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Applications of solar dryer for seaweed and cassava starch

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Abstract. In this paper, the comparisons of seaweed and cassava starch drying using a newly-designed solar dryer is invesigated. The drying operation was done in 2 days, from 8.00 A.M until 4.00 P.M on each day. Both seaweed and cassava starch were rewetted and prepared before drying. Experimental results showed that drying time affects the value of relative humidity and drying temperature. It was shown that drying temperature is invesely proportional to relative humidity. The relative humidity and temperature curves of seaweed drying and starch drying show relatively similar results. The drying process was able to reduce seaweed's moisture content from 72,6% to 12,6% in tray 1, and from 72,6% to 14,1% in tray 2, while the cassava starch's moisture content is reduced from 52,6% to 7,05% on tray 1 from 52,6% to 13,81% on tray 2. All results have met their respective standards of moisture content. The drying rate fluctuates as the drying time changes, with drying temperature significantly affects the drying rate. The product qualities of seaweed and cassava starch show acceptable results based on their respective standards. It can be concluded that solar dryer is a suitable alternative for easier drying and good product quality.

1. Introduction

The usage of solar energy to dry agricultural products such as fruits, vegetables, or other crops have been applied since a long time ago, by directly drying the products under the sun. However, it has several drawbacks, such as uncertain drying time, high operating cost, the need of wide area, and interventions from insects or other living beings. Moreover, the product quality is not good because of the effects of unpredictable weather, such as rains, storms, etc. Therefore, solar drying technology is a good alternative to take care of those problems while still being able to increase the product quality and prevents the product loss [1].

Cassava flour is essentially starches extracted from cassava. In order to obtain this starch, it is important to determine the cassava's age and maturity. When the cassava tubers are kept underground, the number of starches inside it will increase until certain point, at which it begins to harden and becomes wood-like, making it harder to be processed. Cassava starch has a high value of amilopectin, difficult to clot, sticky and not easily damaged. Other than that, it also easily swells in hot water. It has 17-23% amylose and has relatively low gelatinization temperature, at the range of 52^0C – 64^0C. Several studies have discussed about drying of cassava on solar dryer. Studies done by Yahya et al. [2] shows that by using solar dryer, the moisture content of cassava can be lowered from 61% w.b. to 10,5% w.b. in 13 hours, with the air's mass flow rate is 0,124 kg/s. The average temperature of solar dryer is 300C, average thermal efficiency is 25,6%, average drying rate is 1,33 kg/h and Spesific Moisture Extraction Rate (SMER) is 0,38 kg/kWh. Other study done by Aviarra et al. [3] shows that when the drying temperature is increased from 40^0C to 60^0C, energy usage increases from 1,93 to 5,51 J/s, energy utilization ratio increases from 0,65 to 0,6, and energy efficiency increases from 16,036% to 30,645%.

Seaweed is classified into Thallophytes divisio, has no roots, stems, of leaves, but only have stem-like parts called thallus. It grows by attaching itself to corals, rocks, muds, sands, or other hard surfaces [4]. Seaweed consists of protein (5,4%), carbohydrates (33,3%), fat (8,6%), fibers (3%), and ash

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(22,25%). It also contains amino acid, vitamin, and minerals such as sodium, potassium, calcium, iodine, iron, and magnesium. Its amino acid, vitamin, and mineral contents are 10-20 times of that land plants. Several studies about seaweed drying have been published [5,6,7]. Unfortunately, there are limited publications about seaweed drying using solar dryer. Studies done by Fudholi et al. [7], titled "Energy and exergy analyses of solar drying system of red seaweed", shows that 40 kilograms of seaweed can be dried to 4,44 kilograms in 15 hours, with the moisture reduction from 90% w.b. to 10% w.b. The average dryer temperature and average dryer humidity is 48,6^{0}C and 43%, respectively. The Spesific Energy Consumption (SEC) value is 2,62 kWh/kg, with the overall drying efficiency of 27%. The overall exergy efficiency is 30% and Improvement Potential value is 0,247 kW.

