*Research article*

# Moisture Content Prediction of Dried Young Papaya during Drying and Water Absorption

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**Abstract** The effective use of agricultural products and the development of processed foods with guaranteed safety and quality are needed in Kampong Cham Province, Cambodia. Young papaya is an important agricultural product in this area. Dried young papaya is one of the preserved foods. The main objective in this paper was to provide basic information for the optimization of drying process. Two types of young papaya, raw or fresh papaya and blanched young papaya, were used in this study to investigate the influence of drying pretreatment that is, blanching, on the changes in the moisture content during drying and water absorption. The hot air-drying characteristics of each sample were measured at three temperatures (30, 50, and 70°C), three air velocities (1, 2, and 3 m/s), and a relative humidity of 40%. The examination of the effects of temperature, air velocity, and blanching on the drying of samples resulted in the drying characteristics of the raw sample being very similar to that of the blanched sample. A linear relationship existed in the moisture content range between the initial moisture contents and 500% (d.b.). The exponential model was applied to predict the changes in the moisture contents of samples below500% (d.b.) at each drying condition. The drying rate constants in the period above or below500% (d.b.) were increased with increasing air temperature and air velocity and expressed as a linear function of both temperature and air velocity, respectively. The water absorption characteristics of the dried young papaya and the dried blanched young papaya that were dried after blanching were investigated at three temperatures (20, 30, and 40°C). Blanching before drying of the sample had the effect of slowing the water absorption rate. The water absorption rate constant tended to increase with increasing soaking temperature.

**Keywords** young papaya, drying characteristics, water absorption characteristics, blanching, temperature and air velocity dependency, prediction model of moisture content

## INTRODUCTION

The effective use of agricultural products and the development of processed foods with guaranteed safety and quality are needed in Kampong Cham Province, Cambodia. Young papaya is an important agricultural product in Kampong Cham. Recently, in Japan, young papaya has been recognized as a regional biological resource for the diversification of primary producers into processing and distribution, and it is cultivated in the Kanto region.

Although young papayas can be eaten fresh, they can also be used after drying. Drying is one of the oldest preservation methods and does not require special machines or devices in almost all cases. Drying not only increases the shelf life of the product but also increases its food value. Dried young papaya has been sold as a processed food. Usually, dried young papayas are rehydrated to some degree before eating. Pretreatments, for example, blanching, are often added to enhance the quality of dried vegetables. Blanching, a mild thermal treatment similar in temperature-time intensity to pasteurization, is applied to fruits and vegetables primarily to inactivate enzymes that catalyse degradation reactions (Park et al., 2014). Lydia et al. (2017) investigated the effects of pretreatments, including soaking in certain solutions and drying methods, on some qualities of dried mango fruit.

Some researchers (EI-Aouar et al., 2003; Lagunez-Rivera et al., 2007; Fernando et al., 2008; Lemus-Mondaca et al., 2009; Udomkun et al., 2015) have measured and analysed the drying kinetics of papaya. Almost all previous papers have reported the drying characteristics of mature papaya. However, very few studies have measured the hot air-drying characteristics of young papaya with different air velocities, as performed in this study. In previous references (EI-Aouar et al., 2003; Lagunez-Rivera et al., 2007; Fernando et al., 2008; Lemus-Mondaca et al., 2009; Muramatsu et al., 2012; Udomkun et al., 2015), some mathematical models (drying models) were used to describe the relationship between the moisture content of the sample and drying time. Optimum drying and water absorption models, including the values of parameters, are particularly useful for easily predicting the changes in the moisture content of materials. Therefore, determination of the optimum model is important for practical use.

In this study, we examined the hot air-drying characteristics of two types of young papaya: raw and blanched young papaya at three different temperatures and air velocities. In addition, the water absorption (rehydration) characteristics of dried and dried blanched young papaya were also measured at three different temperatures. The results obtained in this study provide important basic information and are needed to optimize drying processes and to design dryers.

## OBJECTIVE

The objectives of this study were 1) to examine the effects of air temperature, air velocity, and blanching treatment on the drying characteristics of the sample, 2) to investigate the influence of blanching treatment and soaking temperature on the water absorption characteristics of the sample, 3) to derive suitable mathematical drying and water absorption models to describe changes in moisture content with time, and 4) to obtain empirical equations to express the relationship between the drying or water absorption rate constants and the measurement conditions.

