Engineering analysis in manufacturing process of Nori made from mixture of *Ulva lactuca* and *Gracillaria* sp

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Abstract A research had been conducted regarding the drying of nori made from local seaweed of *Ulva lactuca* and *Gracillaria* sp. The drying process was carried out at 50°C, 60°C and 70°C using mechanical dryer. Drying rate was evaluated with four thin layer drying models, namely Henderson and Pubis, Lewis, Page and Modified Page. The most suitable model is determined from the the highest R² value and lowest Root Mean Square Error (RMSE) value. The results indicated that nori could be made from local seaweed of *Ulva lactuca* and *Gracillaria* sp with a specific method and composition. Drying rate of local nori showed a long constant drying period as compared to it’s falling rate period. Drying rate increased and drying time decreased as the drying temperature increased. The highest drying rate is obtained at 70°C and the Page model was found to be the best suitable model to describe nori drying characteristics.

1. Introduction
Nori is a typical food from East Asian countries such as Japan, Korea, and China, made from *Porphyra* sp and it has been consumed for centuries. At present nori becomes a potential commodity to be marketed not only in its origin country but also in other countries as an export commodity. This is why currently in Indonesia, nori has become a familiar food. Today, the domestic nori requirements are still fulfilled from imports, while Indonesia has a variety of potential types of seaweed that have not been explored maximally yet as local raw material to produce nori. The effort to produce nori has been carried out by Gupta et al [1] who developed nori from brown algae species in the European region. Development of nori based on native Indonesian seaweed has been trying using *Gracillaria* sp [2] or *Gellidium* [3], however there has not successful yet. To find local raw material, at least two factors are considered, namely the texture and color of the produced nori so that it is as similar as possible to the nori resulted from *Porphyra* or original nori. With natural colors owned by *Ulva lactuca* capable to give green color, while *Gracillaria* sp is used as a binding matrix and provide crisp texture. A study conducted by Putri and Ningtyas [4] in the producing nori from a mixture of *Ulva lactuca* and *Gracillaria* sp seaweed recommended that the best composition was 97.15% of *Ulva lactuca* and 2.85% *Gracillaria* sp.

Various temperature of drying nori have been reported. Nori from *Porphyra* sp made with dried and roasted at light temperature [5]. However some of the drying methods reported are roasting at temperatures of 120-140°C for one minute [6] and 100°C for 3 minute [7]. While Putri and Ningtyas [4] reported drying the nori using an oven at 80°C for 5 hours.
A mathematical model is often needed to control drying process or to develop an equipment to handle that process. There are many mathematical models and each model has its characteristics in the predicting drying process of any material. Four mathematical models were used in this study, namely Newton, Henderson & Pabis, Page and Page Modified. These models are selected as those four models are often used for thin layer drying [8]. The drying equation of the Lewis model is analogous to the mathematical model of equation Newton Colling [9] and this model is the simplest model. The Henderson and Pabis model is a simple forms of a series of general settlement of Fick II Law [10]. The Page model is suitable to explain the drying of many agricultural products and is also easier to be use as compared to the other equations [11]. The values of constants k and n will reflect the behavior characteristic of the models. The greater the value of k the faster the rate of change in the dependent variable [12], in this case the rate of change in water content per unit time to reach equilibrium. The drying rate will be faster if the drying temperature is higher [13].

Evaluation of thin layer drying models has been applied to various types of seaweed such as Eucheuma cottonii [8] but in drying nori from seaweed Ulva lactuca and Gracillaria sp has not been yet carried out. The objective of this study was to investigate the drying characteristics of nori made from a mixture of Ulva lactuca and Gracillaria sp and to find the most precise models to describe the rate of moisture change during nori drying.

