Assessment on Hybrid Solar Dryer for an Effective Red Chili Drying Process

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Abstract. This study aims to assess hybrid solar drying method for processing red pepper compared to sun drying and solar drying. Independently selecting heat variables of 40 °C, 50 °C, 60 °C, 70 °C, and 80 °C, the temperature profiles, drying curves, thermal efficiency and effectiveness, and energy and exergy were analyzed to meet the standardized moisture content of the product as well as other features (color, vitamin C content, and β-carotene content). It was found that the drying rate decreased when the temperature rose, while the drying chamber efficiency and drying effectiveness were inversely proportional to the duration. The collector became the most efficient at 40 °C. The drying air temperature is directly proportional to utility, energy efficiency, exergy input, exergy ouput, exergy loss, exergetic efficiency, and development potential while inversely proportional to the energy utilization ratio. Drying red pepper with a hybrid solar dryer at all observed temperatures was deemed able to meet the nationally standardized water content of ≤ 10.78 %. Processing red pepper at 80 °C resulted in the L, a, and b values of color analysis of 30.37, 27.45, and 10.63 respectively, vitamin C content of 14.79 g 100 g^{-1}, and β-carotene content of 4.43 mg 100 g^{-1}.

Keywords: *Capsicum annuum* L, dyring quality, minimize damage, preservation, red pepper.

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1 Introduction

A vegetable in Indonesia considered to be as substantial as butter in the Netherlands [1]; chili – particularly red pepper and cayenne pepper – is a commodity with high strategic value. Its hot, spicy properties enrich flavor to various cookings, and its absence makes one less appetizing. Being a highly volatile product, the price of red pepper (*Capsicum annuum* L.) can go even higher than USD 6.00 kg^{-1} in low season from normally < USD 1.00 kg^{-1} [2]. That noted the reason to be diminishing supply despite constant, even seasonally increasing, demand. The price of a commodity increases when its supply falls behind demand, and the price plummets when its supply exceeds demand [3]. Such fluctuations occur annually, putting consumers in continual trepidation.

Having short shelf life, red pepper perishes easily. The high-water content of 90 % [4] makes it an ideal environment for microorganisms to grow. Once harvested, red pepper is prone to damages due to bacterial or fungal activities, enzyme alteration, and flawed storing, packing, or transporting process [5]. Fresh red pepper stays for ± 5 d in room temperature and up to 10 d when stored in 45 °F (< 10 °C) [6] and senesces more quickly when the environmental temperature rises since it accelerates deterioration process [7]. Red pepper is supposed to be stored in a low temperature of 2 °C to 15 °C with 90 % to 95 % humidity to maintain its freshness up to ± 20 d [8, 9].

Reducing the water content through drying is a way to preserve red pepper. In Indonesia where the sun radiation rate is as high as 12.38 MJ m^{-2} d^{-1} [10], sun drying is the most common method to dehydrate various products. A complex course of transferring heat and mass between the surface of the product and its surrounding media to vaporize a portion of water in the product prior to safe storing or further processing [11, 12], the process should be put to halt when it starts to cloud or rain [13]. Such reliance on the weather makes sun drying less effective. This method also requires a long drying period and a considerably large drying space. The three factors affect production reliability as well as producer's income.

With a large amount of energy consumption, drying is one of the most energy-intensive industrial operations. Industrial dryer compels immense energy input due to high latent heat needed to vaporize water with relatively low energy efficiency [14–16]. Seeing how costly it is, an attempt to conserve energy while providing optimal processing condition through energy and exergy analyses of drying procedure is called for [17].

The first law of thermodynamics, representing energy conservation principle, generally applies in performance analysis of a management system. Yet, energy analysis has a few debilities. The energy concept is basically inconsiderate of assumptions on where a certain process leads to, *e.g.*, energy does not oppose the presumption that heat is spontaneously transferred to temperature rise [18]. Further, energy analysis may misinterprete a number of processes – environmental temperature, for example, maintains its enthalpy of zero when isothermically compressed despite the exergy of compressing air is larger than zero [17].

Several drying methods invented are rack drying, oven drying (also applies in tray dying), and greenhouse solar drying. Tray drying for red pepper is considered ineffective since the constant temperature of 60 °C for 5 h results in the water content of 12.03 %, which is higher than the nationally standardized (SNI - *Standar Nasional Indonesia*) amount of 11 % [19]. Greenhouse solar drying – employing sunlight and electric fan – is cheaper than rack drying or oven drying, but its relying on the sunlight makes the process last up to 4 h longer [20, 21]. Cabinet oven drying successfully meets the standard by cutting the water content down to 8.12 %, but the duration of 32 h is detrimental to energy cost [22, 23].