## METHODOLOGY

### Sample Preparation

Young papaya (Carica papaya) imported from Thailand was purchased at a supermarket in Tokyo, Japan. Before the test, the young papayas were stored in a refrigerator at approximately 4°C. After the peel was removed from the young papaya, the young papaya was cut into a rectangular parallelepiped (50 mm in depth, 20 mm in width, and 2.5 mm in height) by using a commercial vegetable cutter. We call this sample the “raw sample” in this manuscript. For the blanching treatment, the raw young papayas were immersed in boiling water at 100°C for 30 s and cooled in cold water at 0°C for 2 min. We describe this sample as the “blanched sample” in this manuscript.

### Hot Air-drying Test

The changes in the moisture content of raw and blanched samples using the hot-air drying method were measured at three temperatures (30, 50, and 70°C), three air velocities (1, 2, and 3 m/s), and a relative humidity of 40%. A constant temperature and humidity chamber (KCL-2000, EYELA Co., Ltd.) was used as a drying chamber in this study to maintain air temperature and humidity during the drying test. The air velocity was adjusted with a fan (CUDC 12B4, Japan Servo Co., Ltd.) connected to a DC power source (AD-8735D, A&D Co., Ltd.). A stainless-steel basket (50 mm in depth, 20 mm in width, and 2.5 mm in height with a 3 mm aperture) was utilized as a sample tray. Approximately 100 g of sample was placed on the sample tray and dried in the drying chamber. The sample tray was removed out from the drying chamber at a preset time to measure the mass change of the sample. The mass change of the sample was measured with a digital balance (GX-4000, A&D Co., Ltd.) and recorded at time intervals every 20 min for the initial 2 h and every 30 min from 2 h until the sample's moisture content became 15% (d.b.). After weighing the sample mass, the sample tray was quickly returned to the drying chamber. When the moisture content of the sample reached approximately 15% (d.b.), the mass of dry matter in the sample was determined using a forced hot air oven (VTEC-166, Isuzu Seisakusho Co., Ltd.) at 105°C for 24 h. Utilizing the measured value of the mass of dry matter in the sample, the changes in mass during drying were converted to changes in the moisture content of the sample.

### Measurement of Water Absorption Characteristic

To measure the water absorption characteristics, the raw and blanched samples were dried by the hot-air drying method at a temperature of 30°C, an air velocity of 3 m/s, and a relative humidity of 40% with a drying apparatus as previously mentioned. We describe the dried sample that was added to the blanching treatment before drying as the “dried blanched sample” in this manuscript. Each dried sample was stored in a polyethylene bag and kept for 5-10 days at room temperature before the water absorption test to ensure the uniform distribution of moisture in the bag and equilibrate the moisture content of the sample. The moisture content changes of the samples soaked in water were measured at three different temperatures (20, 30, and 40°C). Approximately 1 g of sample was immersed in a glass beaker containing 200 ml distilled water in a water bath at a preset temperature. At time intervals every 1 min for the initial 6 min, 2 min from 6 to 10 min, 5 min from 10 to 30 min, and then 30 min from 30-90 min, the sample was removed from the water, and the surface of the sample was wiped with Kimwipes® (S-200, Nippon Paper Crecia Co., Ltd.) to remove residual liquid. These measurements were conducted until the moisture content of each sample reached the same moisture content as fresh young papaya (approximately 94% (w.b.)). The moisture content of the sample after soaking was determined by the oven method (105°C for 24 h).

## RESULTS AND DISCUSSION

### Hot Air-drying Characteristics

Fig. 1 (a) shows the changes in the moisture content of each sample at an air velocity of 3 m/s and a temperature of 30°C. The moisture contents of both samples decreased linearly with elapsed time from the initial moisture content to approximately 500% (d.b.) and decreased, exhibiting a gentle downward curve below 500% (d.b.). As shown in Fig. 1 (b), the slope of the relationship between the drying rate and moisture content at each sample was changed at approximately 500% (d.b.). Fig. 1 indicates that the drying characteristics, i.e., changes in the moisture content and drying rate of the raw sample had almost the same trend as the blanched sample and the hot air-drying process of both samples had two periods, i.e., the first and second periods. Similar tendencies were obtained for other measurement conditions not shown in Fig. 1.