2. Methodology

2.1. Materials and manufacturing method
This research was carried out in the Process and Post harvest Technique (TPP) Laboratory of Gadjah Mada University in April-May 2019. In this study to make nori from a mixture of local seaweed refers to the best composition from the method used by Putri and Ningtyas [4] with a little modification (97% Ulva lactuca mixture with 3% Gracillaria sp) (Figure 1). Those seaweed were whased using freshwater then they were soaked to soften the texture. Ulva lactuca soaked by adding salt with ratio sample (gr): water (ml): salt (gr) is 2: 60: 5 respectively. While for Gracillaria sp soaked using rice vinegar with the ratio between sampel (gr): water (ml): rice vinegar (ml) is 2: 60: 1 respectively. Soaking was done for 6 hours, then followed by washing the seaweed to remove salt and vinegar. Those seaweed were then crushed using a blender by adding 8 part of water to produce seaweed pulp and then cooked until boiling. The pulp around 60 gr was then poured on a pan and dried. Drying was done using an oven (memmert UN series 55) with a temperature of 50°C, 60°C and 70°C. These temperature selection according to the drying temperature range of agricultural products, between 45°C - 75°C. [8]. In this drying process the oven exhaust opening was set at 50%, and this condition produced air flow rate of 0.209 to 0.238 m³/min

Figure 1. Ulva lactuca (a), Gracillaria sp (b), mixture of the two seaweeds (c), and (d) resulted nori

2.2. Observed parameters
Measurement of the sample mass during drying process was carried out every 30 minutes and stopped after the mass of the material was constant. Mass measurement was carried out by removing the sample from the oven, weighing it then quickly returned to the oven.
2.2.1. Change in water content during drying. The changes of sample mass during drying was used to calculate water content using the following equation

\[
\frac{W'\text{m}}{W_2} = \frac{m_1 - m_2}{100 - m_1} = \frac{M_1 - M_2}{100 + M_2}
\]

Where \( W_2 \) = Final weight of dried product (gr)
\( W'\text{m} \) = Weight of moisture evaporated (gr)
\( m_1, m_2 \) = Initial and final moisture content (% wet basis)
\( M_1, M_2 \) = Initial and final moisture content (% dry basis)

2.2.2. Drying rate. The drying rate is calculated from the difference in the dry weight of the material during drying with time

\[
\text{DR} = \frac{(M_t - M_{t+dt})}{dt}
\]

Where \( \text{DR} \) = Drying rate (%db/ minute)
\( M_t \) = Water content at t time (% db)
\( M_{t+dt} \) = Water content at t + dt (% db)
\( dt \) = Time difference (minute)

2.3. Mathematical models

The mathematical model of nori drying was calculated based on Moisture Ratio (MR). Four model consisted of Henderson and Pabis, Lewis, Page, Modified Page were evaluated in this research. The values of \( k, a, n \) were found from the relationship between MR and t (time)

| Models                  | Equation                      | Source |
|-------------------------|-------------------------------|--------|
| Henderson and Pabis     | \( \text{MR} = a \exp (-kt) \) | [2]    |
| Lewis                   | \( \text{MR} = \exp (-kt) \)   | [7]    |
| Page                    | \( \text{MR} = \exp (-kt^n) \) | [13]   |
| Modified Page           | \( \text{MR} = \exp[(kt)^n] \) | [14]   |

Moisture ratio is calculated using equation [14] as follow

\[
\text{MR} = \frac{M_t - M_e}{M_0 - M_e}
\]

Where:
- \( \text{MR} \) = Moisture ratio
- \( M_t \) = Moisture content at t time (% db)
- \( M_e \) = Water content equilibrium (% db)
- \( M_0 \) = Initial water content (% db)

The comparison criteria used to determine the best equation model were coefficient of determination (\( R^2 \)) and Root Mean Square Error (RMSE) [11]. \( R^2 \) is used as a comparison criterion to determine the accuracy of the model. Whereas RMSE value indicates a deviation between the predictive and the experimental results. The higher the value of \( R^2 \) and the lower the value of RMSE, the more precise will the evaluated model.

3. Result and Discussion

3.1. Relationship of temperature to drying time

Measured water content in this study is presented in a dry basis, this is due to the requirement for calculating MR. The effect of temperature on moisture content reduction can be seen on Figure 2. The
decrease in water content occurred constantly during drying for a few moments before drying complete. At higher temperatures, the drying time of the nori would be faster. This condition is similar to the results found by Prasetyo et al [13] which dried seaweed at several different temperatures. In this study, drying with a temperature of 70°C was the fastest needed only of 270 minute (4.5 hours) compared to 660 minute (11 hours) for 50°C. The equilibrium moisture content of 50°C has the highest value, this might not reach the equilibrium water content yet. Zakaria et al [7] reported that the equilibrium moisture content on roasted drying nori from mixture Ulva lactuca and Eucheuma cottonii reached 6.39% and non roasted reached 9.85%. Equilibrium moisture content and drying time are presented in Table 2.