In addition to using agricultural materials for drying, several maritime-based foodstuffs were tested using a hybrid solar dryer [24]. Based on a deduction that combining sunlight and Liquid Petroleum Gas (LPG) generated heat should save energy and time simultaneously, this research aims to test the effectiveness of hybrid solar dryer for drying red pepper.

2 Material and methods

Lasted for 3 mo between June and August 2022, this study was carried out in the Waste Management Laboratory of the Faculty of Chemical Engineering of Diponegoro University, Indonesia. The temperature profiles – both input and output – as well as sunlight intensity and relative humidity were examined in order to determine the moisture content, drying rate, collector efficiency and drying chamber efficiency of the device. To ensure its feasibility, product quality analyses on color maintenance, water content, β-carotene content, and vitamin C content were also performed.

2.1 Material

The equipment used is as shown in Figure 1, and the specification is detailed in Table 1. Fresh red pepper of 3 kg was purchased from Small and Medium Businesses (*Usaha Kecil dan Mengah* - UKM) Sidodadi, a local market in Magelang, Central Java, Indonesia as the sample, and three treatments were prepared. T1 involved two racks, each containing 100 g red pepper, for direct sunlight exposure. For T2, 800 g of red pepper was placed in the solar drying chamber without additional heat. As of T3, eight racks of 100 g red pepper – making a total of 800 g – was positioned in the solar hybrid dryer operated with both solar energy and LPG energy for temperature variables of 40 °C, 50 °C, 60 °C, 70 °C, and 80 °C. The initial moisture content of red chili was 75 % for each method, which was measured by baking and calculated from the mass lost at 110 °C for 1 h.

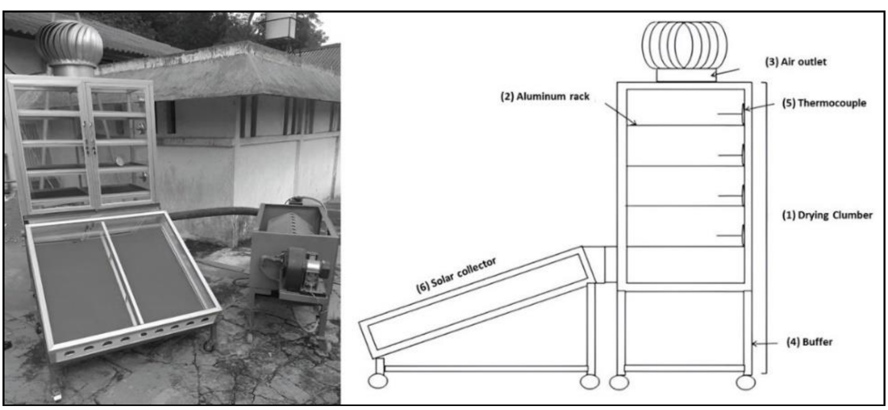

Fig. 1. Hybrid solar dryer.

Table 1. Specification of hybrid solar dryer.

Number	Information	Material	Detail
1.	Drying room	Glass and aluminium	(100 × 60 × 94) cm
2.	Rack	Aluminium	(56 × 45) cm
3.	Air outlet	Aluminium	Ø 36 cm, height 40 cm
4.	Stand	Iron	(101 × 61 × 52) cm
5.	Thermocouple		± 0.5 accuracy
6.	Collector	Glass	(100 × 100) cm

2.2 Methods

Conducted between 8:30 and 15:30, the weather had been sunny with no rain during research. Data were taken every 1 h throughout the drying time of 7 h. In each hourly record, samples were scaled; relative humidity of the environment, the collector, and the drying chamber was measured with a hygrometer; input-output temperature of the collector and the drying chamber was determined with a hygrometer; sunlight intensity of the environment, the collector, and the drying chamber was quantified with a solar power meter; airflow in the drying chamber was rated with an anemometer; environmental temperature was determined using a hygrometer; LPG container was scaled for supporting energy consumption; electricity power was assessed with an ampere meter.

