Physical quality analysis of drying beluntas leaves (*Pluchea indica* L.) using variations of drying methods

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**Abstract.** Beluntas leaves are medicinal plants with pharmacological effects, such as antioxidant, antidiarrheal, antidiabetic, and antibacterial. Drying is one of the processes before the beluntas leaves are consumed. However, drying could degrade the quality of beluntas leaves. This research aims to investigate the impact of drying conditions on the physical qualities of dried beluntas leaves. Beluntas leaves with a moisture content of 83-90% were dried using drying methods, namely the greenhouse effect dryer (ERK), cabinet dryer (CD) at 40, 50, 60, and 70°C, and freeze dryer (FD) at 35, 45, and 55°C. The physical parameters measured were moisture content, color, shrinkage, rehydration ratio, and bulk density. The results showed that the final moisture content of the dried beluntas leaves were 8.40; 4.92-10.70; 4.73-6.77% w.b for ERK, CD, and FD, respectively. Page's model was suitable for explaining the changes in moisture ratio during the drying process ($R^2 = 0.9934 - 0.9999$). The freeze-drying method can preserve the leaves' color and obtain the lowest moisture content with a low drying temperature compared to other methods. Freeze-dried beluntas leaves also exhibited the highest rehydration ratio, which was 2.03 – 2.25.

1. **Introduction**

Beluntas plant is one of 66 medicinal plants based on the Decree of the Minister of Agriculture Number 511 of 2006 [1]. Traditionally, people believe that beluntas leaves can eliminate body odor, increase appetite, help digestion, shed sweat, and relieve fever, bone pain, back pain, and vaginal discharge [2]. In addition, several research results concluded that beluntas leaves have pharmacological effects, such as antituberculosis [3], antioxidant [4], antidiarrheal [5], antidiabetic [6], and antibacterial [7]. The moisture content of fresh beluntas leaves ranges from 83 - 90% w.b, so that storage in this condition will accelerate the quality decline due to withering, respiration, transpiration, and other metabolic processes that are still active.

Drying is one of the most frequently used methods to reduce the moisture content of the material to a level where the activity of microorganisms and chemical reactions is minimized, even inhibited, to extend the material's shelf life [8–11]. Beluntas leaves are generally dried in direct sunlight, and some business owners were processing beluntas leaf into powder using oven drying. Unfortunately, the sun drying method has several disadvantages, such as depending on weather conditions and is often contaminated by pollution, dust, and insects. The quality of the final product, such as the color, aroma, chemical content, is not uniform and is challenging to control [9,10]. Meanwhile, hot air drying, such as a cabinet dryer, can cause several undesirable quality changes, including browning, oxidation by PPO enzymes, case hardening, and nutrient degradation [9,12].
Therefore, a drying method is needed to maintain the quality of dried beluntas leaves, one of which is freeze-drying. The freeze-drying method is better in retaining shape, nutritional properties, and sensors than those in hot air drying due to the release of air from the product through the sublimation mechanism [13]. In addition, freeze-drying can be carried out at low temperatures and under vacuum conditions; therefore, it can maintain the physical and chemical qualities, especially aroma, color, and bioactive compounds in the material [14–16]. This research was carried out to obtain information related to the effect of drying condition of freeze drying on the physical properties of dried beluntas leaves, compared to other drying methods such as greenhouse effect drying and cabinet drying.

2. Materials and methods

2.1. Materials

Fresh beluntas leaves were picked in the morning and evening from 3 different locations: Sumberharjo Prambanan Village, Sendowo Mlati, and the Faculty of Forestry Universitas Gadjah Mada. The leaves of the beluntas are washed with tap water first to remove dust and dirt. Before the drying process, leaves were stored in cold storage at a temperature of 17.2℃ and relative humidity of 97%. The criteria for the beluntas leaf used refers to the study [17] with a slight modification, namely the 1st – 10th leaf after juvenile leaf shoots (leaves 1 – 4 of the shoot with a light green color).

2.2. Drying methods

2.2.1. Greenhouse Effect Drying (ERK). Samples were put into the ERK drying room between 10.00 – 11.00 WIB and removed at 16.00 – 16.30 WIB. The drying process took about two days to reach a moisture content of about 10% w.b.

2.2.2. Cabinet drying (CD). Beluntas leaf samples that have been arranged in containers were put into the drying chamber of the cabinet dryer (PSN-150, Shimizu Scientific Instruments MFG. CO., LTD., Tokyo, Japan). Next, the cabinet dryer was operated with the heater temperature is adjusted according to the variation, namely 40, 50, 60, or 70℃ (CD40, CD50, CD60, and CD70). Temperatures and Rh were collected every 30 minutes. Meanwhile, color data and sample mass were measured every 1 hour (CD40 and CD50) or every 30 minutes (CD60 and CD70). After the sample mass reached constant, the cabinet dryer was turned off.

