Cabya (*Piper retrofractum* Vahl) fruit under open sun drying: drying behavior and modeling of thin layer drying kinetics

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Abstract. Cabya (*Piper retrofractum* Vahl) fruit is one of *Piper* species, which indigenously grown in East Java Province, Indonesia, has huge utilizations but lacks postharvest processing investigation. The present study aimed to quantify moisture removal characteristic as well as to determine thin layer drying kinetics model, which represent the drying behavior of cabya fruit under open sun drying. The effect of blanching pre-treatment on the drying behavior of cabya fruit was also evaluated. The cabya fruit at the red edible maturity stage with 68.57±2.20% (wb) of average moisture content were used as raw material. The moisture content, drying rate, and moisture ratio during drying (18 and 24 h in three and four days) were measured and calculated. The calculated moisture ratio data were fitted to the twelve commonly used thin drying kinetics models. The results indicated that blanching pre-treatment affected greatly on drying behavior, i.e., final moisture content, drying rate, and drying kinetics. From all twelve drying kinetics models investigated, Midilli et al. model is found as the best one to depict cabya fruit drying kinetics in both blanching treated and untreated, based on its coefficient of correlation (*R*), root mean square error (*RMSE*) and reduced chi-square (*χ²*).

1. Introduction

The genus *Piper* consists of 700 species and widely distributed in various parts of the world [1]. According to Mgbeahuruike et al. [2] who reviewed bioactive compounds from numerous *Piper* species, the genus has numerous medicinal and traditional uses. In Southeast Asia like Indonesia and Thailand, one of *Piper* species which widely cultivated is cabya (*Piper retrofractum* Vahl) or known as Javanese long pepper. The species is cultivated for their fruit, which is usually dried and used as a spice, seasoning, and herbal refreshment. Dried cabya has a unique pungent taste and aroma, which commonly used for various therapeutic utilisations. Traditionally, cabya used as a digestive aid, stimulant, carminative, intestinal disorders, and postpartum pre-treatment in women [3]. Some reports have been made on medicinal purpose and utilization of cabya, e.g., anti-obesity [4], hepatoprotective [5], antioxidative effect [6], anticancer and antifungal [3, 7], antileishmanial [8], and antituberculosis [8, 9].

The research regarding cabya fruit still mainly focused on its content, medicinal purpose, and utilization, but less attention on postharvest processing that may affect its content, i.e., drying process. The cabya fruits are perishable and prone to rapid deterioration when improperly handled after harvest due to high moisture content, i.e., 67-75% (wb). Drying process can stop the growth of microorganisms, prevent enzymatic and non-enzymatic chemical reactions, as well as extend shelf life of the product. Few researches have been conducted to evaluate the drying process of cabya fruit in
various drying methods. Tambunan et al. [10] used a freeze-drying method to dehydrate cabuya fruit and concluded that the quality of dry products slightly lower than raw material. Takahashi et al. [11] evaluated the effect of open sun and oven drying on physicochemical and antioxidant characteristics of cabuya fruit.

In Indonesia, especially in East Java Province as one of the main producers, cabuya fruit was harvested by farmers at red edible maturity and then dried under open sun drying. The common practices of cabuya fruit postharvest handling by farmers is the fruit dried under open sun drying for 3-4 days with blanching pre-treatment. According to farmers, hot water blanching is performed to speed up the drying process. Hot water blanching is the most popular and also commercially adopted method due to its simplicity and inexpensive [12]. However, to the best of the authors' knowledge, there is no report has been made regarding the drying behavior, i.e., moisture content alteration, drying rate, and moisture ratio during drying, as well as determination of thin-layer drying kinetics model of cabuya fruit under open sun drying.

Currently, series of studies regarding several methods of cabuya fruit drying process is extensively conducted at Department of Agricultural Engineering, Universitas Brawijaya, Indonesia, and the detailed quantification of drying behavior in a traditional way is needed as a benchmark for further researches. The objective of the present study was to quantify moisture removal characteristic as well as to determine thin layer drying kinetics model which represent drying behavior of cabuya fruit under open sun drying. In addition, the effect of blanching pre-treatment on the drying behavior of cabuya fruit was also investigated.