In the first period (above 500% (d.b.)), the moisture contents decreased linearly with an increase in elapsed time. Therefore, the measured data at each sample and each measurement condition were fitted to Eq. (1).

$$M = -k_1 t + M_0 \tag{1}$$

where $M$: the moisture content (% (d.b.)), $M_0$: the initial moisture content (% (d.b.)), $k_1$: the drying rate constant in the first period (1/min), and $t$: the drying time (min). The measured value of $M_0$ and the values of $k_1$ determined by using the least squares method and the root mean square error (RMSE) are shown in Table 1. In the second period (below 500% (d.b.)), because the drying rate decreased linearly with decreasing moisture content, the following exponential model (Muramatsu et al., 2012) was used to analyse the changes in moisture content.

$$\frac{M - M_e}{500 - M_e} = \exp\left[-k_2\left(t - t_c\right)\right] \tag{2}$$

where $M_e$: the equilibrium moisture content (% (d.b.)), $k_2$: the drying rate constant in the second period (1/min), and $t_c$: the drying time at a moisture content of 500% (d.b.) (min). The value of $t_c$ in Eq. (2) was calculated from Eq. (1). The measured drying data in the second period were fitted to Eq. (2) using the nonlinear least squares method, and the values of $k_1$ and $M_e$ were determined at each sample and each measurement condition. The values of the parameters and RMSE of Eq. (2) are given in Table 2. The comparisons of the observed moisture contents with the results calculated from Eqs. (1) and (2) at an air velocity of 3 m/s for the raw sample are shown in Fig. 2. The solid lines in Fig. 2 show the results calculated from Eq. (1) or (2). As shown in Fig. 2, the measured results matched well with the calculated results. Under all measurement conditions, the changes in the moisture content of the sample caused by hot air-drying could be estimated by Eqs. (1) and (2).

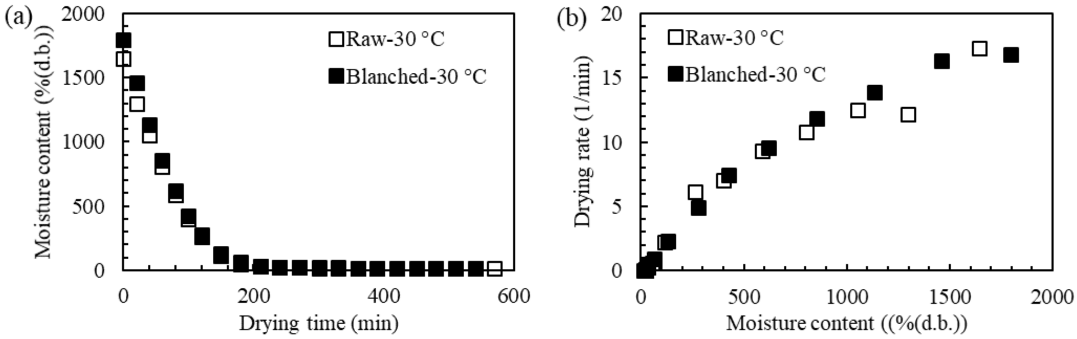


**Fig. 1 Drying curve of each sample at an air velocity of 3 m/s and a temperature of 30°C (a) Changes in moisture content and (b) drying characteristics curves**

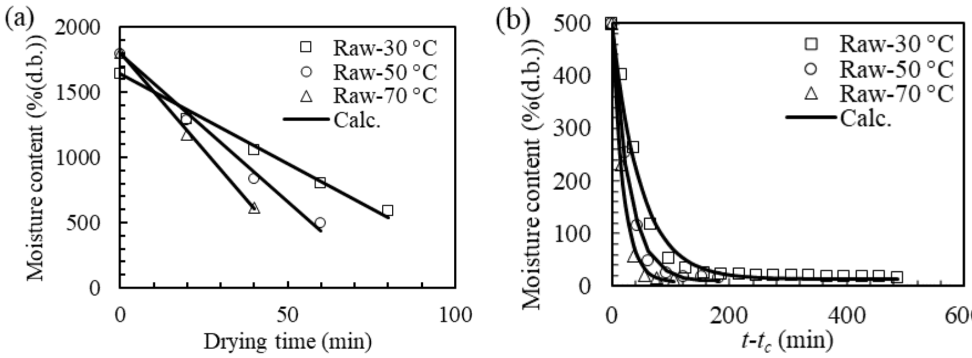


**Fig. 2 Comparisons of observed moisture content changes with the results calculated from (a) Eq. (1) and (b) Eq. (2) at air velocity of 3 m/s for the raw sample during drying**

