Effect of Vibrating Fluidized Bed (VFBD) and continuous microwave drying on drying characteristic of green tea

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Abstract. In industrial green tea processing, people usually use endless chain pressure (ECP) dryers and fluidized bed dryers. ECP dryers have disadvantages including case hardening, uneven dryness, high energy consumption and long drying time, while fluidized bed dryers still have disadvantages of long drying time and high hot air capacity to ensure tea leaves can be fluidized perfectly. Therefore, another alternative dryer is needed that can overcome the problems in the ECP dryer and fluidized bed dryer. This study aims to determine the comparison of drying characteristics between vibrating fluidized bed dryer (VFBD) that have been developed previously with microwave dryers. Drying condition on both dryer was set at 80°C, the airflow velocity at VFBD was 1.09 m/s. Result shows the time needed by the microwave at temperature to dry 500 grams of tea leaves to reach a constant weight is 24 minutes, whereas if using VFBD it takes 85 minute. In VFBD, the constant rate period takes 25% of total drying time, and the rest is critical and falling rate period. While in microwave drying, around 50% of total drying time is constant rate period and the rest is critical and falling rate period. The falling rate period in VFBD requires longer time, which is up to 75% of the total drying time. Highest drying rate in VFBD dryer was 0.08 gr water/gr solid.min, while microwave dryer was 0.14 gr water/gr solid.min.

1. Introduction

Tea (Camellia sinensis) is the most common beverage in the world. Deped on how it is processed, there are several types of tea such as black tea, white tea, green tea, oolong tea, and others. Tea contains active ingredients such as: polyphenols, alkaloids, amino acids, proteins, volatile compounds, minerals and small amount of trace elements [1]. Polyphenols in green tea are dominated by Epigallocatechin (EGC), Flavanolscatechin (C), epicatechin (EC), Gallosecthin (GC), Gallosecthin 3-O-Gallate (GCG), Catechin 3-O-Gallate (CG), Epicatechin 3-O-Gallate (EC) and Epigallocatechin 3-O-Gallate (EGCG) [2-6].

White tea has the highest antioxidant, followed by green tea and then black tea. Drying rate is the change in the moisture content of the dried product in unit time. The catechins content in the tea can be affected by which leaves are harvested, how the leaves are processed, and how the tea is prepared [4]. Polyphenols are quickly oxidized after harvesting due to the enzyme polyphenol oxidase. For the production of green tea, freshly harvested leaves are rapidly steamed or pan-fried to inactivate enzyme polyphenol oxidase [6]. This process approximately 10-15 minute in a process known as fixing [7]. The enzymes in leaf shoots will be deactivate in order to prevent oxidation and fermentation and to maintain
a green color. The main relevant enzymes in tea plants include polyphenol oxidase, peroxidase, catalase, and ascorbic acid oxidase. Fast, even and high-temperature fixing is a feature of green tea processing, and is important for high quality tea [7]. Green tea processing is then followed by rolling, shaping and drying. Rolling aims to obstruct their cell walls, release leaf moisture and form the final product and reduce the volume.

Drying in green tea processing is intended to reduce water content, extend the shelf life by decelerate or stopping microorganisms’ growth [8,9], prevent biochemical change during storage [9] and stop the enzymatic oxidation process of polyphenols if there are still active enzymes. The catechins content in green tea is determined during the fixing and drying process, so the selection of its methods is important to determine the quality of green tea. There are various drying methods including spray drying, rotary drying, fluid-bed drying, infrared heating, microwave heating and others [10]. Drying treatments can affect nutritional and qualitative characteristics of green tea such as color, vitamins, total flavonoid, total phenolic content, chlorophyll and antioxidant activity of final product [8].

In the green industry, the dryer used for processing green tea is an endless chain pressure (ECP) dryer or fluidized bed drier. ECP dryers have disadvantages including case hardening, uneven dryness, high energy consumption and long drying time. Because fluidized bed dryers have more advantages, many tea industries are turning to fluidized bed dryers [11], but fluidized bed dryers still have disadvantages of long drying time and high hot air capacity to ensure tea leaves can be fluidized perfectly. To our knowledge, research on the development of continuous dryers using microwaves for drying green tea has never been done.

Microwave heating is directly related to dielectric material loss. If put in a high-frequency electrical field, the substance can absorb energy. As a consequence, electrical dipole polarization and conducting will be produced within a dielectric material composed of polar molecules with positive and negative poles. Such ordered scattered polar molecules vibrate instantaneously and vigorously in reaction to the alternate high-frequency electrical field of the microwave as shown in Fig. 1. Resistance to molecular resistance and motion must be resolved. The temperature of the substance rises as heat is produced by friction [12].

