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A study on the performance of corn grain dryer using hybrid solar drying with liquefied petroleum gas

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Abstract

Corn is a widely produced and consumed agricultural product, used as fuel, staple food, and livestock feed. The high level of corn production can lead to potential post-harvest food losses. Drying methods offer a solution to extend the shelf life of a substance. Hybrid solar drying, which combines solar drying with additional heating, particularly using liquefied petroleum gas (LPG), was introduced in this research to ensure faster and more efficient drying processes. The three drying methods compared in this study consist of open sun drying, natural solar drying, and hybrid solar drying. The research results show an average corn grain moisture content of 13.95% over 10.5 hrs, 13.75% over 6 hrs, 13.65% over 7 hrs, 13.45% over 5 hrs, and 13.65% over 4.5 hrs in open sun drying, natural solar drying, and hybrid solar drying with temperature variables of 40°C, 50°C, and 60°C. The average drying rates were 0.212 g/min, 0.364 g/min, 0.318 g/min, 0.439 g/min, and 0.477 g/min, respectively. The average drying efficiency values for each variable were 2.968%, 4.719%, 5.358%, 5.271%, and 6.037%. In the proximate test, the corn grain moisture content in the hybrid solar drying variable at 60°C was 13.8%, ash was 1.24%, protein was 7.76%, fat was 4.40%, and carbohydrate was 72.8%. For the corn grain color test, the average values obtained were L = 46.48, a = 4.58, and b = 25.37. Meanwhile, the aflatoxin test for dried corn grains showed values of aflatoxin B1, B2, G1, and G2 <0.5 with a total aflatoxin content <2.00. Therefore, hybrid solar drying is recommended over open sun drying and natural solar drying because of its ability to operate even in unfavorable weather conditions, its temperature control capability, its ability to accelerate the drying process, and its capacity to maintain the quality of the material.

1. Introduction

The most widely produced and consumed plant cereal globally is corn. Most of which is used to produce biofuels, industrial products with added value, or livestock feeds (human or animal). Corn must be harvested as soon as it reaches maturity since, if left unharvested, it can lose its quality. Despite high levels of production, post-harvest loss during storage is a persistent issue that needs to be addressed. Its moisture level is one of the most crucial physiological aspects of corn grain storage. Plants that develop naturally nevertheless contain a significant amount of moisture. To minimize the risk of frost, insects, disease, and kernel damage during harvest, corn is typically harvested with a moisture content of 22% to 35% (wet) (Gürsoy *et al.*, 2013). Corn must be stored as a dry product with a moisture level below 14% if it is to be used as food, particularly in this instance as an element in livestock feed (Djaeni *et al.*, 2013).

One of the main methods for preserving postharvest corn grain is drying (Mendoza *et al.*, 2017). The Drying involves simultaneous heat and mass transfer to reduce water activity and enhance the product shelf-life (Suherman *et al.*, 2012; Sanghi *et al.*, 2017). Reducing water activity prevents the development of microorganisms that lead to food spoilage and enzymes that alter the chemical composition of food (Earle, 1983). Food product drying is a labor-intensive process that uses a significant amount of energy, accounting for 7 to 15% of all industrial energy used globally (Silva *et al.*, 2021), The drying technique utilizing renewable energy

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is required to reduce energy consumption. Open Sun drying, while inexpensive and simple to use, has several downsides, including the potential for product contamination by dirt, dust, insects, and spoilage due to unforeseen rain (Agrawal and Sarviya, 2014). In addition, corn grain needs to dry for 3-5 days in direct sunlight to attain the necessary standard corn moisture content (Antu, 2016).

Solar drying is introduced as a simple drying method utilizing solar radiation energy, which is the most cost-effective and easy-to-implement approach. Solar dryers are equipped with closed chambers featuring transparent walls, and a rectangular heat collector painted black at its base. This configuration enables the dryer to shield itself from contaminants (Suherman *et al.*, 2018). Solar drying has several benefits over open sun drying, including a decreased risk of product loss (Silva *et al.*, 2021). However, solar dryers are still subject to various restrictions, such as their limited use during the day when there is enough solar radiation and their reliance on climatic factors that impact the drying rate (El Hage *et al.*, 2018). Solar radiation is periodic, and its intensity varies with time and location, which can consequently reduce the effectiveness of drying materials using solar energy (Imre, 2014).