2.2.3. Freeze drying (FD). The freeze dryer used was self-designed in the Food and Postharvest Engineering Lab of Universitas Gadjah Mada (Figure 1). There are three central systems: a vacuum, cooling, and heating system. The total dimensions of the dryer were 100 x 80 x 100 cm, with the base material is stainless steel and a capacity of 1 kg. The beluntas leaf samples were arranged in a sample tray of the drying chamber. After that, the cooling system was set to -18℃ (freezing stage). At the 6th hour, the heater was turned on at 0℃ for the next 18 hours (sublimation stage). Finally, at the 24th hour, the heater temperature is set to the drying target temperature, namely 35, 45, or 55℃ (FD35, FD45, and FD55) for the next 12 hours (desorption stage). All processes took place under a vacuum (absolute pressure 0.15 cmHg) for a total time of 36 hours.
2.3. Mathematical modeling of thin layer drying

The moisture ratio (MR) of beluntas leaves for the experimental sample was calculated according to equation (1). In this study, the Page model (equation (2)) was selected to describe the changes in the moisture content ratio of beluntas leaves followed the development of research results [18]. The model was then mounted on the experimental drying curve using direct least squares and the model coefficients were estimated using a solver in the excel for microsoft 365 software. The optimized value in the least squares method is the sum square error (SEE).

\[
MR = \frac{M_t - M_e}{M_o - M_e}
\] (1)

\[
MR = \exp(-kt^n)
\] (2)

Where MR is the moisture ratio, \(M_o\) is the initial moisture content of the beluntas leaves (% d.b), \(M_t\) is the moisture content at any time the beluntas leaves during drying (% d.b), and \(M_e\) is the final moisture content in the FD and CD treatments (% d.b).

2.4. Physical characteristics analysis

2.4.1. Moisture content. Measurement of moisture content of fresh beluntas leaves samples and drying results using the thermogravimetric method. The samples were weighed and dried in an oven (oven drying model MOV-112, Sanyo, Japan) at 105°C for 24 hours. The weight loss during the drying process is considered as the amount of water contained by the sample, which is presented in equation (3).

\[
M = \frac{W - W_1}{W} \times 100\%
\] (3)

Where \(M\) is the moisture content (%w.b.), \(W\) is the initial mass of the sample (g), and \(W_1\) is the final mass of the sample after being in the oven for 24 hours (g).

2.4.2. Shrinkage ratio (DS). The volume changes of the dried sample were estimated in terms of the shrinkage ratio (SR) measured using a digital vernier caliper (0 – 150 mm, Krisbow). Equations (4) and (5) were used to calculate the shrinkage in length and width of beluntas leaves during drying, as reported by [15,19].

\[
S_P = \left(\frac{P_f - P_t}{P_t}\right) \times 100\%
\] (4)

\[
S_L = \left(\frac{l_f - l_t}{l_t}\right) \times 100\%
\] (5)
Where $S_P$ is the length shrinkage (%), $S_L$ is the width shrinkage (%), $P_i$ and $l_i$ are the initial length and width of the beluntas leaf sample (mm), and $P_f$ and $l_f$ are the final length and width of the beluntas leaf sample (mm).

2.4.3. Rehydration ratio. The capacity or rehydration ratio of dried beluntas leaves was determined based on a combination of methods used by [20] on cabbage (*Brassica oleracea* L.) with slight changes. The measurement procedure was that 1 g of dried beluntas leaves sample was put into a 1000 ml Pyrex beaker filled with 500 ml of tap water, at room temperature (29.5 ± 1.1°C). After soaking for 10 minutes, the beluntas leaves samples were drained for 10-15 minutes. Then, the water on the surface of the leaves is slowly wiped with tissue paper, then the mass is weighed. Next, the rehydration ratio (RR) is calculated as the ratio of the weight of the rehydrated sample ($W_2$) to the weight of the dry sample ($W_1$), as in equation (6).

$$RR = \frac{W_2}{W_1}$$ (6)

2.4.4. Bulk density uncompacted ($\rho_b$). The measurement of $\rho_b$ of beluntas leaves followed the method reported by [19], in which the leaves of beluntas were put into a tubular container with a volume of 100 cm$^3$ to fill the volume of the container. Then, the mass of the beluntas leaves sample that occupies the container is weighed, then the $\rho_b$ value is calculated by equation (7).

$$\rho_b = \frac{m}{v}$$ (7)

Where $\rho_b$ is bulk density uncompacted ($g/cm^3$), $m$ is the mass of the beluntas leaves sample that occupies the container (g), and $v$ is the volume of the container (100 cm$^3$).