The microwave heating rate and energy consumption affected by the dielectric property of a material to be dried. The main factors that determine the dielectric behavior of dielectric materials include the frequency and temperature of microwave heating and the moisture content of the material [12]. The dielectric property also depend on density, composition and structure of material [13].

Moisture content can effect the dielectric constant and dielectric loss. Regardless of the temperature, materials with higher moisture contents consistently exhibit higher values of the dielectric constant and dielectric loss, because the microwave absorption and dissipation increase with increasing free water in the material [14].

In hot air drying, the material is heated by an external heat source (from outside the material to be heated) and the heat is transferred from the outside to the inside material. Microwave heating, on the other hand, is based on the quick polarization and depolarization of the charged groups as the material is exposed to a microwave field, resulting in simultaneous internal heat generation [12]. Microwave has the ability to penetrate and heat the substance volumetrically due to the interaction between the electrical
field and the water molecules [15,16]. A large vapor pressure formed at the central region of a material facilitates quick moisture removal [17].

Microwave for drying application has many advantages compared to other types of dryers include [12,17-20]:

- Shorter drying time.
- Lower power consumption due to shorter process time with respect to traditional drying.
- Deep penetration of microwave energy which enables heat to be produced effectively without directly contacting the materials to be dried.
- Better product quality.
- Less space and easy control.
- In combination with vacuum drying, high product quality can be achieved by low temperatures and the rapid transfer of energy from microwave heating.
- Fast drying in the microwave will produce a product with a better antioxidant impact [15,21], color and appearance, sensory and textural attributes [18].

Research on microwaves for drying has been done in mackerel [18], strawberries [22], potato slices [19,23], ginseng slices [24], cassia alata [25], strobilanthes crispus [15], shitake mushroom [26], agaricus bisporus [27], blueberry leaves [28], green asparagus [29], celery [30], lemongrass [31], etc.

2. Material and methods

2.1. Material
Fresh tea leaves (Camelia sinensis var. assamica) are supplied by PT Rumpunsari Medini, Kendal, Indonesia, clone TRI 2025.

2.2. Apparatus of vibrating fluidized bed drying
The vibrating fluidized bed dryer was a square continuous vibrating fluidized bed dryer with 2000 x 200 mm drying area [32] and consist of blower, LPG burner, mixing chamber, vibration generator, bed, hopper, panel and cyclone. The air is heated by an LPG burner and then sprayed into the mixing chamber and flows vertically to the bed. The air flow rate can be varied by changing the rotation of the blower using an inverter, while the temperature can be controlled automatically from the panel using thermocontrol. The VFBD was equipped with thermometer and hygrometer in the inlet, along the bed and outlet side. The schematic of the vibrating fluidized bed dryer can be seen in Fig.2 [32].

![Figure 2. Schematic of vibrating fluidized bed dryer.](image)

2.3. Apparatus of microwave-based drying machine
The microwave-based drying equipment was designed for laboratory scale, consist of hopper, microwave, fan, conveyer, electric motor, agitator and control panel, as presented in Fig.3. The dimension of the equipment is 3300mm(L) x 550mm(W) x 600mm(H). There are four commercial microwave oven, which has 2450 MHz frequency, placed directly after the hopper. Each microwave equipped with agitator to stir the tea leaves in order to be exposed to the waves evenly. A thermocontrol is used to turn off the microwave power if the temperature is in accordance with the desired setting.
2.4. Method

Tea leaves that have been plucked are sorted until the third leaf from the shoots, then followed by fixing process in the microwave for 2 minutes. Tea leaves that have undergone fixing process are then rolled manually and ready to be dried.

VFBD was set at a temperature of 70°C and an air flow velocity of 1.09 m/s at a blower frequency of 50 Hz after the temperature and velocity have been reached then 500 gr tea leaves were fed into the hopper. The tea leaves were weighed every 15 minutes when they come out of the equipment [32]. The process were repeated until a constant weight was reached.

The microwave was set to 70°C, after the temperature has been reached, then 500 gr tea leaves were fed through the hopper. The conveyor will carry the tea leaves across the microwave and then out into the cooling area. This cooling area is only used during the fixing process. The tea leaves were weighed every 2 minutes when they come out of the equipment. The process were repeated until a constant weight was reached.

Moisture content of tea leaves was determined in dry basis, calculated as the rate of water amount in the product to its dry weight [33]. Moisture content (g water/g dry matter) values were calculated using Equation (1).

\[ M_t = \frac{m_w}{m_w - m_s} \]  

(1)

In this equation, \( m_w \): water mass of tea leaves (gr), \( m_s \): dry mass of tea leaves (gr).