In this study, a newly-designed solar dryer has been made and the drying operations on both seaweed and cassava starch have been performed. To the authors' best knowledge, there is no study about the comparison of solar dryer applications on drying seaweed and cassava starch. Therefore, the purpose of study is to determine the drying curve, the drying rate, and the product qualities of both seaweed and cassava starch dried by the newly-designed solar dryer and compare both results.

2. Experimental methods

2.1. Solar dryer design

The newly-designed solar dryer has a dimension of 40 cm x 40 cm x 150 cm. The materials used to make the dryer has several characteristics. Firstly, the materials are relatively cheap in order for it to be applicable to most farmers. Second, the materials chosen are relatively light-weighted, making it easier to move the dryer, if needed Third, the materials chosen has the ability to absorb heat, therefore the heat is accumulated inside the dryer, making the drying process faster. Finally, the materials chosen are strong, not easily break or decay after prolonged use, in order to reduce the risk of damage and loss. The frame is made from aluminium, which is a good heat conductor, light-weighted, and has a good availability. To cover the sides, transparent acrylics are used to increase the solar radiation absorption. The black-painted iron sheets are used as heat collectors because it is a good heat conductor.

The solar dryer design is a closed chamber with transparent side wall, therefore it prevents outside interventions such as contaminations, effects of weather, etc. At the bottom of the dryer, a rectangular-shaped solar collector is installed to collect the heat. It is painted black to increase the solar radiation absorption. The dryer is designed in trays in order to increase the drying capacity. The dryer roof is slanted in order to prevent the water, moisture, or other substances on the roof from entering the dryer and wetting the materials, by letting it flow downward the roof. At the dryer's roof, several holes are made as an outlet of evaporated moisture, in order for it to exit the dryer and prevent moisture accumulation inside the drying chamber. The materials are inserted to the trays present in the dryer. The air duct is at the bottom of the drying chamber, automatically heated by the sun when it flows toward the drying chamber. The heated air then enters the drying chamber and heat the product. The heating system is effective because it comes from two sources, namely direct sun radiation and the hot air flow from the bottom of the dryer (convective heating). Figure 1 shows the constructed solar dryer.

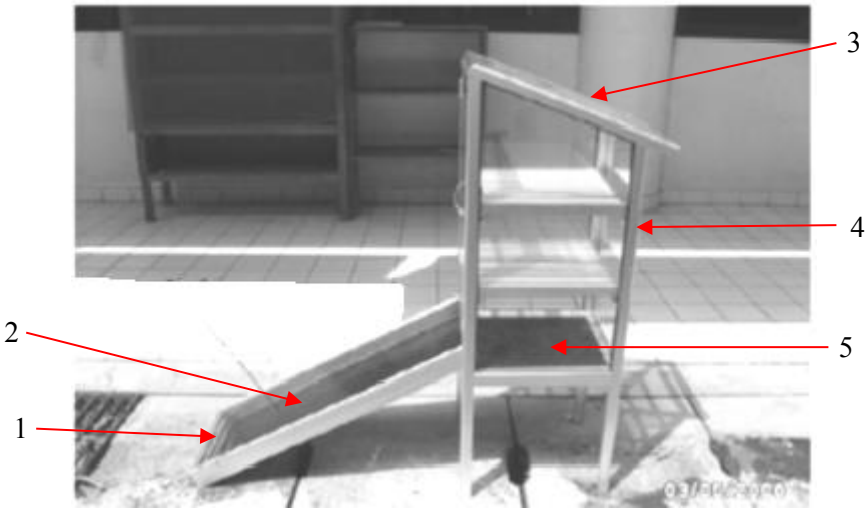

Figure 1. The constructed solar dryer; 1 = Drying air inlet, 2 = Black-painted solar collector, 3 = Dryer roof, 4 = Dryer frame made from aluminium, 5 = Dryer trays

2.2. Experimental procedure and analysis

This research was done in the Laboratory of Chemical Engineering Department, Faculty of Enginering, Diponegoro University.