Utilizing a hybrid solar drier is one way to solve the sun-drying deficit. This dryer consists of a solar dryer connected to a traditional energy source, like biomass or LPG gas. Because it does not have to rely solely on solar energy, the solar dryer can still be used in inclement weather or even during the rainy season. Additionally, drying can be carried out continually to save time (Gudiño-Ayala and Calderón Topete, 2014). Air pollution, which has a number of negative health effects, can be caused by emissions from burning biomass. These emissions contribute to a rise in atmospheric gases such as volatile and semi-volatile organic compounds (VOC), CO, NO_x, CH_2O, CH_4, and SO_2 (Gomez *et al.*, 2022).

By using LPG, which is more environmentally friendly, air pollution can be solved. There hasn't been much research done yet on hybrid drying of agricultural products, particularly corn. In order to dry corn at different temperatures, namely 40°C, 50°C, and 60°C, a hybrid solar dryer with LPG gas was used in this study.

2. Materials and methods

2.1 Materials and equipment

The main materials needed in this study were 5 kg of corn grains taken from the corn garden, Faculty of Animal Husbandry and Agriculture, Diponegoro University, Semarang. The tools utilized in this study were a hybrid solar dryer that included a drying chamber unit covered in UV plastic to withstand heat from sunlight in the drying chamber, as shown in Figure 1, and a blower and burner unit, as shown in Figure 2. A total of 3 kg of LPG were used for burner or heating purposes. Three pieces of equipment were required to analyze the initial moisture content of maize kernels: an oven, a porcelain cup, and a desiccator. Measurement devices utilized in this study included the KRISBOW Electronic Kitchen Scale 5 kg Slim Plate digital scales, the BONAD SM206 Solar Power Meter, the KRISBOW Temperature and Relative Humidity meter, and the KRISBOW air velocity meter Flexible Thermo Anemometer Unit.

Figure 1. Solar dryer.

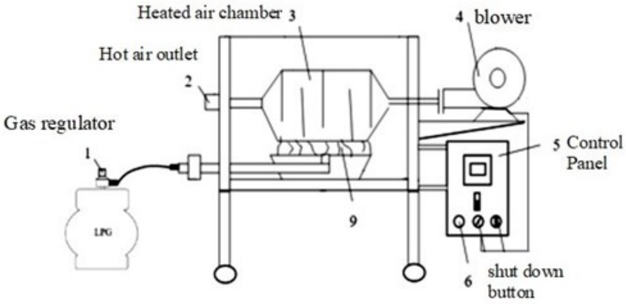

Figure 2. Blower and burner unit schematic.

2.2 Experimental procedures

The shelled corn grain was measured for moisture content using the oven method in accordance with guidelines from the Association of Official Agricultural Chemists (AOAC) (Nielsen, 2017). This involved drying the corn in an oven at 105°C until the weight of the corn kernels remained constant. Additionally, the initial moisture content of the corn grain was 26%.

The experiment was conducted in the Chemical Engineering Research Laboratory, Department of Chemical Engineering, Diponegoro University, under sunny conditions with few clouds. Three different drying techniques were implemented, starting at 9:00 a.m. and continuing until the corn kernel moisture percentage was less than 14%. The first method involved conventional drying by sun-drying the corn grains in an open area under direct sunlight. The second technique utilized solar dryers for natural drying without additional LPG energy. The third technique involved hybrid solar dryers with

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additional LPG energy to maintain the drying chamber temperature according to the specified variable temperature.

The drying process using the hybrid solar dryer began with calibrating the equipment for 15-30 mins. This involved turning on each component to activate the drying equipment components, such as fans and LPG burners. The LPG burner was adjusted according to the proposed drying temperature variables (40°C, 50°C, and 60°C). If the LPG burner was not used, the airflow connection from the LPG burner outlet to the input hole of the dryer could be disconnected. Once the calibration was completed, 100 grams of corn kernels were weighed and evenly spread on each experimental tray. Every 30 mins, data from the experiment were collected. Data on the mass of the kernels were collected using a digital scale. Relative humidity, temperature, and solar radiation intensity were measured using a relative humidity meter, temperature gauge, and solar radiation intensity meter (in the surrounding air and the drying chamber). Meanwhile, the steps for conventional drying techniques were more or less the same as drying using a hybrid solar dryer, with the only difference being the placement of the material under direct open sun drying.

