer is efficient for drying coffee and also does not cause any hindrance to the contents.

Protein Content Analysis

Coffee in this study was measured using the SNI 235422015 method, which had a protein content of 17.3% for robusta bean and 18.2% for arabica bean. The research results by Tarigan and Towaha showed that coffee that is dried directly under the sun contains 14.94% protein [20]. The protein content in this study is higher than the protein content in previous studies. It can be concluded that drying using a hybrid solar dryer is efficient for drying coffee.

Colorimetric Analysis

The colorimetric result on coffee with a hybrid drying method is shown in Table 3. Based on the results of color analysis on coffee, the values of L, a, and b are obtained, where the value of L indicates the brightness of the color, the value of a represents red and yellow if the value of a is positive, the color represent is red and the negative value is yellow. The b results represent blue and green, where positive values indicate green and negative values represent blue. The value range of the a and the b are -120 to 120. From both of result showing positive values, the color scale shown represents approaching red and blue. Pigment damage is influenced by three indications: L, a, and b. In this study, it was found that the brightness color index (L) of drying coffee using solar hybrid at a temperature of 50°C was 23.56, where (L) stated the dark and light levels in the range of 0 to 100. A value of 0 states black or very dark, while 100 states very bright. In this study, the average values of L, a, and b were 23.56, 19.98, and 23.68.

Table 3. Colorimetric result on coffee with hybrid drying method

No	Sample	Parameter	Result			Method
			L	a	b	
1	Coffee	Color	26.00	19.12	23.78	Digital colorimetric
			22.19	20.59	24.26	
			22.50	20.24	23.00	

Economic Performance Analysis

Data on coffee harvest production were obtained in 2020. This can change according to existing conditions and the amount of energy costs and electricity following prices in 2020 with data and also uses the formula in Equation (4) to Equation (12).

Economic analysis of the dryer (hybrid solar dryer) in this case for the sole purpose of drying robusta and arabica coffee beans is substantial to find the economic feasibility and sustainability of the dryer, where the dryer is targeted towards Indonesia's coffee farmers also possible for any coffee producing countries close to the equatorial line.

The assessments needed to be reported are the cost of drying the product, the payout period, and the life of the dryer. Table 4 presents the value of the input and output parameters for the economic assessments. The results showed that compared with the local subsistence farming, 20%–30% loss caused spoilt coffee. The loss of 20%–30% is quite large.

Table 4. Economic value and data

List	Data
Cost of dryer	32,800,000 IDR
Life of dryer	20 years
Production of coffee robusta	750 kg/ha
Production of coffee arabica	1,000 kg/ha
Price of robusta	35,000 IDR/kg
Price of arabica	45,000 IDR/kg

List	Data
Cost of operation for robusta	14,980 IDR/kg
Cost of operation for arabica	15,169 IDR/kg
Salvage value	12,000,000 IDR
Interest rate	8%
Inflation rate	5%
Tax	10%

The cost of drying per unit quantity (kg) of coffee varies and can quite fluctuate, increasing from 10%–25%, depending on the intensity of the solar dryer, which is not a very significant change for each unit quantity of coffee. The payback period for this tool when drying arabica coffee is one year and three months, while for robusta coffee, the payback period is two years and five months. The result is not very disappointing, considering the life of the dryer could reach a maximum of 20 years.

CONCLUSION

At experimental temperatures (40°C, 50°C, and 60°C), the lowest water content for robusta and arabica coffee beans is at 60°C. This phenomenon occurs due to higher temperatures, resulting in faster evaporation and lower water content in the material. The efficiency of a forced-circulated solar dryer depends on the amount of moisture released into the environment in proportion to the amount of energy used. The maximum efficiency value for robusta coffee is at a temperature of 50°C, which is 78.06%. For arabica coffee, a temperature of 50°C also has the maximum efficiency, which is 99.75%. This is due to the use of more energy to reach a temperature of 60°C. Higher energy consumption can affect average efficiency, drying rate, and the amount of water vapor released into the environment. In the analysis, it was found that the dominant peak on the gas chromatography-mass spectrometry (GCMS) results of the coffee sample showed a caffeine compound. This compound is one of the compounds that determine the taste of coffee, with a total area percentage of 30.89%. Apart from caffeine, several other aromatic compounds were also detected from the ester group, the phenol group, and the furan group. The description of the coffee bean structure using the scanning electron microscopy (SEM) test resulted in a hole size of 5–10 µm. The fat content obtained was 1.6%. The protein content was obtained at 17.3%. The payback period for the tool for drying robusta coffee is two years and five months, while for arabica coffee is one year and three months.

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