2.2.1. Seaweed drying. From the intitial moisture content test, the seaweed's initial moisture content obtained is 72,6%. There are 2 steps on seaweed drying process, namely seaweed washing and drying operation. Seaweeds are washed to remove any impurities that might present in the seaweed, such as sat, coral, and wood. 1000 grams of seaweed are soaked with plain water, with the water volume of 10 times of the seaweed's weight. The water is replaced with the new one once per day, and the soaking is done for 2-3 days until the seaweed's texture becomes soft, white-colored, and not fishy anymore. After that, the seaweeds are soaked in 1% whiting/lime betel water for three days, while the whiting water is replaced with the new one once per day. Before the drying operations begin, the seaweeds are cut with the dimensions of 3 cm x 0,5 cm x 0,2 cm each, then spreaded uniformly on the drying trays. The seaweeds are weighted once per hour. The dryer temperature, wet-bulb temperature, and dry-bulb temperature are also measured.

2.2.2. Cassava starch drying. The drying experiment begins by wetting the starch. According to the initial moisture content test, the cassava starch's initial moisture content is 52,6% w.b. After the wetting, the drying operations can be performed. The drying is conducted for 4 days, with 100 grams of starch on each tray. The starch weight measurement is done once per day. For one hour and every eight hours, the tray temperature is measured. The temperatures measured are inlet, outlet, ambient, and drying chamber temperature. To determine the relative humidity (RH), the dry-bulb and wet-bulb temperature must be measured. Wet-bulb temperature can be measured by putting wet cotton at the end of the thermometer, while the dry-bulb temperature can be normally measured. By connecting the lines of wet-bulb and dry-bulb temperature values on the psychrometric chart, the relative humidity can be obtained.

2.2.3. Drying curve analysis. After measuring the sample weights during the drying operation, the relation of moisture content and drying time can be obtained. The sample's moisture content (wet basis) at any given time can be obtained using equation (1) [8]:

$$X = \frac{M_w - M_d}{M_w} \quad (1)$$

where M_w is the mass of wet samples and M_d is the mass of dry sample (all in grams).

2.2.4. Drying rate analysis. To obtain the drying rate, sample weight reduction at every drying time is needed. Using equation (2), drying rate value can be determined and the relations between drying rate and drying time can be known [8]

$$Rd = \frac{M_i - M_d}{t} \quad (2)$$

where M_i is initial mass at given time (grams), M_d is the final mass at given time (grams), t is the drying time (minutes), and Rd is the drying rate (gram/minutes)

2.2.5. Proximate analysis. The proximate analysis consists of ash test and water content test. Both the ash test and the water content test are done according to the standards made by Association of Official Analytical Chemists [9].

2.2.6. Cassava starch quality analysis. Aside from the proximate analysis, another quality analysis also performed on cassava starch, namely degree of whiteness analysis, acidity analysis, and chemical composition analysis. In whiteness analysis, a KETT Digital Whiteness Meter Model C-100 is used to measure the degree of whiteness from starch powder using reflective index from the sample's surface according to the international standards. Acidity analysis is done by measuring the pH of cassava starch using pH indicatior after the starch is moistened. The chemical compositions of cassava starch is tested by AOAC method [9], then compared with SNI standards to understand the effects of solar dryer on starch's quality.