2. Materials and methods

2.1. Material preparation

The fresh cabuya fruit obtained from farmers in Pasuruan, East Java Province, which harvested at the red edible maturity stage (figure 1) with 68.57±2.20% (wb) of average moisture content according to the standard gravimetric method by AOAC [13]. The fruits were randomly harvested from different trees in July 2019. The ten fruits then grouped into two groups, i.e., consist of five fruit each, for open sun drying without and with blanching pre-treatment prior to the drying process. Each fruit from each group was considered as replication. The average initial mass of each sample fruit was 2.34±0.36 g. The blanching pre-treatment was conducted using a soaking method, i.e., the fruit soaked into hot water with 80-100°C of temperature for 10 min according to common traditional practices by farmers. The cabuya fruit without and with blanching pre-treatment then dried under open sun drying.

Figure 1. The red edible maturity stage of cabuya fruit.
2.2. Open sun drying of cabya fruit

Open sun drying process was conducted on 15-18 July 2019 in Malang, located at 7° 95’S and 112° 61’E in the middle part of East Java Province, Indonesia. The without and with blanching pre-treatment fruits were placed onto a wire mesh tray and located on the open-top floor of an eight-floor building, which positioned at 1 m from the floor to have good exposure to direct solar radiation. The drying process started at 09.00 and continued till 15.00 of local time for consecutive three and four days, i.e., 18 h and 24 of total drying duration for the with and without blanching pre-treatment fruits, respectively. The solar radiation during the open sun drying process was measured by the digital light meter (Sunche, HS1010 series) and approximately converted into W/m², i.e., 0.0079 W/m² per Lux. In addition, the ambient humidity, ambient temperature, and fruit temperature during the drying process were recorded. A thermo hygrometer (EXTECH, 444731, China) with reading accuracy of ±0.1% and ±1°C was used to measure ambient humidity and temperature. An infrared thermometer (Krisbow, IR Dual Laser, Indonesia) with reading accuracy ±1°C was used to measure fruit temperature.

The fruit weighed in every 60 min except for the first hour for every 30 min using precision balance (PL303 series, Mettler Toledo, USA). The weight measurement on regular basis was used to determine moisture content alteration of the fruit during the drying process according to the standard gravimetric method by AOAC [13] in wet basis.

2.3. Drying rate alteration

The drying rate alteration during the drying process was calculated using Eq. 1 [14], where \(M_t\) and \(M_{t+\Delta t}\) were the moisture content at \(t\) and moisture content at \(t+\Delta t\), respectively, and \(t\) is drying time. The calculated drying rate then presented graphically with drying time and moisture ratio for both without and with blanching pre-treatment fruit.

\[
DR = \frac{M_{t+\Delta t} - M_t}{\Delta t}
\]

2.4. Mathematical modeling of drying kinetics

The moisture ratio of cabya fruit during drying experiment was determined using Eq. 2 [14], where \(M_t\), \(M_i\), and \(M_e\) were the moisture content of product at time \(t\), initial moisture content of the product, and equilibrium moisture content of the product, respectively. The equilibrium moisture content was reached when three consecutive weights of the product were constant, indicating the end of the drying process.

\[
MR = \frac{M_t - M_i}{M_e - M_i}
\]

Twelve commonly-used drying kinetics models were used, as listed in table 1. Nonlinear regression analysis was performed by using Microsoft Excel 2010 (Microsoft, USA) with the Add-In Solver feature, i.e., Generalized Reduced Gradient (GRG) Nonlinear, to obtain the fittest constants for the respective model. Three statistical parameters, namely coefficient of determination (\(R^2\)), reduced mean square of deviation (\(\chi^2\)), and root mean square error (RMSE), were used for selecting the fittest model with the first as main criteria and the other two indicating the goodness of model to fit the data. The latter two statistical parameters were calculated as follow, respectively, with where \(MR_{ex,i}\) is the i-th experimentally observed moisture ratio, \(MR_{pr,i}\) is the i-th predicted moisture ratio, \(N\) is the number of observations and \(np\) is the number constants.