Moisture ratio was calculated using this equation [30]:

\[ M_t = \frac{m_w}{m_w - m_s} \]  

(2)

where MR is the moisture ratio, M is the moisture content at a given time (gr water per gr dry solids), Mo is the initial moisture content (gr water per gr dry solids), Me is the equilibrium moisture content (gr water per gr dry solids).

The drying rate is the change in the moisture content of the dried product by unit time [33]. Drying rate was determined as follows [34]:

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

(3)

whereas, \( M_t \) and \( M_{t+dt} \) are the moisture content at t and \( t+dt \) respectively and t is the drying time (min).

3. Results and discussion

3.1. Drying time and microwave content

The time needed by the microwave to dry 500 grams of tea leaves to reach a constant weight is 24 minutes, whereas if using VFBD it takes 85 minutes (Fig.4). Significant time reduction is the main advantage of microwave dryers. Comparison between microwave dryers and spouted beds, ovens, also shows a reduction in time between 25% to 90% [16,35]. Shorter drying time will increase productivity and reduce drying costs. Based on the work published in the open literature by various researchers, the key factors affecting the time required for the drying of biological products are mainly affected by the
drying mechanism and the conditions as well as the inherent properties of the material [19]. After fixing process, tea leaves containing high moisture contents, water accounts for the bulk of the dielectric component and is very intense in its reaction to microwave energy[19]. The same results were obtained for drying mint leaves [36], cassia alata [25], persimmon chips [37], chamomile leaves [38], sorbus fruits [39] and shitake mushrooms [26].

Comparison between the decrease in moisture content (dry basis) of tea leaves which are dried with a fluidized bed dryer and microwave can be seen in Fig.4. In VFBD, the constant rate period takes 25% of total drying time, and the rest is critical and falling rate period. While in microwave drying, around 50% of total drying time is constant rate period and the rest is critical and falling rate period. The falling rate period in VFBD requires longer time, which is up to 75% of the total drying time. Throughout the falling rate period, drying is inefficient as the dry product surface yields a high heat and mass transfer resistance layer, and the temperature gradient may be in the opposite direction of the moisture gradient.[16] In addition, during the falling rate period, the moisture content is low, the water molecules therefore have a higher evaporation enthalpy, and the removal of these molecules by evaporation requires higher energy input. When drying foods and agricultural products with conventional hot-air drying methods, this low heat and mass transfer efficiency will results in prolonged drying time and hence a severe quality degradation [16].

High energy efficiency can be achieved in microwave drying during the falling rate period. It is because the energy directly penetrates the central area of the leaves, comes into contact with the moisture, so there is no need to transfer heat from the low moisture surface to the high moisture area [16].

![Figure 4. Comparison of changes in moisture content based on time of tea leaves in fluidized bed drying and microwave drying, a. dry basis, b. wet basis.](image)

3.2. Moisture ratio
The dimensionless moisture ratio of green tea leaves was obtained using equation 1 and the relation of drying time and moisture ratio can be seen on Fig.5.
3.3. Drying rate

Figure 6 shows the drying rate (gr. water/gr solid.min) against drying time for vibrating fluidized bed dryer and microwave. The drying rate of tea leaves in the continuous microwave drying was higher than vibrating fluidized bed drying, due to the shorter drying time.

In microwave drying, the initial phase of the drying, the drying rate increased quickly because more energy of the microwave was absorbed and the moisture content of the tea leaves was very high. As the drying process continues, drying rate drops rapidly due to the solids surface moisture content decreases.

In VFBD, the longer the drying time, the removal of water from tea leaves due to the decreasing of drying rate. The drying rate decreased because the temperature difference between the tea and the air was very small and even roughly constant. As a result, the driving force of water to evaporate therefore decreases significantly [9].

Highest drying rate in VFBD dryer was 0.08 gr water/gr solid.min, while microwave dryer was 0.14 gr water/gr solid.min.

4. Conclusion

The time needed by the microwave to dry 500 grams of tea leaves to reach a constant weight is 24 minutes, whereas if using VFBD it takes 85. In VFBD, the constant rate period takes 25% of total drying time, and
the rest is critical and falling rate period. While in microwave drying, around 50% of total drying time is constant rate period and the rest is critical and falling rate period. The falling rate period in VFBD requires longer time, which is up to 75% of the total drying time. Highest drying rate in VFBD dryer was 0.08 gr water/gr solid.min, while microwave dryer was 0.14 gr water/gr solid.min.

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