2.2.1 Moisture content

The weights of fresh samples and dried ones on each tray were required to run through Equation (1) in order to find the moisture content [20].

$$Mc = \frac{Md}{Mi + Md} \text{ x } 100 \quad (1)$$

Where,
Mi = Fresh sample mass (g)
Md = Dried sample mass (g)

2.2.2 Drying rate

The weight reduction of each tray shows the drying rate once computed according to Equation (2) [20].

$$Rd = \frac{Mi - Md}{t} \text{ x } 100 \quad (2)$$

Where,
Rd = Drying rate (g s^{-1})
Mi = Fresh sample weight (g)
Md = Dried sample weight (g)
t = Drying duration (s)

2.2.3 Collector efficiency

Equations (3) and Equation (4) are employed to calculate the collector efficiency rate [25].

$$\eta c = \frac{Qu}{I.A} \quad (3)$$

$$\eta c = \frac{mCp\,(To - Ti)}{I.A} \quad (4)$$

Where,
ηc = Collector efficiency
Q_u = Heat to dry sample (J)
I = Sunlight intensity (W m^{-2})
A = Collector width (m^2)
M = Airflow (kg s^{-1})
C_p = Specific heat (J kg^{-1} °C)
T_0 = Output temperature of the collector (°C)

T_i = Input temperature of the collector (°C)

2.2.4 Drying chamber efficiency

To ensure whether the drying chamber works optimally, the data need to be calculated as per Equation (5) [25].

$$\eta d = \frac{m_w h_{fg}}{IAt + E + m_f Cv} \times 100 \quad (5)$$

$$\eta d = \frac{m_w h_{fg}}{IAt + m_f Cv} \times 100$$

Where,
ηd = Drying chamber efficiency
m_w = Sample mass dried in t-time (g)
h_{fg} = Latent heat from water vapour (kJ g^{-1})
E = Energy from the blower (kWh)
m_f = Fuel/biomass (kg h^{-1})
C_v = Fuel/bio specific heat (kJ kg^{-1})
T_o = Output temperature of collector (°C)
T_i = Input temperature of collector (°C)

2.2.5 Product quality

(i) Color maintenance
With a chroma meter (Minolta CR 300, Minolta Camera Co. Japan. no 82281029), the lightness (L) should be recorded as a number between 0 (black) and 100 (white) on a paper sheet, while the light wavelength of red-green chromatic colors (a) goes with +a of 0-100 for red and –a of 0-(-80) for green and the one of yellow-blue chromatic colors (b) goes with +b of 0-70 for yellow and –b of 0-(-70) for blue.

(ii) Water content
The lost mass during the heating process represents the most amount of water contained in the samples. Dry-based calculation as per Equation (6) was run to establish the water content [25].

$$X_{bk} = \frac{M_w - M_d}{M_d} \times 100\ \% \quad (6)$$

Where,
X_{bk} = Dry-based water content (%)
M_w = Fresh sample weight
M_d = Dried sample weight

(iii) β- caroten content
Having an ability to absorb light and UV ray, carotenoid in a certain product can be measured with spectrophotometry [26, 27]. Performing it should reveal the contents of β-caroten in red pepper prior to and following drying process.

(iv) Vitamin C content
A nutrient contained in red pepper aside from protein, fat, carbohydrate, calcium, vitamin A, and vitamin B1 is vitamin C (ascorbic acid). Its being a strong antioxidant promotes immunity and protects bodily cells from cancer-generating agents [28–31]. As a water-soluble nutrient which is also essential in collagen biosynthesis [32], it is

expected to dissolve due to heating. Any change that may occur in the end product calls for an analysis.

3 Discussion

3.1 Temperature profiles of hybrid solar dryer

The data explained in Figure 2 were based on the hybrid solar dryer when operating without supportive LPG heat. It is noticeable that the environmental temperature ranged between 30 °C and 35 °C and that the temperature in the drying chamber was higher than the one on the collector. The collector was black color in order to absorb as much heat as possible from the sun, which was then carried by the passing air into the drying chamber and intensified there. The heat then vaporized moisture in chili pepper.

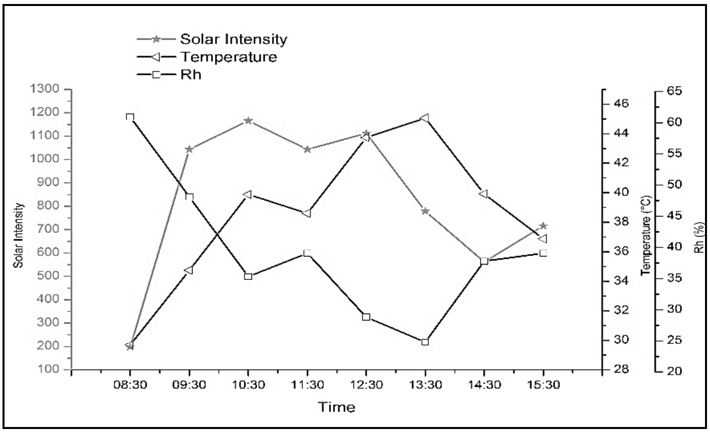

Fig. 2. Hourly temperature of hybrid solar dryer.