2.4.5. Color measurement. Color was measured using a Color Meter (Color Meter TES-135A, TES Electrical Electronic Corp., Taipei, Taiwan). Color was measured with the $L^* a^* b^*$ scale (CIELAB), which was designed to quantify the colors perceived by the human eye. The value of $L^*$ represents brightness or dullness which it has a range of 0 – 100, $a^*$ represents redness (+) or greenness (-), and $b^*$ represents yellowness (+) or blueness (-). Furthermore, the results of color measurements $L^*$, $a^*$, and $b^*$ were used to calculate the chroma value, hue angle, total color change ($\Delta E$), and browning index (BI) using equation (8) – (11). Measurements were carried out on 10 leaf samples with 3 replications.

$$C^* = \sqrt{(a^*)^2 + (b^*)^2}$$ (8)

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2}$$ (9)

$$H = tan^{-1} \left( \frac{b^*}{a^* + 1.75L^*} \right) \times 57.3$$ (10)

$$x = \frac{5.645L^* + a^* - 3.012b^*}{100(x - 0.31)}$$ (11)

2.5. Statistical Analysis

Collected data were subjected to analysis of variance (ANOVA) using software IBM SPSS Statistics 20. When a significant (p < 0.05) main effect was found, mean values were further analyzed using the Tukey HSD (honestly significant difference) test.

3. Results and discussion

3.1. Drying characteristics of beluntas leaves

In Figure 2 it can be seen that there is no constant drying rate in the drying of beluntas leaves. This is in accordance with what was reported [10] that the period of drying the rate of decline did not occur in
leaf drying because the free water in the leaves was relatively small. The final moisture content of beluntas leaves ranged from 4.73 to 10.70% d.b. depending on the drying temperature and type of dryer. From Figure 2b it can be said that the higher temperature of the heater cabinet dryer, the shorter the drying time. The results of research [21] on bay leaves (Laurus nobilis L.) using a hot air dryer also showed the same pattern. In Figure 2c it can also be seen that the decrease in water content of beluntas leaves occurs most often at the sublimation stage (primary drying) from the 6th to the 24th hour, from 80.67% wb (417.45% d.b) to 10.53% w.b (11.77% d.b). Meanwhile, in the desorption stage (secondary drying) from the 24th to the 36th hour, the water content decrease was relatively less and tended to be close to constant.

From the large value of its $R^2$, the Page’s model was concluded as semi-theoretical mathematical model of thin layer drying that best modeled the 8 variations of beluntas leaves drying methods in this study. It can be seen that the predicted water content of the Page model is very close to the observed water content ($R^2 = 0.9934 - 0.9999$). The results of previous studies that support the results of this study, namely [22,23] reported that Page's model is the best to predicts the drying behavior Moringa Oleifera and pandanus (Pandanus amaryllifolius), respectively.

![Figure 2](image-url)

**Figure 2.** Predicted and observations moisture content of beluntas leaves during drying with (a) Greenhouse effect drying, (b) Cabinet drying, and (c) Freeze drying.

### 3.2. Effect of drying on various quality parameters of beluntas leaves

#### 3.2.1. Moisture content, shrinkage, rehydration ratio, and bulk density

It can be observed from Table 1 that all the final moisture content of dried beluntas leaves were below 8% w.b except for the cabinet dryer treatment at 40°C (CD40) and drying with the greenhouse effect (ERK). The final moisture content in the FD treatment was smaller than in the CD and ERK treatments, except for the CD70 treatment. The same result was also obtained by [15] who reported that the final moisture content of
cabbage leaves dried by freeze dryer was lower than that of hot air dryer at 45°C. The lowest final moisture content was found in the freeze dryer treatment at 55°C (FD55). During freeze drying process, the drying chamber was in a vacuum condition so that the freezing point of water in the beluntas leaves rose which resulted in a faster sublimation process and the boiling point of the water in the beluntas leaves decreased which resulted in lower water content. This causes the water to evaporate faster at the desorption stage.