2.3 Moisture content analysis

To calculate the water content, the weight of dry and wet corn grains must be obtained. Furthermore, Equation (1) was used to calculate the moisture content of corn grain based on % wet (M) (Nidhi, 2015), Mi is the mass of wet corn grain (g) while Md is the mass of dry corn grain (g).

$$\mathrm{M} = \frac{Mi-Md}{Mi} \times 100 \qquad (1)$$

2.4 Drying-rate analysis

The drying rate can be calculated by dividing the weight loss of corn grain in the next two measurements by the drying time interval (t), as shown in equation (2) (Nidhi, 2015).

$$DR = \frac{M_i-M_d}{\Delta t} \qquad (2)$$

2.5 Determination of dryer efficiency

The dryer efficiency (η_d) can be defined as the proportion of the total energy used for moisture removal from the product compared to the total energy entering the drying chamber (Suherman, Susanto, Zardani *et al.*, 2020).

$$\eta_d = \frac{m_w.hfg}{Iat+Et+m_fC_v} \times 100\% \qquad (3)$$

Where η_d is the drying efficiency (%), m_w is the total mass of water evaporated (kg), hfg is the latent heat of evaporation of water, I is solar radiation (W/m^2), A is the area of the solar collector (m), t is the total drying time (s), E is the energy consumption by the blower (kJ), mf is the total mass of fuel used (kg), and Cv is the calorific value of LPG (kJ/kg).

2.6 Color analysis

Color analysis was performed using a Minolta CR 300 Chromameter (Minolta Camera Co. Japan. No 82281029). The instrument was initially calibrated using a white ceramic plate and at regular intervals during the analysis (Saenz *et al.*, 2020). A glass cell containing a sample is placed above a light source and post-processing (Alamu *et al.*, 2023). Initially, the color of the fresh corn was assessed, while the color of the dried product was monitored at 60-min intervals during the drying process (Mondal *et al.*, 2022). Data from L, a, and b color measurements were recorded on the paper sheet tool. The L value represents the brightness parameter which has values from 0 (black) to 100 (white). The a value was the reflection of light, which produces a red-green mixed chromatic color with a value of +a (positive) from 0-100 for red and -a (negative) value from 0 -(-80) for green. The b notation indicates a mixed chromatic color of blue - yellow with a value of +b (positive) 0 - 70 for yellow and a value -b (negative) 0 - (-70) for blue.

2.7 Proximate analysis

Proximate analysis can be used to represent the crude components of a food product. Proximate analysis was carried out using the following methods: water content (Horwitz and Latimer, 2005), ash content (SNI-01-3451-2011), fat content (Horwitz and Latimer, 2005), protein content (Horwitz and Latimer, 2005), and carbohydrate content.

For ash content, 5 g of powdered sample were placed into a pre-weighed crucible (W_1). Subsequently, the crucible was placed in a muffle furnace at 550-600°C for 5-6 hrs. After the ashing process, the crucible was cooled within a desiccator and then re-weighed (W_2). The ash content was then determined using the following equation (Alam *et al.*, 2023).

$$\%\,Ash = \left(\frac{W_1-W_2}{W}\right) \times 100\% \qquad (4)$$

Where W_1 is the weight of ash with crucible (g), W_2 is the weight of empty crucible (g), and W is the weight of sample (g).