Further, the sun radiation fluctuated from 08:30 to 15:30. With the most intense of it was during midday when the sun is right above, the increase and decrease of the heat occurred gradually [33].

3.2 Drying rates

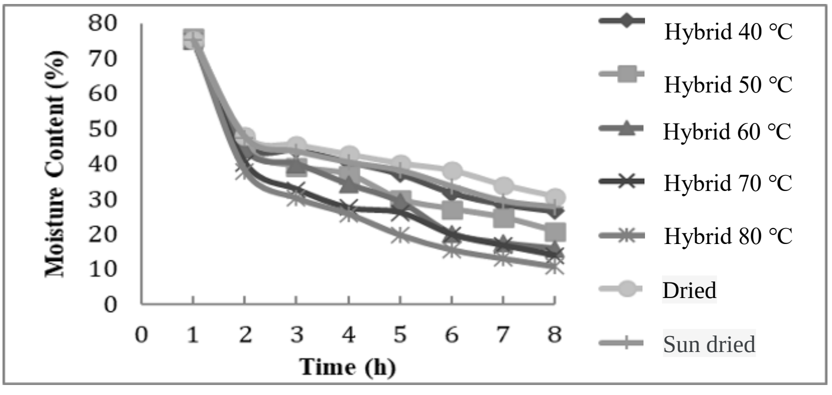

Fig. 3. The water contents of red pepper after hybrid solar drying process compared to sundrying and solar drying.

The water content ranges in accordance with applied temperatures during the 8 h drying process are presented in Figure 3. It is apparent that the longer the drying period lasts, the less moisture that remains in red pepper will be.

While conventional sundrying came out with water content of 30.55 % and solar drying was of 27.59 %, hybrid solar drying was able to suppress it even further with 26.42 %, 20.66 %, 15.76 %, 13.86 %, and 10.78 % at their respective temperatures of 40 °C, 50 °C, 60 °C, 70 °C, and 80 °C. The moisture contents in the product vary in different heats, and it shows that a higher temperature reduces relative humidity further in the device. Low relative humidity guarantees less water in red pepper as they are in balance [34].

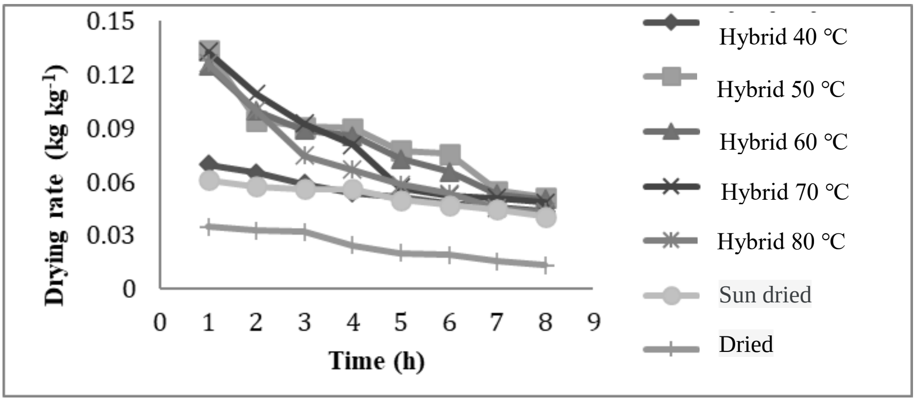

Fig. 4. Drying rapidity rates of hybrid solar dryer compared to solar dryer.

Figure 4 reveals the fact that drying rapidity in all methods drops when the drying process lasts longer. All variables – sun drying, solar drying, and hybrid solar drying – showed decreasing trend due to the temperature gap between the process and the surroundings before getting constant, with the highest drying rates in the early stage of the process. As expected, the product dried fastest at 80 °C. The higher the temperature in the device, the hotter the air will be, allowing more moisture to vaporize from the surface of the product [25].

3.3 Collector efficiency

Relying on airwave input, heat output, and sunlight intensity, the collector efficiency rates at studied temperatures is submitted in Figure 5.