The shrinkage that occurs during drying can reduce the drying rate because the water in the material is trapped in the solidified cells and the movement of water vapor to the surface is hindered due to the deformation [24]. From Table 1, the lower percentages in the FD treatment were found compared to that in the CD treatment. The results obtained in this study were similar from those of [15] which dried cabbage (Brassica oleracea L.) leaves using a hot air dryer (45°C & 1 m/s) and freeze dryer (-21°C & 85-90 Pa). This could be happened since in the FD treatment the beluntas leaves are in a solid state (frozen) at the freezing and sublimation stages, so that the shrinkage that occurs is can be controlled (because the beluntas leaf matrix strengthens) [25]. Meanwhile, in the CD and ERK treatments, the release of water from the beluntas leaves did not occur under frozen conditions, but took place under rubbery conditions (more dominant). As a result, beluntas leaf edges are shrinking more quickly (compacting, curling, and warping), causes the dimensions of the leaf width to decrease drastically.

The rehydration ratio indicates the ability of dried beluntas leaves to reabsorb water which depends on the internal structure and the extent to which water-retaining components, such as protein and starch, have been damaged during drying [26]. Fast and uniform rehydration is a desirable property of dried beluntas leaves. In Table 1, the rehydration ratio of beluntas leaves drying with FD was greater than that of CD and ERK, except for the CD treatment at 40°C. The highest rehydration ratio was obtained in the FD45 treatment, which was 2.25 and the lowest was in the CD70 treatment, which was 1.67. The rehydration ratio value of 2.25 on FD45 showed that the dried beluntas leaf sample was able to absorb water as much as 2.25 times the mass of the dried beluntas leaf sample. The low rehydration ratio in CD were assumed to occurred due to the high drying air temperature so that moisture came out quickly during drying, resulting in the damage to cell structure. Meanwhile, in FD treatment, most of the water from the beluntas leaves is removed by sublimation, leaving many small pores inside and on the leaf surface. As a result, water diffuses more easily through the pores on the leaf surface.

Bulk density can vary with water content in dry food products and its magnitude depends on the shrinkage rate, which in turn is strongly influenced by the drying method [27]. The low bulk density of dry samples is a desirable characteristic [24]. The lowest uncompacted bulk density value was obtained in the FD55 treatment, which was 16.00 ± 0.82 kg/m³ and the highest was obtained in the CD50 treatment, which was 21.00 ± 3.61 kg/m³. The results obtained in this study were similar to the

| Table 1. Measurement results of several physical qualities of fresh and dried beluntas leaves. |
| Treatment | Final water content (% w.b) | Shrinkage in length (%) | Shrinkage in width (%) | Rehydration ratio | \( \rho_b \) (kg/m³) |
|------------|-----------------------------|-------------------------|------------------------|-----------------|------------------|
| Control    | 85.57                       | 51.57 ± 4.72            | 27.57 ± 1.39           | -               | 96.43 ± 2.57     |
| FD35       | 6.77 ± 1.14<sup>ab</sup>    | 38.60 ± 4.38            | 36.15 ± 5.90           | 2.08 ± 0.15     | 17.70 ± 1.56     |
| FD45       | 5.84 ± 0.93<sup>ab</sup>    | 42.47 ± 1.29            | 37.04 ± 5.08           | 2.25 ± 0.04     | 17.77 ± 0.40     |
| FD55       | 4.73 ± 1.05<sup>a</sup>     | 35.44 ± 7.15            | 35.97 ± 5.79           | 2.03 ± 0.06     | 16.00 ± 0.82     |
| CD40       | 10.70 ± 0.94<sup>c</sup>    | 29.68 ± 3.54            | 49.59 ± 0.99           | 2.16 ± 0.08     | 20.57 ± 1.36     |
| CD50       | 7.18 ± 0.80<sup>ab</sup>    | 34.44 ± 1.99            | 50.33 ± 3.01           | 1.88 ± 0.05     | 21.00 ± 3.61     |
| CD60       | 6.12 ± 0.13<sup>ab</sup>    | 34.97 ± 3.07            | 52.00 ± 3.41           | 1.80 ± 0.05     | 18.40 ± 2.69     |
| CD70       | 4.92 ± 1.73<sup>c</sup>    | 39.85 ± 9.87            | 55.40 ± 7.88           | 1.67 ± 0.01     | 20.17 ± 2.42     |
| ERK        | 8.40 ± 1.96<sup>bc</sup>   | 38.31 ± 8.35            | 52.83 ± 2.24           | 1.72 ± 0.04     | 18.80 ± 4.65     |

Note: Data are expressed in mean ± standard deviation and different letter superscripts showed statistical significance (p < 0.05). FD35, FD45, and FD55 = Freeze drying at 35, 45, and 55°C, respectively; CD40, CD50, CD60, and CD70 = Cabinet drying at 40, 50, 60, and 70°C, respectively; ERK = Greenhouse effect drying.
results of the study [27] which dried the quince (Cydonia oblonga) fruit. This is because the ice crystals formed in the cells and spaces between the cells of the material during the freezing stage, sublimate in the sublimation stage, leaving holes (pores) in the material structure without significant shrinkage.