\[
RMSE = \sqrt{\frac{\sum_i (MR_{ex,i} - MR_{pr,i})^2}{N}}
\]

\[
\chi^2 = \frac{\sum_i (MR_{ex,i} - MR_{pr,i})^2}{N - np}
\]
\[
\chi^2 = \frac{\sum_{i=1}^{N} (MR_{ex,i} - MR_{pr,i})^2}{N - np}
\]  
(3)

\[
RMSE = \left[ \frac{1}{N} \sum_{i=1}^{N} (MR_{pr,i} - MR_{ex,i})^2 \right]^{1/2}
\]  
(4)

Table 1. The considered drying kinetics models [14, 15]

| No | Model name | Model |
|----|------------|-------|
| 1  | Lewis      | \(MR = \exp(-kt)\) |
| 2  | Page       | \(MR = \exp(-kt^\nu)\) |
| 3  | Modified Page | \(MR = \exp\left( -(kt)^\nu \right)\) |
| 4  | Henderson-Pabis | \(MR = a \exp(-kt)\) |
| 5  | Logarithmic | \(MR = a \exp(-kt) + c\) |
| 6  | Midilli et al. | \(MR = a \exp(-kt^\nu) + bt\) |
| 7  | Two-term   | \(MR = a \exp(-k,t) + b \exp\left( -k,t \right)\) |
| 8  | Two-term Exp. | \(MR = a \exp(-kt) + (1-a) \exp(-kat)\) |
| 9  | Mod. Henderson-Pabis | \(MR = a \exp(-kt) + b \exp\left( -gt \right) + c \exp\left( -ht \right)\) |
| 10 | Wang and Singh | \(MR = 1 + at + bt^2\) |
| 11 | Diffusion approach | \(MR = a \exp(-kt) + (1-a) \exp(-kt)\) |
| 12 | Verma et al. | \(MR = a \exp(-kt) + (1-a) \exp(-gt)\) |

3. Results and discussions

3.1. Environmental condition

The open sun drying of cabya fruit was carried out under the weather conditions of Malang, Indonesia. The hourly evolution of solar radiation, measured ambient temperature, relative humidity, as well as the temperature of fruit during the typical four days experimental run are shown in figure 2 and figure 3. The solar radiation varied from 161 W/m² to 971 W/m² on the horizontal plane during the experimental run. For four days of the drying process, the solar radiation increased sharply from the morning and reached the maximum at about 12.00-13.00 of local time, and decreased in the afternoon. The ambient air temperature and relative humidity were ranged from 24-32°C and 31.1-63.7%, respectively, during the experimental run. The evolution of daily solar radiation was responsible for the variations of the ambient temperature and relative humidity during the drying process. The ambient relative humidity decreased with increasing solar radiation, and at the same time, the ambient temperature increased. The maximum ambient temperature was found at about 11.00-14 of local time, while the minimum for the ambient relative humidity. The results from figure 2 and figure 3 also
reveal that the cabya fruit temperature, without and with blanching pre-treatment, both has a higher temperature than ambient temperature.

![Figure 2. Solar radiation on a horizontal plane and cabya fruit temperature during the experimental run](image)

**Figure 2.** Solar radiation on a horizontal plane and cabya fruit temperature during the experimental run

![Figure 3. Ambient temperature and relative humidity during the experimental run](image)

**Figure 3.** Ambient temperature and relative humidity during the experimental run

3.2. Drying curves

Figure 4 presents the variation of experimentally measured moisture content in function of drying time of cabya fruit under open sun drying for both fruit without and with blanching pre-treatment. It can be seen that measured moisture content decreased with different patterns as affected by different pre-treatment prior to the drying process. The fruit with blanching pre-treatment has a more significant negative slope of moisture content curves if compared with the fruit without blanching pre-treatment. The fruit with blanching pre-treatment also made shorter drying time periods to remove considerably higher contained moisture, i.e., for the first six hours of drying time, the fruit with blanching pre-treatment has reached 21.43±4.94% (wb) of average moisture content, whereas 54.37±2.69% (wb) of average moisture content for the fruit without blanching pre-treatment. After 18 and 24 hours of the open sun drying process, the fruit without and with blanching pre-treatment has 22.41±3.65% (wb)
and 5.19±2.61% (wb) of final average moisture content, respectively. The lower final average moisture content of cabya fruit with blanching pre-treatment may be partially due to disruption of the cellular structure and soften of the fruit texture caused by hot water blanching, which eased the resistance to water flux and increased moisture movement and water mass transfer during drying process [16, 17].