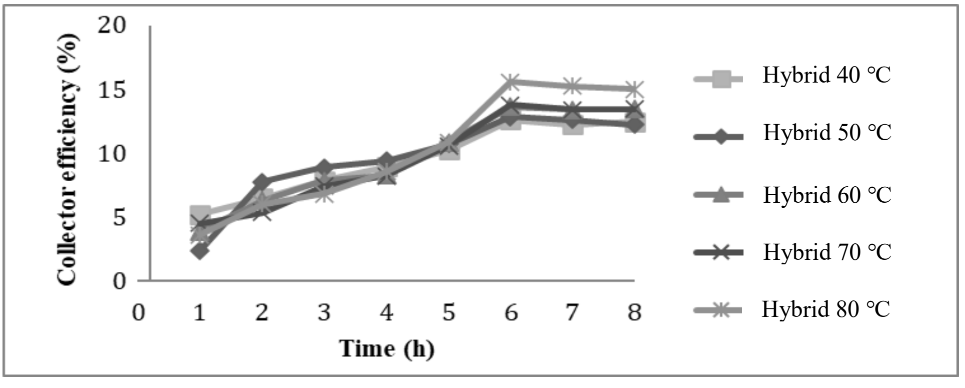

Fig. 5. Collector efficiency rates of hybrid solar dryer.

It is clear that the efficiency rates span between 2.35 % and 15.53 %, where longer operational period improves the efficacy at 40 °C, 60 °C, and 70 °C but depletes at 50 °C and 80 °C. Equation (4) figures out that collector efficiency is proportional to solar intensity, which relies on the environment. The process becomes more efficient as the collector captures more heat with longer exposure, allowing the device to dry red pepper faster [25]. When the last-minute solar intensity gets lower, the efficiency rate decreases.

3.4 Drying chamber efficiency

Ranging from 10 % to 16 %, the thermal efficiency rates of hybrid solar drying chamber in all studied temperatures are displayed in Figure 6.

The efficiency rates at 40 °C, 50 °C, 60 °C, 70 °C, and 80 °C are of 0.90 %, 1.53 %, 1.79 %, 2.43 %, and 2.64 % respectively, with the highest efficiency rate at the temperature of 80 °C. It is also seen that the longer the drying process was, the less efficient the produced energy would be. Therefore, it is deduced that the hotter the drying chamber is, the shorter period of time it takes to dry red pepper. This finding confirms by Safrizal *et al.* [35] that a high drying temperature optimizes the energy since it allows more moisture to vaporize.

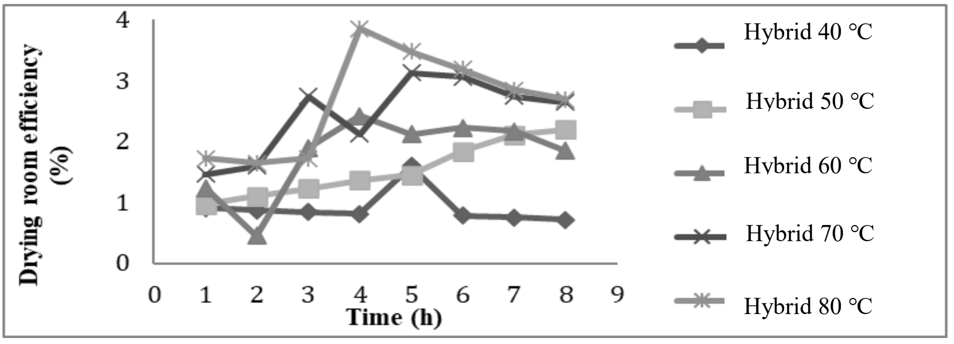

Fig. 6. Hybrid solar drying chamber efficiency rates.

3.5 Drying effectivity

Figure 7 demonstrates the drying effectivity rates of hybrid solar dryer at the observed temperatures and of solar dryer.