3.2.2. Color. It was obtained from Table 2 that the lowest \( \Delta E \) value was obtained in the FD treatment (6.44 – 7.45), this was because the drying temperature was lower and drying took place under vacuum. The combination of the two causes the conversion of magnesium molecules that make up the chlorophyll pigment to pyropheophytin and pheophytin to be slower and the enzymatic and non-enzymatic browning reactions also run more slowly during drying [12,22]. Thus, the color of the leaves of beluntas drying with freeze dryer (FD) is better than other treatments.

### Table 2. Results of \( H \), \( C^* \), \( \Delta E \), and BI values of fresh beluntas leaves and drying results.

| Treatment          | \( H \)       | \( C^* \)     | \( \Delta E \) | BI       |
|--------------------|---------------|---------------|---------------|----------|
| Control            | 126.00 ± 1.57 | 27.76 ± 1.26  | -             |          |
| FD35               | 122.41 ± 4.83 | 23.31 ± 2.57  | 7.24 ± 3.11   | 35.09 ± 9.79 |
| FD45               | 127.01 ± 8.60 | 23.14 ± 2.99  | 6.44 ± 3.98   | 25.16 ± 10.55 |
| FD55               | 123.87 ± 0.75 | 21.12 ± 3.41  | 7.45 ± 4.39   | 25.23 ± 5.51 |
| CD40               | 127.25 ± 14.70| 18.85 ± 5.09  | 10.22 ± 7.06  | 25.04 ± 22.17 |
| CD50               | 122.33 ± 3.58 | 19.57 ± 8.06  | 13.27 ± 9.36  | 33.10 ± 22.54 |
| CD60               | 99.03 ± 2.97  | 19.28 ± 2.43  | 15.56 ± 3.22  | 65.29 ± 7.84 |
| CD70               | 104.12 ± 18.09| 15.15 ± 4.11  | 15.39 ± 5.31  | 30.20 ± 12.76 |
| ERK                | 104.64 ± 12.58| 17.56 ± 4.52  | 13.74 ± 4.36  | 42.00 ± 2.68 |

Note: Data are expressed in mean ± standard deviation and in the same column and different superscript letters, the data is significantly different at = 5%. \( H \) = Hue angle; \( C^* \) = Chroma; \( \Delta E \) = color difference; BI = Browning Index; FD35, FD45, and FD55 = Freeze drying at 35, 45, and 55°C, respectively; CD40, CD50, CD60, and CD70 = Cabinet drying at 40, 50, 60, and 70°C, respectively; ERK = Greenhouse effect drying

Overall, it can be said that during the color change of beluntas leaves during drying in the FD, CD40, CD50, and ERK treatments was more due to chlorophyll degradation due to long drying time, rather than due to enzymatic reactions caused by polyphenol oxidase activity. Especially in the FD treatment which takes place under vacuum conditions. Meanwhile, in the CD60 and CD70 treatments, the color changes that occur can be caused by a combination of chlorophyll degradation to pheophytin and Maillard's non-enzymatic browning reaction. In addition, at higher temperatures the rate of water removal from beluntas leaves is faster so that it can cause physical damage to leaf tissue. This physical damage can cause the leaves to turn brown. However, the discoloration of beluntas leaves due to Maillard's non-enzymatic browning reaction during drying needs further investigation. The results [28] showed that changes in surface color parameters (\( L^* \), \( a^* \), and \( b^* \)) of red chilies during drying showed a positive correlation with changes in natural pigment content and negatively correlated with non-enzymatic browning reactions.

4. Conclusions

This study investigated the effect of drying conditions on the physical properties of dried beluntas leaves. It was found that the self-constructed freeze-drying method could dry beluntas leaves to 4.73-6.77\%w.b, lowest than those using Cabinet and Greenhouse effect drying method. Page's model chosen is suitable to model the changes in moisture ratio during the drying process \( (R^2 = 0.9934 – 0.9999) \). The freeze-drying method relatively resulted in a lower shrinkage ratio in width and a higher rehydration ratio. The lowest color change value \( (\Delta E) \) obtained from freeze-dried beluntas leaves, 6.44 – 7.45, indicating that freeze-drying can preserve the original color of beluntas leaves better than other drying methods. The results suggested the freeze-drying method's potential to produce preserved...
beluntas leaves as a healthy herbal drink. The effect of the drying method on the nutritional and antioxidant value of beluntas leaves is to be discussed further.

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