Design of bed dryer for sweet corn seeds (*Zea mays saccharata* L.)

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Abstract. One of the problems faced by corn farmers in Indonesia is the unavailability of corn dryers during rainy season. As a result, seed production decreased both in terms of quantity and quality. This study aims to design and introduce a bed seed dryer. Bed dryers are considered since it is simpler and cheaper. The dryer is designed for a capacity of 500 kg of corn, with corn cobs with a gasification combustion system as its fuel. This study also compared the effect of bed drying and sun drying (with two different floor materials; tarpaulin mat and concrete base) on dried-corn germination rate. The results showed that the designed dryer was able to reduce the moisture content from 22% (w.b.) to 14% (w.b) for 30 hours. The drying temperature is kept below 43°C and had no significant difference with the drying temperature of the sun drying. The germination rate of all samples has met the National standard for corn seed (SNI 01-03920-1995), which was 92%. The self-fabricated bed dryer has the potential to dry corn seed as good as using sun while retaining its quality.

1. Introduction

Corn is the second-largest carbs-producing crop in Indonesia after rice. Owing to their diverse uses, corn has become one of the strategic and important commodities [1]. For many years, farmers in Indonesia have been breeding corn seeds. The seeds resulting from the breeding have been preserved and are still alive today. For farmers, corn seeds are not only things that produce plants, but more than that. So that until now, farmers keep exchanging seeds for agricultural purposes. Corn seeds have also become a medium of social relations among farmers, not only because seeds have social value but also very high economic value. This understanding has led to the commercialization of seeds carried out by industry. With the legalization of patent rights on seeds selling, the seed industry can control most of the seed distribution in Indonesia.

Aldillah et al. [2] summarized data on the development of corn agribusiness, said that the demand for corn both for the world and domestic markets increased every year. Thus, there is often a limited supply of vegetable horticulture, due to constrained area and low stock of good quality seeds. The lack of concrete action from government policies to face the rapid demands make the corn imports become widely developed in Indonesia [3]. One of the factors causing the slow rate of corn production is the post-harvest yield losses in terms of quality and quantity. Based on the survey conducted by Directorate of Postharvest Food Crops of Indonesia [4], the losses of corn yields, especially in Central Java Province, is still relatively high, reaching 4.97%, with losses details of 1.69% in harvesting stage, 0.3% in corn shelling stage, and 2.9% in drying stage.
UD. Agro Nusantara Prima, which is located at Randubelang, Bangunharjo, Sewon, Bantul, 55187, Yogyakarta, Indonesia, is one of the SMEs (Small and Medium-sized Enterprises) providing corn seeds. This SME has a floor facility for drying 1500 m$^2$, a storage warehouse with a capacity of 40 tons. The equipment owned is a measuring device for water content and a blower that is used during the rainy season. This blower serves as an emergency measure to help reduce moisture content temporarily during the rainy season. The breeding area in the Bantul area is 10 Ha, with a production of 10 tonnes per year. This SME manages more than 200 breeder farmers located in the Bantul area. In this SME, waste in the form of damaged corn is used for animal feed. Meanwhile, corn cobs waste has only been sold at low prices. The price of this corn cobs is IDR 5,000.00 per sack. Until now, the main business of this SME is sweet corn seeds. The marketing of these seed products covers the islands of Java (West Java and Central Java, Kalimantan (East Kalimantan), Sumatra, and Gorontalo.

As mention before, the drying process done in this SME is still a simple sun drying. This drying process is uneasy to maintain since temperature and humidity tend to fluctuate. Furthermore, there has been a risk of being contaminated due to dust, insects, birds, or other animals [5]. Therefore, this activity aims to design and implement post-harvest technology, namely bed drying machines with good performance, ease of operation and maintenance, and affordable prices for vegetable horticultural seed SMEs. The bed dryer would use corn cob as the fuel for heat generator. This study also compared the effect of bed drying and sun drying (with two different floor materials; tarpaulin mat and concrete base) on its drying temperature and corn germination rate.

2. Materials and methods

2.1. Materials
The material used in the test is sweet corn in the form of cobs. The variety of corn is “hibrida”, originally from Yogyakarta, Indonesia. The average moisture content of corn prior drying process is around 30\% (wb).

2.2. Bed dryer design
The manufacturing process of the bed dryer was carried out in the Laboratory of Energy and Agricultural Machinery, Department of Agricultural Engineering, Universitas Gadjah Mada, Yogyakarta. The bed drying system includes several important parts incuding: the frame, heating element, drying chamber, the thermostat, and the blower.

2.2.1. Frame. The frame serves as the structure base of the dryer where all other components are attached. It has rectangular shape and constructe with 1.2 mm thickness of steel iron. The dryer has two sections: the drying compartment and the supporting stand.

2.2.2. Heating element. The heater supplies heat for the corn drying, in which the energy generated from gasifier generator.

2.2.3. Drying chamber. The drying chamber is the part where the corn to be dried are put and where the drying process takes place. The drying chamber is part of drying compartment, and positioned above the drying plenum. A perforated plate is placed between the plenum and drying chamber, and used to hold the corn load and distribute hot air below from plenum to drying chamber uniformly.