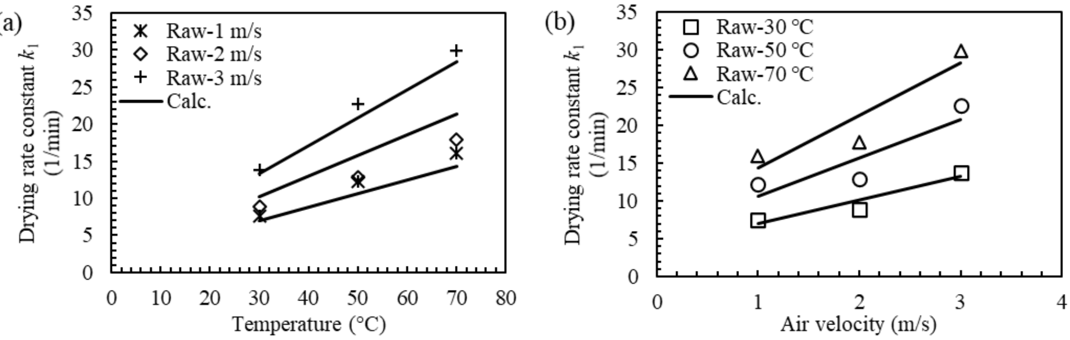


**Fig. 3 Relationships between the drying rate constants in the first period (above a moisture content of 500 % (d.b.)) of the raw sample and (a): temperature and (b): air velocity**

**Table 1 Initial moisture content ($M_0$), drying rate constant in the first period (above 500 % (d.b.)) ($k_1$), and root mean square error (RMSE) of Eq. (1) under each set of measurement conditions**

| Sample | Air velocity (m/s) | Temperature (°C) | $M_0$ (% (d.b.)) | $k_1$ (1/min) | RMSE (% (d.b.)) |
|---|---|---|---|---|---|
| Raw sample | 1 | 30 | 1525 | 7.572 | 19.2 |
| | | 50 | 1625 | 12.23 | 20.9 |
| | | 70 | 1615 | 16.03 | 2.6 |
| | 2 | 30 | 1359 | 8.909 | 25.8 |
| | | 50 | 1253 | 12.87 | 14.7 |
| | | 70 | 1331 | 17.83 | 3.0 |
| | 3 | 30 | 1643 | 13.76 | 47.0 |
| | | 50 | 1797 | 22.63 | 54.3 |
| | | 70 | 1800 | 29.92 | 20.0 |
| Blanched sample | 1 | 30 | 1926 | 9.189 | 27.8 |
| | | 50 | 1963 | 14.35 | 31.6 |
| | | 70 | 2008 | 19.77 | 10.2 |
| | 2 | 30 | 1807 | 10.69 | 63.2 |
| | | 50 | 1576 | 15.12 | 12.9 |
| | | 70 | 1661 | 21.51 | 2.2 |
| | 3 | 30 | 1794 | 15.31 | 39.3 |
| | | 50 | 1896 | 23.82 | 47.3 |
| | | 70 | 2302 | 37.15 | 18.1 |

*The values of $M_0$ were measured data. The values of $k_1$ were determined by the least squares method based on the measured results in the first period (above 500 %(d.b.)). The values of RMSE were calculated from the measured results and the results calculated from Eq. (1).*

As shown in Tables 1 and 2, the drying rate constants varied with temperature and air velocity. Figure 3 represents the temperature and air velocity dependencies of $k_1$ for the raw sample. Although the values of $k_1$ for both samples were not much difference between 1 m/s and 2 m/s, the values of $k_1$ at 2 m/s were higher than that at 1 m/s for each temperature. The first period (above 500% (d.b.)) was considered as the apparent falling drying rate period including the sample shrinkage, i.e., the constant drying rate period from the measurement results of changes in the sample surface temperature. In the constant drying rate period, the drying or water vaporization rate depends on the heat transfer coefficient, the thicknesses of boundary layers for temperature and air velocity, and so on. Since there was not much difference in the values of heat transfer coefficient and the thicknesses of boundary layers between 1 m/s and 2 m/s, the effect of air velocity on the drying rate in the first period might be weak below 2 m/s. The $k_1$ and $k_2$ of each sample increased almost linearly with the increase in air velocity at each temperature and the increase in the temperature at each air velocity. Therefore, we derived the following empirical equation to express the temperature and air velocity dependencies.

$$k_{1\ \mathrm{or}\ 2} = aTV + bT + cV + d \tag{3}$$

where $T$: temperature (°C), $V$: air velocity (m/s), $a$, $b$, $c$, $d$: constant. The regression results for Eq. (3) are shown in Table 3. The solid lines in Fig. 3 are the results calculated from Eq. (3). The $k_1$ and $k_2$ values of each sample were represented as a function of both temperature and air velocity by Eq. (3).