3. Results and discussion

3.1. The effects of drying time on relative humidity and drying temperature

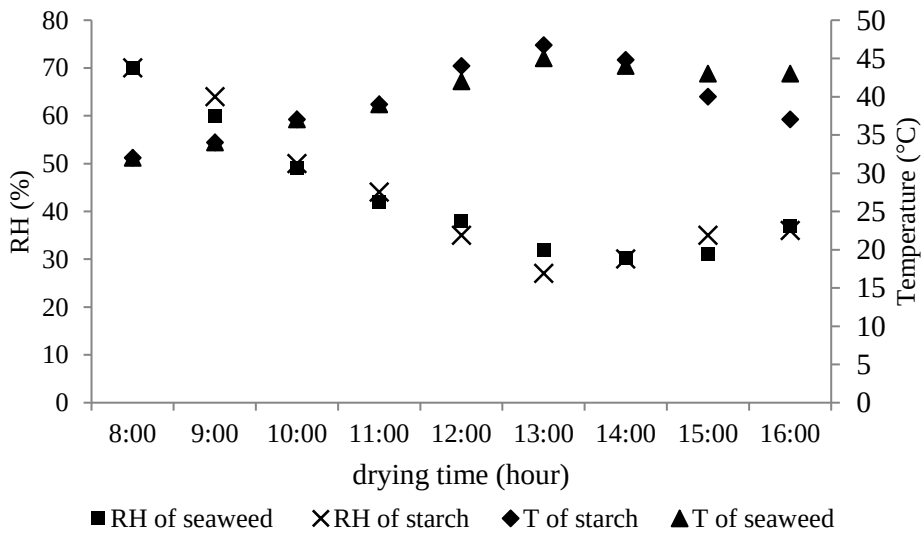

Figure 2. The effects of drying time on relative humidity and temperature in solar drying of seaweed and cassava starch on the first day.

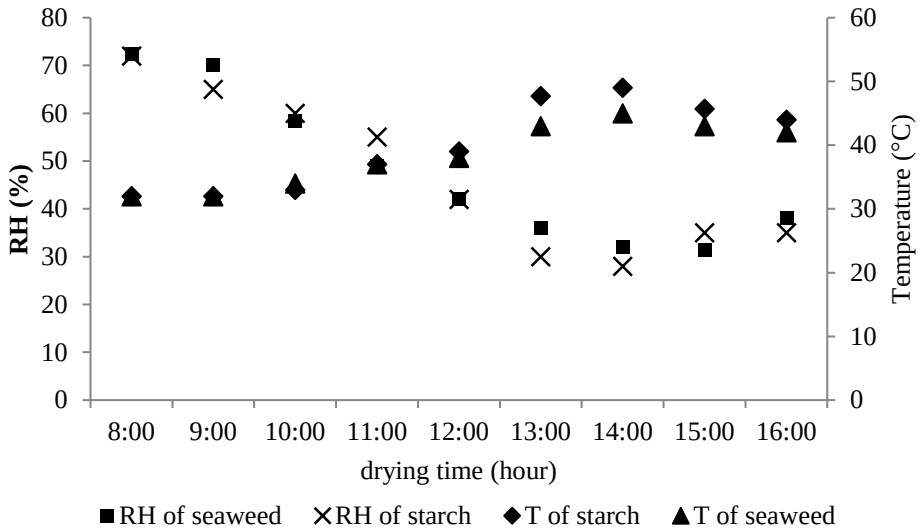

Figure 3. The effects of drying time on relative humidity and temperature in solar drying of seaweed and cassava starch on the second day.

According to the figure 2 and figure 3, it can be observed that drying time affects the value of RH and drying temperature. The temperature increases gradually until noon and decreasing gradually on afternoon. As the time passes by until noon, the solar radiation absorbed by solar collector increases, thus the heat absorbed by collector is high and this increases the temperature inside the dryer. From the figures above, it can be found that drying temperature is invesely proportional to relative humidity [10]. When the water is evaporated from the sample because of the hot air, the relative humidity indside the dryer is reduced, thus reducing the sample's moisture content [11]. The comparison of figure 2 and figure 3 shows that there is no significant difference between the first day and the second day of drying. Also, the RH and temperature curves of seaweed drying and starch drying show relatively similar results.