The fat content was analyzed using the Soxhlet apparatus, employing petroleum ether as the solvent for extraction. A 5 g oven-dried sample was placed in a crucible (W_2), previously weighed dry (W_1). The Soxhlet extractor, connected to a round-bottom flask filled 3/4 with petroleum ether at 40-60°C. The sample in the crucible was subjected to reflux extraction with petroleum ether for 3 hrs. After extraction, the crucible was dried in an oven at 105°C for 24 hrs, cooled in a desiccator, and re-weighed (W_3). The fat percentage was then calculated using a formula (Akpoghelie *et al*., 2022).

$$\% Fat = \left(\frac{W_2 - W_3}{W_2 - W_1}\right) \times 100\% \qquad (5)$$

Where ($W_2 - W_3$) is the weight loss of the sample (extracted fat) and ($W_2 - W_1$) is the original weight of the sample.

The Kjeldahl method was employed to determine crude protein, involving wet digestion, distillation, and titration. Multiplying the measured nitrogen content by 6.25 yielded the total protein content (Akter *et al*., 2024).

$$\% Nitrogen = \frac{(sample\ titre - blank\ titre \times normality\ of\ acid \times 14 \times 100)}{sample\ weight \times 1000} \qquad (6)$$

The protein percentage was determined by using above equation to the total nitrogen percentage.

$$\%\ \text{Protein} = \%\ \text{Nitrogen} \times 6.25 \qquad (7)$$

For the carbohydrate content, one gram of powdered dried maize sample was mixed with 50 mL of distilled water in an Erlenmeyer flask and left to stand for about 1 hr with occasional stirring. After filtration and washing the residue with an additional 50 mL of distilled water, the sample underwent hydrolysis with 10% HCl under reflux for 2.5 hrs. The resulting hydrolysate was neutralized with 0.1 N NaOH, filtered, and diluted to 100 ml with distilled water. This solution was then analyzed for reducing sugar using Fehling's titration method. Starch content in the sample was determined using a specific equation (Alam *et al*., 2023).

$$\%\ \text{Starch} = \text{Reducing sugar (\%)} \times 0.9 \qquad (8)$$

2.8 Aflatoxins analysis

The determination of the presence of aflatoxins B1, B2, G1, and G2 is conducted using HPLC to analyze the quality and content of aflatoxins. The procedure was adjusted to extract aflatoxin using a mixture of acetonitrile and acetic acid (9:1) as the solvent, along with additional agitation steps. Samples were ground and homogenized using a Grinder. A 2 g sample was transferred into a 50 mL centrifuge tube with 5 mL of distilled water, vortexed for 1 min, and then 5 mL of the extraction solution was added after 5 mins of standing. The mixture was agitated at 250 rpm for 15 mins and vortexed for 3 mins using a Vortex machine. Following this, the mixture was combined with 1.32 g of anhydrous $MgSO_4$ and 0.2 g of NaCl, vortexed for 1 min, and agitated at 250 rpm for 5 mins. Before injection, the upper organic layer was filtered through a 0.45 µm nylon syringe filter after centrifugation for 5 mins at 4000 rpm. The filtered extract was then injected into the high-performance liquid chromatography (HPLC) apparatus at a volume of 0.5 mL (Kaburi *et al*., 2023). The sample extracts were analyzed using an isocratic method with a mixture of 65% water, 25% methanol, and 10% acetonitrile as the mobile phase. The column was maintained in a column oven at 45°C with a flow rate of 1.0 mL/min to ensure optimal resolution of the aflatoxins. Both the sample and standard solutions were injected at a volume of 10 µL (Sirhan *et al*., 2014).

3. Results and discussion

3.1 Moisture content analysis

The drying curve of corn grain is shown in Figure 3 as time (h) vs. moisture content (%). The initial measurement of the water content in corn grain used the oven method, and the result was 26%. Figure 3 illustrates how the corn's water content will drop as drying time increases. The Indonesian National Standard states that corn grain may contain up to 14% water. Corn grain moisture content in open sun drying, solar drying without extra heating, and hybrid solar dryer with temperature variables of 40°C, 50°C, and 60°C was determined to be 13.95%, 13.75%, 13.65%, 13.45%, and 13.65%.