**Figure 4.** Variation of moisture content with drying time of cabya fruit under open sun drying

3.3. Drying rate

Figure 5 depicted the variation of drying rate in function of drying time of cabya fruit under open sun drying for both fruit without and with blanching pre-treatment. It can be seen that the initial drying process of cabya fruit was proceeded by warming up period, which indicated by increasing of drying rate and followed by falling rate period, which indicated by decreasing of drying rate. Figure 5 also revealed that blanching pre-treatment has a significantly higher drying rate at the initial phase of the drying process, i.e., the first six hours of the drying process. The drying rate data also confirmed why the significant difference was found on the variation of measured moisture content for fruit without and with blanching pre-treatment during the drying process.

**Figure 5.** Drying rate alteration with the drying time of cabya fruit under open sun drying
Figure 6 showed a comparison between the variation of drying rate in function of moisture ratio of cabya fruit without and with blanching pre-treatment under open sun drying. It can be seen that untreated cabya fruit was released its moisture more evenly during the drying process, i.e., about one-third of its contained moisture was released for each six hours drying session per day. The significant difference was found for cabya fruit with blanching pre-treatment, i.e., about three-fourth of its contained water was released at the first six hours of drying session alone. The phenomenon could be attributed to the fact that fruit with blanching pre-treatment increased the drying rate by assisting moisture loss from the internal regions of the fruits to its surface during the drying process [18].

![Figure 6. Comparison of drying rate with moisture ratio at different pre-treatment of cabya fruit under open sun drying](image)

3.4. Mathematical modeling
The experimentally measured moisture content data from both fruit without and with blanching pre-treatment were transformed into moisture ratio expression. The moisture ratio curves data then fitted into twelve considered drying kinetics models listed in table 1 using nonlinear regression, which performed using Microsoft Excel 2010 (Microsoft, USA). Tables 2 and 3 summarized model constants as well as statistical parameters obtained from nonlinear regression. The most suitable drying kinetics model was evaluated and selected based on the three statistical parameters, i.e., coefficient of
determination ($R^2$), reduced mean square of deviation ($\chi^2$), and root mean square error (RMSE). The most suitable drying kinetics model to define thin layer drying behavior of cabya fruit under open sun drying was selected with consideration to the highest coefficient of determination ($R^2$) values, and the lowest reduced mean square of deviation ($\chi^2$) and root mean square error (RMSE) values.

**Table 2.** Model constants and statistical parameters for open sun drying of without blanching pre-treatment cabya fruit

| Model Name       | Model Constant                  | $R^2$ | RMSE | $\chi^2$ |
|------------------|---------------------------------|-------|------|----------|
| Newton           | $k = 0.00155$                   | 0.97408 | 0.09618 | 0.00961  |
| Page             | $k = 0.00001; n = 1.7759$       | 0.99752 | 0.01839 | 0.00037  |
| Modified Page    | $k = 0.00156; n = 1.00000$      | 0.97408 | 0.09618 | 0.00999  |
| Henderson-Pabis  | $a = 1.14958; k = 0.00181$      | 0.96316 | 0.07462 | 0.00601  |
| Logarithmic      | $a = 5.76740; k = 0.00018; c = -4.71620$ | 0.97049 | 0.09314 | 0.00976  |
| Midilli et al.   | $a = 1.00031; k = 0.00001; n = 1.77099; b = -1.02e^{-05}$ | 0.99764 | 0.01778 | 0.00037  |
| Two term         | $a = 0.56467; k0 = 0.00168; b = 0.56457; k1 = 0.00168$ | 0.96932 | 0.07732 | 0.00702  |
| Two term Exp.    | $a = 0.00048; b = 3.23826$     | 0.97408 | 0.09631 | 0.01002  |
| Wang-Singh       | $a = -0.00108; b = 2.42e^{-07}$ | 0.98846 | 0.04901 | 0.00259  |
| Diffusion        | $a = -18.88862; k = 0.00374; b = 0.94094$ | 0.99567 | 0.02592 | 0.00076  |
| Verma et al.     | $a = -10.11366; k = 0.00385; g = 0.00344$ | 0.99568 | 0.02599 | 0.00076  |