3.2. The effects of drying time on moisture content

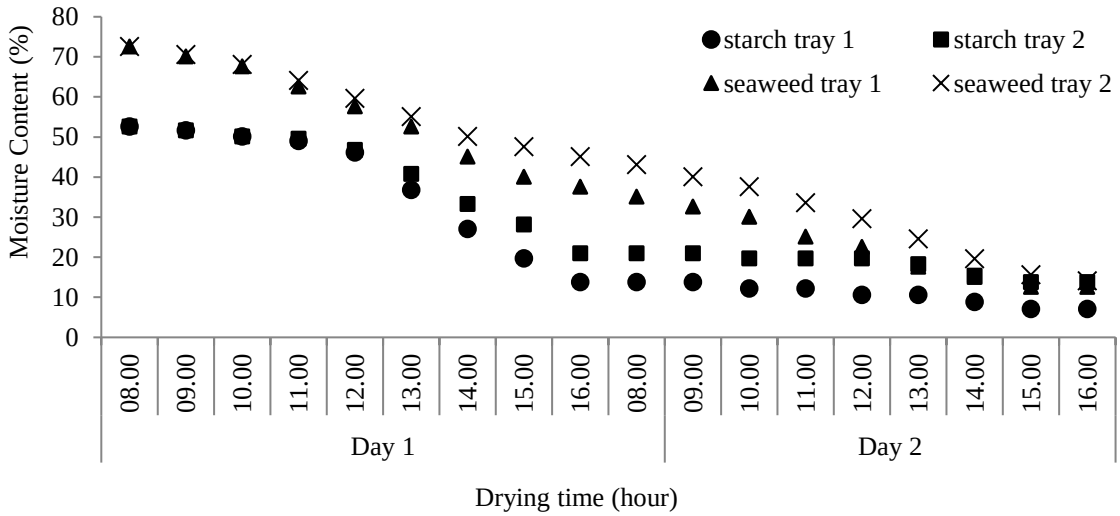

Figure 4. Effects of drying time on moisture content in solar drying of seaweed and cassava starch.

From the figure 4 above, it can be observed that, on seaweed drying, the drying process was able to reduce seaweed's moisture content from 72,6% to 12,6% in tray 1, and from 72,6% to 14,1% in tray 2,

with operating time of 08.00 A.M until 04.00 P.M on each day for 2 days. Between the first day and the second day the samples were kept inside the dryer, and during the next day it is found that there is an approximately 2% moisture content reduction on both trays when the seaweed is being kept. The seaweed's final moisture contents of 12,6% in tray 1 and 14,1% in tray 2 show that the dried seaweed has fulfilled the standard limit of maximum moisture content of dry seaweed, which is 15% [12]. On cassava starch drying, the starch's moisture content on tray 1 is reduced from 52,6% to 7,05% in 2 days, with the same operating time as seaweed drying, while the starch moisture content on tray 2 is reduced from 52,6% to 13,81%. Both tray 1 and tray 2 final moisture content results have fulfilled the moisture content limit of 15% for cassava starch [13,17].

The final moisture content of both seaweed and cassava starch at tray 1 is higher than their final moisture contents at tray 2 because tray 1 is placed at the bottom of the dryer, at which it is directly connected with the air duct and the solar collector, therefore the highest amount of heat is located on tray 1. Then, when the hot air flows upward to tray 2, the air is less hotter, because some of the heat are used to evaporate the water from starches located in tray 1, so the moisture reduction on tray 2 is less faster than tray 1. From the figure above, it can be seen that there is a clear difference of drying curve trend between seaweed drying and cassava starch drying on both trays. According to the drying curve, the seaweed dries faster than cassava. This might be caused by higher free moisture content (the amount of moisture, higher than equillibrium that can be evaporated at a given temperature or pressure) in seaweed compared to the cassava starch, making it easier and faster to evaporate the water.