2.2.4. Thermostat. Thermostat maintains and regulates the temperature with specified range in the drying chamber.

2.2.5. Blower. The blower is used for distributing the heat, by sucking ambient air from the surrounding to the heater housing. The blower also discharges heated air from the heater housing to
the drying chamber. An axial flow fan is used to ensure the proper distribution of heat to the drying chamber.

2.3. Evaluation of drying performance
The self-fabricated dryer was then tested with the distribution of air flux and air temperature. A drying test with corncob was conducted to evaluate the performance of the dryer. The drying temperature and product moisture content during the drying process was analyzed by plotting the data in a graph. The evaluation of germination rate was carried out for two weeks (fourteen days) using a tray with a tissue base. In this evaluation, 100 samples of dried sweet corn kernels were used which were randomly selected. To keep the germination process developing properly, watering the kernels regularly every morning during the germination period is carried out. In the end of germination period, the number of seeds that grow was counted.

3. Results and discussions

3.1. Gasifier
The heater used in this drying process was a gasification combustion system. The gasifier has a capacity of 10 kg per hour of dry corn cobs. The principle of this generator is that the material is conditioned at high temperature with minimum air. Therefore, the process of switching from the solid into the gas phase of CO and CH$_4$ occurs. The gas resulted from this process is then burned, so fire resulted from the process is cleaner. The heat generated from this generator can then be sucked in and pushed into the plenum of the bed dryer.

![Figure 1](image1.png)

**Figure 1.** The process of gasifier generator (a) Corncob as the material; (b) setting process of inlet air; (c) combustion; (d) clean fire as gasifier process result

Figure 1 shows the process of gasifier generator using corn cobs. Corn cob is a biomass feedstock with direct potential as an energy resource that can be used in gasification systems for energy production. It has a number of advantages over other biomass feedstocks including its dense and uniform nature as well as its increased energy content and its low sulfur and nitrogen concentrations [6]. Previous study [7] evaluated corn cob with regard to its gasification-related characteristics based on fuel analysis. The results presented showed that corn cob is a biomass feedstock suitable for gasification due to its low moisture content and metallic elements. In this study, the performance of
bed dryer designed was evaluated using LPG as the preliminary experiment, before it was operated using gasifier generator.

3.2. Components design of bed dryer

3.2.1. Components design of bed dryer. Load capacity of the machine, \( W = 500 \text{ kg} \) Bulk density of corn (Brooker et al., 1973) = 684 kg/m³

Volume of corn [9], \( V_c = \frac{\text{mass of corn}}{\text{density of corn}} = \frac{500 \text{ kg}}{684 \text{ kg/m}^3} = 0.731 \text{ m}^3 \)

According to the standard, the width required for bed dryer \( (w_d) \) is 1 m, and the height \( (h_d) \) is 0.6 m (0.1 m for plenum, 0.4 m for corn depth, and 0.1 m is the distance between dryer surface and corn surface). Therefore, the dimension of drying chamber is calculated below:

Volume of drying chamber, \( V_d = V_c \times \frac{w_d \times h_d}{w_d \times h_d} = 0.731 \text{ m}^3 \times 0.6 = 1.827 \text{ m} (\text{approx. 2 m}) \)

\[ V_d = w_d \times l_d \times h_d = 1 \times 2 \times 0.6 = 1.2 \text{ m}^3 \]

3.2.2. Determining the blower capacity. According to National Standardization Agency of Indonesia [10], the physical properties of corn for bed drying process is stated as below:

\[ M_0 = 30 \% \text{w.b.} \]
\[ M_1 = 14 \% \text{w.b.} \]
\[ k = 3 \% \text{/h} \]

where \( M_0 \) and \( M_1 \) is the moisture content of corn before and after drying process, respectively. While \( k \) is the drying rate.

\[ t = \frac{M_0 - M_1}{k} = \frac{30 - 14}{3} = 5.3 \text{ h} \]

\[ M_0 = 30 \% = \frac{30}{100} \times 500 = 150 \text{ kg} \]

Total solid, \( t_s = 500 - 150 = 350 \text{ kg} \)

\[ M_1 = 14\% = \frac{14}{100} x 350 = 56.98 \text{ kg} \]

Therefore, moisture content that must be evaporated is

\[ W_m = \frac{150 - 56.98}{53} = 17.44 \text{ kg/h} \]

From psychrometric chart, the information obtained were:

Air temperature before heating process, \( T_0 = 30 \text{°C} \)

Humidity ratio of air before heating process, \( Rh_0 = 70\% \)

Specific humidity before heating process, \( \omega_0 = 19 \text{ g moisture / kg d.a.} \)

Entalphy before heating process, \( E_0 = 78.406 \text{ kJ/kg d.a.} \)

Air temperature after heating process, \( T_1 = 42\text{°C} \)

Specific humidity after heating process, \( \omega_1 = 25 \text{ g moisture / kg d.a.} \)

Entalphy after heating process, \( E_1 = 92.048 \text{ kJ/kg d.a.} \)

Therefore, specific humidity during drying process is

\[ \omega = 25 - 19 = 6 \text{ g moisture / kg d.a.} \]