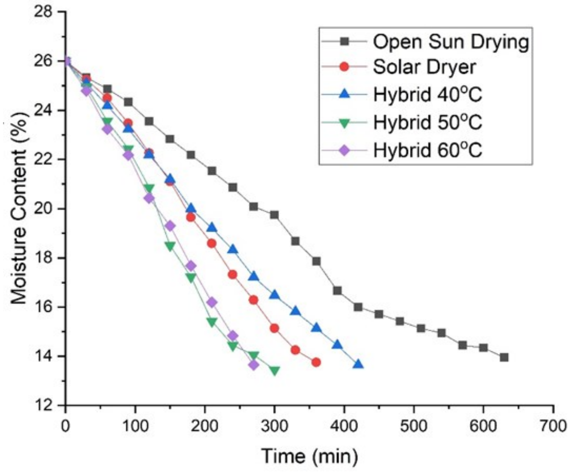

Figure 3. Corn grain moisture content curve in different drying methods.

With a drying time of 4.5 hrs and a temperature range of 60°C, hybrid solar drying produced the fastest drying results, with a moisture content of 13.65%. The drying temperature and drying time are inversely related; the higher the drying temperature, the quicker the drying process (Kosasih *et al*., 2020). This was due to the amount of liquid that evaporates from a material's surface increasing with the amount of heat energy applied, accelerating the process by which water diffuses from the interior of the material to the surface and causing a rapid drop in the moisture content of corn grains.

3.2 Drying rate curve analysis

The drying rate of the corn grain using hybrid solar drying and open sun drying is shown in Figure 4. The experiment was conducted until corn water content was under 14% so the time drying for each variable for the temperature in hybrid solar drying and open sun drying was different. The average drying rate for open sun drying, solar drying, and hybrid solar drying at 40°C, 50°C, and 60°C was 0.212 g/min, followed by 0.364 g/min, 0.318 g/min, 0.439 g/min, and 0.477 g/min. The solar hybrid dryer with a temperature variable of 60°C had the fastest drying rate, which was followed by dryers with temperature variables of 50°C, unheated solar dryers, and solar hybrid dryers with temperature variables of 40°C. Open sun drying had the slowest drying rate. This was due to the fact that temperature was the primary factor influencing the drying rate, the greater the drying temperature, the faster the drying rate (Deeto *et al.*, 2018). Due to the hotter weather when the drying experiment was conducted using a solar dryer without extra heating, the drying rate of the solar dryer in this study was faster than that of the solar hybrid at 40°C. As a result, the drying process moved forward more quickly.

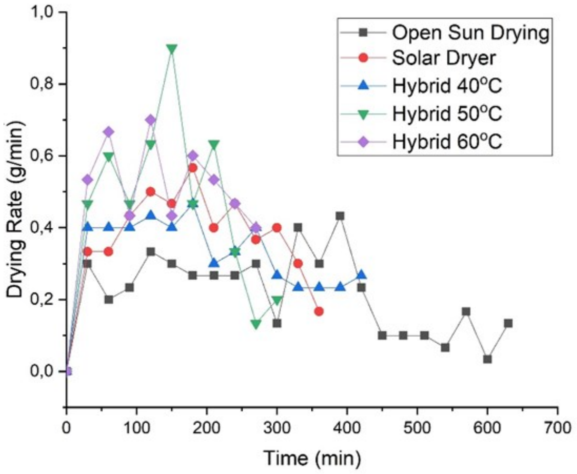

Figure 4. Corn grain drying rate curve in different drying.

It was discovered that when drying time increased, the drying rate dropped. This was because a material's water content was likewise dropping (Ando *et al.*, 2016). So, the fastest drying rate happens early in the drying process and subsequently gradually slows down for each variable. This was due to the large amount of water, in this case grains that are categorized as free water, that was present on the material's surface. Contrarily, as the material dries and is given more time, water attached to its cells is left behind, causing the substance's water content to gradually decrease until it is constant. Because it is in the liquid phase and fills the holes of the cells and the gaps between them, the free water content evaporates quickly. Bound water, however, sticks to the cell wall hygroscopically and is more difficult to remove. The decreasing drying rate indicated that corn grain drying occurs during the falling-rate period, which is a characteristic shared by most agricultural products (Misha *et al.*, 2013; Suherman, Hadiyanto, Susanto, Rahmatullah *et al.*, 2020).