Overall, drying using solar dryer can reduce the moisture content faster than sun drying (conventional method), mainly because drying temperature in solar dryer is higher than sun drying. This happens because solar dryer is able to increase the air temperature with the help of solar collector installed in the dryer. Moreover, conventional drying method is affected by open winds, which might nicrease the humidity around the drying area, while on solar dryer, the dryer itself is a closed-space, with only few parts that can be passed by outside air. Therefore, the outside air does not affect the drying conditions inside the dryer. Other than that, the air that flows inside by passing through some unclosed parts of the dryer will carry the evaporated water from the materials outside the dryer by flowing upwards to the holes on top of the dryer [14].

3.3. The effects of drying time on drying rate

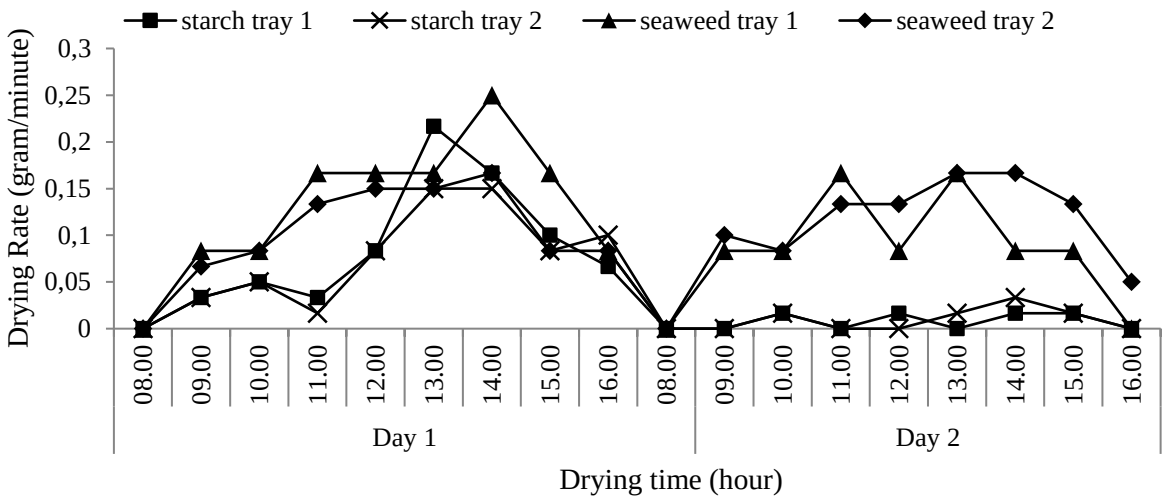

Figure 5. Effects of drying time on drying rate of seaweed and cassava starch drying.

From figure 5, it can be seen that drying rate values are affected by drying time. As explained in subsection 3.1, as the time reaches noon, the solar radiation increases, which increase the temperature inside the dryer. The higher temperature will increase the drying rate of the materials. Conversely, when

the time reaches afternoon, the solar radiation will decrease, making the dryer temperature lower and lowering the drying rate. Both seaweed drying and cassava starch drying show similar results. From the figure above, it can also be observed that the drying rate on the second day is lower compared to the first day, for both seaweed drying and cassava starch drying. This might be caused by lower water content of samples on the second day compared to the first day, thus the amount of water evaporated at any given time is fewer and reducing the drying rate. According to the figure above, the seaweed dries faster than cassava. This might be caused by higher free moisture content in seaweed compared to the cassava starch, making it easier and faster to evaporate the water.

3.4. Product quality analysis

3.4.1. Seaweed drying. The analysis consists of proximate analysis and organoleptic analysis. Figure 6 and 7 below shows the quality results of the dried seaweed

Figure 6. Dried seaweed product.