The air needed for the drying process \( (W_{d.a}) \) = \[ \frac{W_m}{\omega} \text{ kg/m}^3 \]

\[ \frac{17.44}{6} = 2.854.18 \text{ kg d.a./h} \]

The density of air at air temperature of \( T_0 = 30\text{°C} \), \( \rho_a \) is known to be 1.164 kg/m³

Therefore, the blower needed for drying process needed to have capacity of \[ \text{kg d.a./h} \]
Blower capacity \( \frac{W_{d.a}}{\rho_a} = \frac{2854.18}{1.164} = 2452.04 \text{ cm}\text{h} \)

3.2.3. Determining the LPG consumption. Based on the information from psychrometric chart, the enthalpy change during heating process, as much as:
\[ \Delta E = E_{1} - E_{0} = 92.048 - 78.406 = 13.642 \text{ kJ/kg d.a.} = 38,936.65 \text{ kJ/h} \]
Heating efficiency desired for this drying process is put to 90%. To obtain this number, Suplly energy provided by the LPG will be
\[ HE = 1.10 \times 38,936.65 = 42,830.31 \text{ kJ/h} \]
Calorific value of LPG is known to be 47,269 kJ/kg
Therefore, the LPG consumption for dryin process will be \( \frac{47,269}{42,830.31} = 1.104 \text{ kg/h} = 5.89 \text{ kg} \)

Figure 2 shows the fabricating process of bed drying. The drying chamber of the bed dryer was designed for a capacity of 500 kg for corn cobs. The height of the plenum space is 10 cm, where this space is used to provide uniformity to the air flowed. To strengthen the material, an indentation technique is made on this plate so that the plate will be strong enough when a drying operator is standing on the plat. This bending technique also reduces the amount of energy required to weld and the cost of cutting the material. The type of blower used is high pressure to penetrate the space between the corn kernels. This blower requires 500 watts of power and a voltage of 220 volts, so it is economical and can still be used for electricity at the SME level.

Figure 2. Self-fabricated bed dryer

Corn is harvested at the peak of the rainy season, making preservation difficult and causing most of the grains to perish. This results in scarcity in the supply of the grains which leads to subsequent hunger and malnutrition. Meanwhile corns are routinely seen dumped in villages and major cities during the peak of harvest. Therefore, it is necessary that corn are properly dried and stored to yield better quality grains and ensures availability and viability [9].

3.3. Evaluation on drying performance
The evaluation of drying performance including the evaluation of temperature distribution and moisture content during drying process, as well as the germination index.

3.3.1. Temperature distribution. Table 1 presented the temperature and air velocity distribution of drying air. The hot air produced from this dryer reaches 60°C. During the the drying process, the highest temperature reached for corn kernels is around 43°C. This result is stil acceptable, considered the standar set by the National Standardization Agency of Indonesia [10], in which the maximum temperature among corn cobs during drying is 65°C.
Table 1. Temperature and velocity distribution of drying air

| Position | Velocity (m/s) | Air temperature (°C) |
|----------|---------------|----------------------|
|          | Left  | Middle  | Right  | Left  | Middle  | Right  |
| Front    | 0.80  | 1.73    | 1.00   | 53.17 | 52.43   | 52.33  |
| Centre   | 0.43  | 0.64    | 1.03   | 46.57 | 45.80   | 43.10  |
| Backside | 1.33  | 1.73    | 1.66   | 32.93 | 30.77   | 30.37  |

3.3.2. Moisture content. The test was carried out with the drying chamber filled with corn cobs, with an initial weight of 500 kg. Initial moisture content is 22% (wet basis). Drying process is carried out for 38 hours. The final moisture content of the drying product is 14.8%, with the drying rate of this machine is 0.7% / hour. According to the standard set by the National Standardization Agency of Indonesia [10], the maximum moisture content of dried corn is 14%. According to Khanali et al. [11] Shelled corn (Zea mays L.) is one of the major grains that is usually harvested at considerably high moisture content and has to be dried to a moisture content of around 0.14 d.b for long-term preservation.

![Graph showing moisture content vs. time](image)

Figure 3. Corn moisture content during drying process

3.3.3. Germination rate. Table 2 shows the results of germination rate evaluation. The result of the seed quality test showed that the germination capacity of the dried seeds for bed dryer results was still above 90%, while the required SNI seed germination capacity was 85% (SNI 01-03920-1995). The germination can decrease due to errors from drying. When compared to the germination index of corn seeds with tarpaulin drying which reaches 95%, this seed is still quite good.

Table 2. Germination index evaluation

| Drying process                      | Percentage grown cernels (%) |
|-------------------------------------|------------------------------|
| Sun drying (tarpaulin mat)          | 95                           |
| Sun drying (concrete base)          | 82                           |
| Bed drying                          | 92                           |

4. Conclusion
From the study, it can be concluded that the application of this bed dryer can help the SME of sweet corn seed business in the drying process. The biomass waste from corn cobs can be used as a heating
source for drying air. The bed dryer can be used effectively as a drying machine that meets the standards for seed production set by the National Standard of Indonesia (SNI).

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