**Table 2 Drying time at a moisture content of 500 % (d.b.) ($t_c$), drying rate constant in the second period (below 500 %(d.b.)) ($k_2$), equilibrium moisture content ($M_e$), and root mean square error (RMSE) of Eq. (2) under each set of measurement conditions**

| Sample | Air velocity (m/s) | Temperature (°C) | $t_c$ (min) | $k_2$ (1/min) | $M_e$ (% (d.b.)) | RMSE (% (d.b.)) |
|---|---|---|---|---|---|---|
| Raw sample | 1 | 30 | 135 | $1.224\times10^{-2}$ | 16.09 | 11.2 |
| | | 50 | 92 | $2.058\times10^{-2}$ | 9.542 | 14.2 |
| | | 70 | 70 | $2.940\times10^{-2}$ | 5.132 | 14.0 |
| | 2 | 30 | 96 | $1.708\times10^{-2}$ | 14.37 | 12.8 |
| | | 50 | 59 | $2.549\times10^{-2}$ | 8.183 | 12.0 |
| | | 70 | 47 | $3.649\times10^{-2}$ | 5.153 | 16.2 |
| | 3 | 30 | 83 | $2.052\times10^{-2}$ | 13.36 | 16.0 |
| | | 50 | 57 | $3.438\times10^{-2}$ | 8.604 | 11.8 |
| | | 70 | 43 | $5.157\times10^{-2}$ | 5.226 | 16.1 |
| Blanched sample | 1 | 30 | 155 | $1.136\times10^{-2}$ | 13.65 | 23.0 |
| | | 50 | 102 | $1.845\times10^{-2}$ | 5.345 | 21.9 |
| | | 70 | 76 | $2.785\times10^{-2}$ | 0.02047 | 24.5 |
| | 2 | 30 | 122 | $1.759\times10^{-2}$ | 14.63 | 9.9 |
| | | 50 | 71 | $2.302\times10^{-2}$ | 5.895 | 18.8 |
| | | 70 | 54 | $3.315\times10^{-2}$ | 0.4881 | 23.6 |
| | 3 | 30 | 85 | $1.931\times10^{-2}$ | 11.37 | 18.4 |
| | | 50 | 59 | $3.643\times10^{-2}$ | 9.005 | 10.0 |
| | | 70 | 49 | $4.249\times10^{-2}$ | 5.628 | 26.7 |

*The values of $t_c$ were calculated from Eq. (1) by using the values of $M_0$, $k_1$, and $M$=500. The values of $k_2$ and $M_e$ were determined by the nonlinear least squares method based on the measured results in the second period (below 500 %(d.b.)). The values of RMSE were calculated from the measured results and the results calculated from Eq. (2).*

**Table 3 Values of the parameters and root mean square error (RMSE) of Eq. (3) for each drying rate constant and sample**

| Drying rate constant (1/min) | Sample | $a$ (s/min·°C·m) | $b$ (1/min·°C) | $c$ (s/min·m) | $d$ (1/min) | RMSE (1/min) |
|---|---|---|---|---|---|---|
| $k_1$ | Raw | $9.626\times10^{-2}$ | $8.708\times10^{-2}$ | $2.687\times10^{-1}$ | 1.238 | 2.052 |
| | Blanched | $1.407\times10^{-1}$ | $7.896\times10^{-2}$ | -1.541 | 3.613 | 2.469 |
| $k_2$ | Raw | $1.736\times10^{-4}$ | $2.163\times10^{-4}$ | $-1.305\times10^{-3}$ | $1.962\times10^{-3}$ | $1.438\times10^{-3}$ |
| | Blanched | $7.535\times10^{-5}$ | $3.151\times10^{-4}$ | $2.234\times10^{-3}$ | $-1.735\times10^{-3}$ | $2.251\times10^{-3}$ |

*The values of a, b, c, and d were determined by the least squares method based on the values of $k_1$ and $k_2$ shown in Tables 1 and 2. The values of RMSE were calculated from the values of drying rate constant ($k_1$ or $k_2$) shown in Table 1 or 2 and the results calculated from Eq. (3).*