3.3 Dryer efficiency analysis

According to research findings, as shown in Figure 5, the effectiveness of open sun drying varies from 0.35% to 6.38%, that of solar drying from 2.72% to 6.18%, and that of hybrid solar drying on variables at 40°C from 3.24% to 9.17%. At a variable temperature of 50°C, the solar hybrid drying efficiency ranges from 2.54% to 10.06%. The solar hybrid drying efficiency ranges from 4.37% to 10.40% at a variable temperature of 60°C. Due to variations in solar intensity from day to day, the measured drying efficiency statistics fluctuated. The amount of sunlight, incoming air velocity, intake air temperature, the drying area, and the type of glass used in solar collectors all have a significant impact on drying efficiency (Suherman, Widuri, Patricia *et al.*, 2020).

According to Figure 5, the solar hybrid's best drying efficiency occurs at 60°C with an initial drying time of 10.40%. This was because the drying chamber's hot air has an impact on drying efficiency. After all, with enough hot air, moisture in the material can be evaporated (Utari *et al.*, 2022). Additionally, drying effectiveness also declines as solar intensity rises. The efficiency decreases as solar intensity increases. This was because the drying system's energy input was not used to its full potential. Because the input energy and the energy utilized for drying are not equal, there is a low efficiency (Putra and Pitri, 2013). The capacity of the material might also have an impact on dryer efficiency.

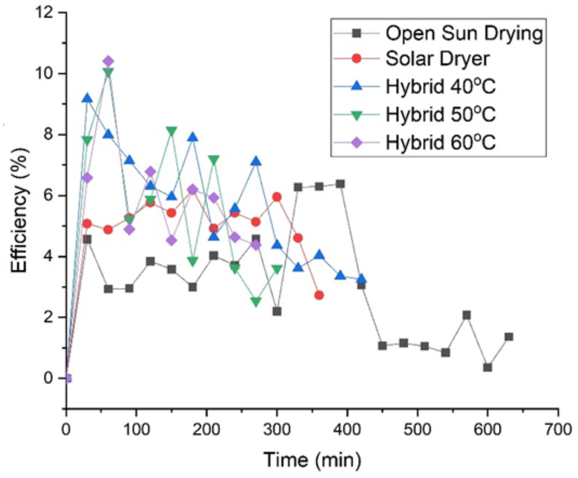

Figure 5. Dryer efficiency curve for different drying methods.

The dryer becomes less effective when less material is dried because less water evaporation occurs from the material. With a larger capacity and the same airflow, the residence time of air inside the dryer increases, allowing more water to be evaporated (Djaeni *et al*., 2015; Anum *et al*., 2017). The amount of material that needs to be dried must therefore be increased, using thermal storage or the drying air may be circulated, to improve drying performance in terms of energy efficiency (Sansaniwal *et al*., 2018).

3.4 Color analysis

The color degree test was performed because color is what people are most attracted to in feed and food products. Based on Table 1, the average values for the findings of color analysis on the items are L = 46.48, a = 4.58, and b = 25.37. The white, gray, and black achromatic colors are produced by reflected light, which is represented by the L value. A value in the L notation ranges from 0 to 100. When the L value was higher, it was closer to white, and when it was lower, it tended to be blacker or darker (Haerudin and Aprilia, 2019). According to test results, corn seeds are brightly colored with a hint of darkness. A positive value for red and a negative value for green is used to represent the chromatic color of the red-green mixture in the notation a (Rahmawati and Sri, 2020). The analysis's findings indicate that corn kernels, with an average value of +4.58, have a positive value, making corn more likely to be red. A mixed blue-yellow chromatic color with a positive b value for yellow and a negative b value for blue is indicated by the b notation (Rahmawati and Sri, 2020). With an average b score of +25.37, the research findings for corn grain indicate that corn is more likely to be yellow.

3.5 Proximate content analysis

The results of the identification of nutritional components such as water content, ash content, protein, carbohydrates, and fat in corn kernels were carried out in the proximate test as shown in Table 2. The identification reveals that after drying, the moisture level of corn grain was 13.8%; this moisture content satisfies the minimum 14% quality criterion of the Indonesian National Standard. A food product will be more sensitive and have a shorter shelf life if it has a higher water content (Amanto *et al*., 2015). Foodstuffs' water content affects their freshness as well since a high water content facilitates the growth of bacteria, molds, and yeast, which can alter the composition of food ingredients.