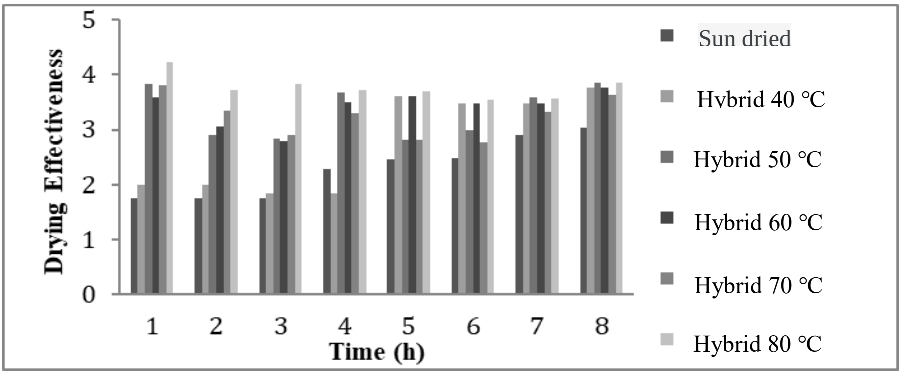

Fig. 7. Drying effectivity rates of hybrid solar dryer compared to solar dryer.

Drying effectivity is determined by how fast the water vapor accumulated on the surface of the product evaporates. The highest effectivity rate is of 4.22 after heating at 80 °C in the first 1 h. From Equation (7), it is known that the faster the drying process is, the more amount of water will evaporate. Moreover, longer drying time will reduce the effectivity due to less water vaporizing later [36, 37]. That solar hybrid dryer is constantly effective from hour 1 to hour 8 indicates that it is more effective than sun drying [25].

3.6 Product quality

3.6.1 Color

The brightness (L) rates of hybrid solar dried red pepper (Table 2) range between 26.92 and 30.37. With the darkest scale of 0 and the brightest one of 100, it is noticeable that the 80 °C drying temperature has instigated the highest darkening effect towards the product. This finding concurs the statement of Indrawati *et al.* [38] that the pigment deterioration in red pepper occurred at the temperature of 63 °C and beyond. The best result is recorded by drying temperature of 40 °C with L 30.37, a 27.45, and b 10.63. It agrees with the outcome by Tello-Ireland *et al.* [39] that the maximum color preserving attempt in dried red pepper was at 40 °C [40].

Table 2. Colors of red pepper after solar hybrid drying at studied temperatures and sundrying.

Number	Temperature	L	a	b
1.	40 °C	30.37	27.45	10.63
2.	50 °C	29.35	23.22	8.36
3.	60 °C	29.75	28.50	9.81
4.	70 °C	27.68	25.18	8.95
5.	80 °C	26.92	21.12	8.41
6.	Sun dried	28.05	25.49	7.38

3.6.2 Vitamin C

Limited to comparison between vitamin C content in fresh red pepper and one in 80 °C dried red pepper, the results are listed in Table 3.

Table 3. Vitamin C contents in fresh and 80 °C dried red pepper.

Product	Vitamin C (g 100 g^{-1})
Fresh red pepper	44.63 ± 2.68
Dried red pepper (80 °C)	14.79 ± 0.74

The vitamin C content in fresh red pepper is similar to the finding of Ramdani *et al.* [41] at 44.32 g 100 g^{-1}. It is significantly reduced after drying at such a high temperature, which is in tune with the finding of Burdurlu *et al.* [42], and Setyobudi *et al.* [43, 44] that heat could ruin half or more of ascorbic acid in a product.

3.6.3 β-caroten

The beta-caroten content in fresh red pepper (Table 4) is of 5.57 mg 100 g^{-1} – similar to what cited by Octaviani *et al.* [45] of 5.41 mg 100 g^{-1} – while a 20.46 % reduction transpired when dried as it reached as much as 4.43 mg 100 g^{-1}. When in contact with light, air, and heat, carotenoids are easily oxidated, resulting in fading colors in fruit and vegetables [46, 31, 44].

, Table 4. Beta-caroten contents in fresh and 80 °C dried red pepper.

Product	**β-caroten (g 100 g^{-1})**
Fresh red pepper	5.57 ± 0.39
Dried red pepper (80 °C)	4.43 ± 0.31

4 Conclusion and recommendation

Solar hybrid dryer is effective in red pepper drying process as it is able to evaporate moisture in the product more quickly and thoroughly than solar dryer or direct sun drying. As most water vaporizes in the early stage of the process despite varied temperatures due to constant heat in the drying chamber, shorter processing time should be feasible to ensure energy efficacy, particularly regarding the LPG use.

As all observed heat levels are proven to be able to meet the nationally standardized water content of ≤ 10.78 %, further study on the most appropriate temperature and duration of hybrid solar dryer in order to maintain the optimum color of red pepper as well as vitamin C and β-caroten contents is called for.

This research was funded by a research grant from Diponegoro University (international publication research, No. contract: 569-134/UN7.D2/PP/IV/2023). The authors would like to thank the Diponegoro University.

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