**Table 3.** Model constants and statistical parameters for open sun drying of with blanching pre-treatment cabya fruit

| Model Name       | Model Constant                  | $R^2$ | RMSE | $\chi^2$ |
|------------------|---------------------------------|-------|------|----------|
| Newton           | $k = 0.00353$                   | 0.98912 | 0.05676 | 0.00338  |
| Page             | $k = 0.00029; n = 1.43559$      | 0.99861 | 0.01351 | 0.00020  |
| Modified Page    | $k = 0.00353; n = 1.00000$      | 0.98912 | 0.05676 | 0.00356  |
| Henderson-Pabis  | $a = 1.10008; k = 0.00389$      | 0.98656 | 0.04418 | 0.04418  |
| Logarithmic      | $a = 1.13948; k = 0.00335; c = -0.05932$ | 0.98944 | 0.03670 | 0.00157  |
| Midilli et al.   | $a = 0.99345; k = 0.00023; n = 1.47046; b = 7.60e^{-06}$ | 0.99864 | 0.01317 | 0.00021  |
| Two term         | $a = -6.93513; k0 = 0.00764; b = 7.92951; k1 = 0.00674$ | 0.99837 | 0.01444 | 0.00026  |
| Wang-Singh       | $a = -0.00246; b = 1.47e^{-06}$ | 0.98922 | 0.03748 | 0.00155  |
| Diffusion        | $a = -18.88518; k = 0.00730; b = 0.95411$ | 0.99837 | 0.01447 | 0.00024  |
| Verma et al.     | $a = -10.34352; k = 0.00743$    | 0.99837 | 0.01448 | 0.00024  |
As shown in table 2 and 3, it can be seen that $R^2$ values were ranged from 0.94701 to 0.99558 and 0.98656 to 0.99864 for cabya fruit without and with blanching pre-treatment, respectively. In addition, for cabya fruit without blanching pre-treatment, the RMSE values were varied between 0.02301 and 0.10448, and $\chi^2$ values between 0.00065 and 0.01207. In case of cabya fruit with blanching pre-treatment, the RMSE values were varied between 0.01317 and 0.05768, and $\chi^2$ values between 0.00020 and 0.00368. The statistical parameter values indicate that the twelve proposed drying kinetics models satisfactorily predict the experimental moisture ratio of cabya fruit under open sun drying.

Based on statistical parameter results, i.e., the highest value of $R^2$ and the lowest value of RMSE and $\chi^2$, it can be concluded that Midilli et al. model is the most suitable and adequate model to fit experimental data originated from the open sun drying, and to describe the open sun drying of cabya fruit for both without and with blanching pre-treatment. Figure 7 depicted ideal accordance between the experimental moisture ratio and the predicted moisture ratio by employing Midilli et al. model. The Midilli et al. model is a semi-empirical model first proposed by Midilli et al. [19] in 2002 and widely used for evaluating drying kinetics of numerous agricultural products at various drying methods, especially open sun drying. A recent report in which Midilli et al. also satisfactorily describe drying kinetics of agricultural products under the open sun was reported by Essalhi et al. [20], who conducted the drying process of grapes under an indirect solar dryer and open sun drying.

![Figure 7. Moisture ratio with the drying time of cabya fruit under open sun drying: Measured and predicted with Midilli et al. model](image)

**4. Conclusions**

The drying characteristics of cabya fruit were studied under open sun drying. The effect of hot water blanching pre-treatment on the drying behavior of cabya fruit was also investigated. The twelve commonly used drying kinetics models were used to depict the drying characteristic of cabya fruit. The moisture content reduces as drying time increases and finally retains less than 24% (wb) and 6% (wb) of moisture content for cabya fruit without and with blanching pre-treatment, respectively. The blanching pre-treatment greatly affected the drying rate and final average moisture content of cabya fruit after 18 h of open sun drying, i.e., higher drying rate and lower final average moisture content. Among twelve proposed drying kinetics models, the Midilli et al. model selected as the most suitable model to describe the open sun drying of cabya fruit for both without and with blanching pre-treatment.
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