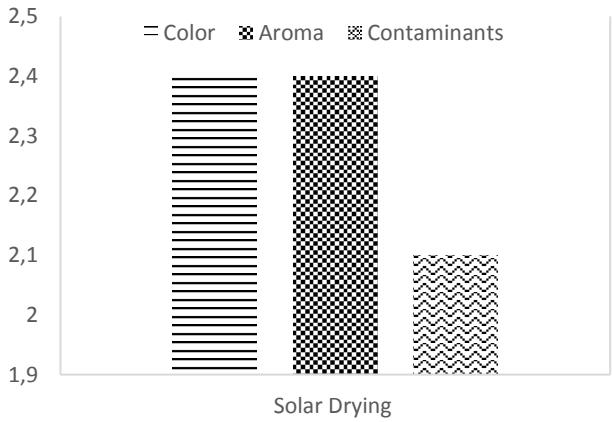

Figure 7. Organoleptic test results.

Figure 6 shows the dried seaweed result. It can be seen that the dried seaweed has a bright color. To evaluate the dried seaweed results based on its color, aroma, and contaminants, the dried seaweed was tested by ten panelists, who will assess the results with the score range of 1-3 (3 is the best result while 1 is the worst), and the results is shown in figure 7. From the figure 7 it can be seen that the color and aroma of the dried seaweed is quite good, and the number of contaminants are not too high. Table 1 below shows the proximate analysis results of dried seaweed.

Table 1. Proximate analysis results of dried seaweed

Analysis	Standard of dried seaweed	Solar dryer	
		Tray 1	Tray 2
Water content	Max 15% [15]	12,6%	14,1%
Ash content	20-40% [17]	25,2%	24,3%

From the table 1, it can be seen that water content of the dried seaweed on tray 1 and 2 is 12,6% and 14,1%, respectively, which fulfills the limit of standard water content of dried seaweed, which is 15% [15]. The ash content of the dried seaweed is 25,2% for tray 1 and 24,3% for tray 2, respectively. These results are on the range of the dried seaweed's standard ash content [16]. Overall, quality tests of dried

seaweed show acceptable results. This indicates that solar dryer is suitable as an alternative for easier drying and good product quality.

3.4.2. Cassava starch drying. The results of quality tests of the dried cassava starch are shown in table 2 below.

Table 2. Quality results of cassava starch

Type of analysis	Standard of cassava starch [17]	Solar dryer	
		Tray 1	Tray 2
Water content	15%	9,07%	10,83%
Ash content	0,5%	1,59%	1,45%
Protein content	1,1%	1,50%	1,33%
Fat content	0,5%	0,64%	0,62%
Carbohydrate content	85%	87,20%	85,77%
Degree of whiteness	Min. 91%	75,21%	78,91%
Acidity (pH)	5-7	4,94	4,81
Starch content	Min. 75%	66,12%	71,81%

Based on the table 2, it can be seen that the cassava starch's moisture contents on both trays have fulfilled the maximum moisture content limit of cassava starch product, which is 15% [17]. The results of the other tests show agremeent with their respective standards [18], except the whiteness test. The degree of whiteness of the cassava starch on both trays did not meet the minimum requirement, therefore further treatment is needed. A possible way to increase the degree of whiteness is to add some whitener [19]. Overall, the quality tests of cassava starch on both trays show acceptable results. This indicates that solar dryer is suitable as an alternative for easier drying and good product quality.

4. Conclusions

Based on the studies performed, the drying temperature and relative humidity fluctuates as the drying time changes, and drying temperature are inversely proportional to relative humidity. The moisture content of the material is decreased as drying temperature increases. Solar dryer can dry the material better than conventional drying method because of the installation of solar collector which increases the temperature inside the dryer and the closed-space design of the dryer, which prevents outside factors from affecting the drying conditions inside. The drying rate fluctuates as the drying time changes, with drying temperature significantly affects the drying rate. The product qualities of seaweed and cassava starch show acceptable results, indicating that solar dryer is a sutable alternative for easier drying and good product quality.

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