Table 2. Equilibrium moisture contents and drying time of nori

| Temperature (°C) | Equilibrium moisture content (%) | Drying time (minute) |
|-----------------|---------------------------------|----------------------|
| 50              | 18 %                            | 660                  |
| 60              | 13 %                            | 210                  |
| 70              | 9 %                             | 270                  |

Figure 2. Correlation between moisture content (db) and time (minute)

3.2. Drying rate and moisture content

The drying rate indicates the amount of water evaporated per unit time. The effect of time on the drying rate is shown in Figure 3. The drying rate of nori at 70°C showed the highest value compared to 50°C and 60°C. At the beginning of drying, there were a constant rate of water removal (constant rate period) until certain extend, then followed by falling rate period for the rest until the drying process finish. At higher drying temperatures, the temperature difference between the surface of the material and the drying air was getting larger, this triggered an increase in the amount of moisture to be vaporized and resulted in an increase in the drying rate [15]. Drying curves indicated a pattern that was dominated by a constant rate period and as the drying temperature decreased it seemed that the length of constant rate period was also longer.
Figure 3. Correlation between drying rate and time

The drying rate of nori depended on the moisture content of the material as shown in Figure 4. For all of drying temperatures, it showed a rapid increase on the drying rate which indicated the heating process of the material to reach evaporation temperature of the contained water. Next step showed an almost constant condition while the material still contained high water content this was a constant rate period. Finally, as the contained water had decreased, drying rate sharply increased but only in a short time.

Figure 4. Correlation between drying rate and moisture content.

3.3. Mathematical model
The observed moisture contents were used to calculate the constants of the fourth models evaluated. Those constants are presented in Table 3. In this study showed that increased of constants value of k and n are linear with an increase in drying temperature. Moisture content at 70°C drying temperature and prediction of the fourth evaluated models are shown in Figure 5. Among the evaluated models, three models showed a good prediction accuracy and revealed good performance over the entire of the drying process. However, Henderson and Pabis model overestimated while Lewis and Page modified were found to be underestimate at the beginning of drying process.

The values of R² and RMSE for the fourth models are showed in Table 3. Page model gave the best prediction result of the thin layer drying characteristics with R² values between 0.951-0.985, and fairly
low value of RMSE between 0.040-0.083. The same condition was reported by Arda [12] who stated that model Page was a model that able to describe the drying of stoic bamboo shoots.

Table 3. Model and the coefficients for thin layer nori drying at various temperature

| Temperature (°C) | Models                  | k    | n     | a     | R²   | RMSE |
|------------------|-------------------------|------|-------|-------|------|------|
| 50               | Henderson and Pabis     | 0.003| 2.35  | 0.813 | 0.440|      |
|                  | Lewis                   | 0.002|       | 0.915 | 0.123|      |
|                  | Page                    | 0.001| 1.078 | 0.951 | 0.083|      |
|                  | Modified Page           | 0.0016| 1.078| 0.937 | 0.099|      |
| 60               | Henderson and Pabis     | 0.014| 2.718 | 0.792 | 0.283|      |
|                  | Lewis                   | 0.011|       | 0.865 | 0.180|      |
|                  | Page                    | 0.0006| 1.470| 0.978 | 0.054|      |
|                  | Modified Page           | 0.00064| 1.470| 0.900 | 0.149|      |
| 70               | Henderson and Pabis     | 0.029| 3.01  | 0.790 | 0.196|      |
|                  | Lewis                   | 0.023|       | 0.859 | 0.169|      |
|                  | Page                    | 0.001| 1.553 | 0.985 | 0.040|      |
|                  | Modified Page           | 0.0124| 1.553| 0.905 | 0.143|      |

Figure 5. Observed and predicted moisture content at 70°C drying temperature

4. Conclusion
Nori could be produced from a mixture of Ulva lactuca and Gracillaria sp with a specific composition and method. Drying rate of this nori was dominated by constant rate period as compared to the falling rate period. The drying rate increased and drying time decreased as the drying temperature increased. Page model was found to be the most suitable model to describe drying characteristic of nori drying.

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