### Water Absorption Characteristics

The moisture content of dried and dried blanched samples increased with the elapsed time, exhibiting a gentle upward curve from the beginning of soaking at all three temperatures, as shown in Fig. 4. The water absorption rate of dried blanched samples was slower than that of dried samples at each temperature. The dried blanched sample was harder and had a smaller size than the dried sample. The difference in organizational structure for the samples after drying could be caused by the difference in water absorption characteristics. The exponential model Eq. (4) (Tagawa, et al. 1997) was used to analyse the changes in moisture content from the initial moisture content of 15% (d.b.).

$$\frac{M - M_s}{15 - M_s} = \exp\left(-k_3 t_{\mathrm{WA}}\right) \quad (4)$$

where $M_s$: saturated moisture content (% (d.b.)), $k_3$: water absorption rate constant (1/min), and $t_{WA}$: soaking time (min). The solid lines and broken lines in Fig. 4 represent the results calculated from Eq. (4). The values of $k_3$, $M_s$, and RMSE of Eq. (4) are shown in Table 4.

The $k_3$ of each sample increased with increasing soaking temperature and was related to soaking temperature by the following Arrhenius equation.

$$k_3 = d \cdot \exp\left[-E/R\left(T + 273.15\right)\right] \tag{5}$$

where $R$: ideal gas constant 8.314 (J/mol･K), $d$, $E$: constant. The values of $d$ and $E$ were $6.047\times10^2$ and $2.477\times10^5$ for the dried sample and $6.444\times10^3$ and $3.278\times10^5$ for the dried blanched sample, respectively.

**Table 4 Water absorption rate constant ($k_3$), saturated moisture content ($M_s$), and root mean square error (RMSE) of Eq. (4) for each sample**

| Sample | Temperature (°C) | $k_3$ (1/min) | $M_s$ (% (d.b.)) | RMSE (% (d.b.)) |
|---|---|---|---|---|
| Raw | 20 | $2.417\times10^{-2}$ | 2572 | 43.8 |
| | 30 | $2.994\times10^{-2}$ | 2748 | 42.1 |
| | 40 | $4.640\times10^{-2}$ | 2525 | 37.6 |
| Blanched | 20 | $9.129\times10^{-3}$ | 3549 | 35.0 |
| | 30 | $1.499\times10^{-2}$ | 2999 | 38.0 |
| | 40 | $2.153\times10^{-2}$ | 2696 | 59.3 |

*The values of $k_3$ and $M_s$ were determined by the nonlinear least squares method based on the measured results. The values of RMSE were calculated from the measured results and the results calculated from Eq. (4).*

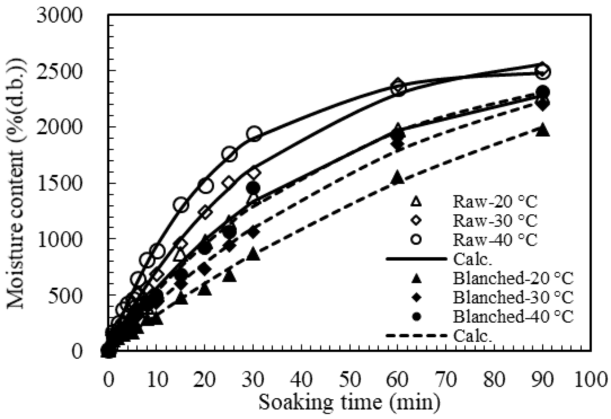


**Fig. 4 Changes in moisture contents during water absorption for each sample**

## CONCLUSION

The hot-air drying characteristics of two types of young papaya, raw or fresh papaya and blanched young papaya, were measured at three temperatures (30-70°C), three air velocities (1-3 m/s), and a relative humidity of 40%. The drying characteristics of both samples had almost the same tendency. The linear function and the exponential model were used to express the changes in the moisture content of the sample with drying times above or below 500% (d.b.), respectively. The drying rate constant of each sample and each drying period (above or below 500% (d.b)) increased with an increase in air temperature and air velocity and was expressed as a linear function of both air temperature and air velocity, respectively.

The water absorption characteristics of the dried young papaya and the dried blanched young papaya were measured at three temperatures (20, 30, and 40°C). The water absorption rate of dried young papaya that did not receive the blanching treatment before drying was faster than that of the sample that was blanched before drying (dried blanched sample). The exponential model could be applied to explain the water absorption process of both samples. The water absorption rate constant increased with increasing soaking temperature.

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