Ash content in corn seed was 1.24%, this content was within the 2.0% of the Indonesian National Standard. The mineral content of a food item, which might take the form of either organic salts or inorganic salts, is related to the ash content in that ingredient. Drying at high temperatures will rapidly evaporate water, potentially preventing minerals from being carried away by the drying air altogether; in other words, the ash content in the material may increase (Suherman, Hadiyanto, Susanto, Utami *et al*., 2020).

Table 2. Proximate analysis results.

Parameter	Units	Results
Water	%	13.8
Ash	%	1.24
Proteins	%	7.76
Fat	%	4.40
Carbohydrates	%	72.8

The protein content of the corn grain tested was 7.76%, which was above the maximum allowed by the Indonesian National Standard of 7.5%. Protein is a crucial component of meals for the body because it not only serves as a source of energy but also as a constituent and regulator. It's crucial to analyze the protein level of food ingredients to ascertain their overall protein content.

Following investigation, it was discovered that corn grains have a fat content of 4.40%, which complies with the Indonesian National Standard's requirement for a minimum fat content of 3.0%. Additionally, compared to carbs and protein, which are present in practically all food items with varying quantities, fat is a more efficient source of energy. The carbohydrate content of corn grain was 72.8%. Since corn contains 70% carbs, it can be utilized to replace rice's carbohydrates in this study due to the study's high carbohydrate concentration in corn grain.

Table 1. Grains color test result.

No.	Sample	Parameter	Results			Method
			L	a	b	
1	Grains	Color	43.93	+7.66	+28.49	Digital colorimetry
			44.16	+4.66	+24.64	
			50.65	+2.34	+16.59	
			47.02	+3.59	+23.17	
			44.15	+1.95	+18.04	
			49.01	+7.28	+41.29	

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3.6 Analysis of aflatoxin content

Aflatoxin types B1, B2, G1, and G2 were identified because they are the four most prevalent and dangerous kinds of aflatoxins. Following drying, from Table 3 it can be seen that the amount of each type of aflatoxin in corn kernels was 0.5 and the total amount of aflatoxin was 2.00. Because the amount of aflatoxin generated was substantially lower than the amount required by the Indonesian Standard of Corn for food and feed of 50 ppb or 50 g/kg, this level was ideal as a food or feed ingredient.

The water content in corn grain, which was less than 14% and fits the requirements so that aflatoxins cannot easily grow, maybe the cause of this extremely low aflatoxin content. Additionally, the area around Semarang City's natural air was highly helpful in minimizing aflatoxin contamination. Based on measurements, the relative humidity of the environment during the drying process averaged 64.89%, whereas *Aspergillus flavus* can easily grow in food at a relative humidity of the environment of 80% or more (Nino and Eduardus, 2020).

Table 3. Aflatoxin analysis results.

Parameter	Units	Results
B1	µg/kg	<0.5
B2	µg/kg	<0.5
G1	µg/kg	<0.5
G2	µg/kg	<0.5
Total aflatoxin	µg/kg	<2.00

Cabrera-Meraz *et al.* (2021) argue that the pre-treatment, drying duration, kind of drying technique, and type of material being dried all have an impact on the quality and quality of materials or products. The goal of drying was to reduce the amount of water in the material to a point where the growth of bacteria, yeast, or mold that might cause decay, such as the creation of aflatoxins, can be stopped. This will preserve the material's quality and allow it to be stored for a longer period (Dushimeyesu *et al.*, 2023).

4. Conclusion

The solar hybrid dryer with a variable temperature of 60°C, a drying period of 4.5 hrs, a moisture content of 13.65%, and a drying rate of 0.477 g/min produced the fastest drying results. At 60°C, at the start of the 10.40% drying time, solar hybrid drying was most effective. After drying, corn grains have a moisture content of 13.8%, ash of 1.24%, protein of 7.76%, fat of 4.40%, and carbohydrate of 72.8%. After drying, the levels of each type of aflatoxin in corn seeds were well below the Indonesian Standard.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

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