Experimental Study on the Performance Characteristics of a Microwave - Solar Heating Dryer

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Abstract: The use of microwave energy for drying of agricultural products is recently developed due to the advantageous of heating the product much faster and more effective than conventional methods. Moisture content of agricultural product should be evaporated immediately after harvesting in order to inhibit microbial growth and decrease enzymes activity. This work aim to investigate characteristics of microwave-solar hot air drying of agricultural products such as rice grain and potato using a commercial microwave oven and hot air from a can solar collector. A domestic microwave oven was modified in order to operate as a microwave dryer device. The state of the art of microwave-solar heating was developed for investigation on drying performance of agricultural products such as grains and potato slices. Measurements on the temperature of drying chamber and moisture content of the product were conducted under different power inputs of microwave (low, middle and high) and intensity of solar drying. It was observed that microwave-solar air dryer proposed good heating performance and quality of products. Furthermore, temperature, moisture changes and drying rate could be controlled during the drying process.

1. Introduction
Drying is an important preservation processes of moisture removal from an agricultural product. This process be intended to evaporate the moisture content and to reduce water activity, in order to inhibit microbial growth and decrease enzymes activity inside the product [1]. The process can be quality enhancement, ease of handling and transporting, and probably the oldest method of food preservation [2]. Delayed drying of the crops may result in deterioration of products quality [3]. Drying processes is influenced by heat and mass transfer between hot airflow and product. Common traditional way of dehydration process is using hot air that is characterized by ineffective drying. Heat is transferred to the surface of the material by conduction, convection or radiation and into the interior part of material by thermal conduction. In this process moisture is initially evaporated from the surface and remaining water diffuses to the surface. The process time is limited by the rate of the heat flow into the body of the material which is depend on specific heat, thermal conductivity, density and viscosity of the material [4]. To overcome the limited of this scheme drying and to improve quality of the products, combination with the modern drying system is needed.
Microwave heating is an attractive heating scheme recently. Conventional heating and drying methods approach material from the surface, applying heat only to the outside edges. In this heating system the energy transmits from the surface to the interior while the moisture is transferred in opposite way from the inner to the surface. Microwave, however, is not forms of heat but forms of energy as heat that generates from interaction with materials. Electromagnetic wave produced from the magnetron of the microwave penetrates directly inside the material, Heat generated depends on the dielectric properties, shape and thickness of material [5-6]. In microwave drying system, the inner part of material is warmed as heat travels from the outer layers inward. If the material is highly wet and the pressure inside rises rapidly the moisture will be removed from the material due to the difference in pressure. This phenomenon creates a force action on the liquid to push it to the surface. Microwave energy does not heat the room but only the desired materials [7-8]. Heat producing in microwaves processes can be used for several dielectric solid and liquid materials containing some water [9-11].

Modern heating schemes propose high efficient drier as can be done in the microwave heating. Use of microwave energy in drying system offers a shorten time drying and completion the internal residual moisture by conventional drying in later steps [1,12]. Several studies have been using microwave as energy sources and compared with another heating schemes. Beaudry et al. [13] studied the effect of several heating methods including microwave convective (0.7W/g and 62°C), hot air (62°C), freeze and vacuum drying (94.6 kPa) on the quality of cranberries. They reported that all dried samples were acceptable and closest to commercial dried cranberries. Same effect was also studied by Piotrowski et al. [14] using strawberries. They reported that the fastest drying method was microwave convective, and the longest was for hot air drying at 62°C. This work aims to investigate the performance heating of microwave and hot air heating from can solar collector for agricultural products. In this study, preheating of microwave is supposed to bring all the moisture to the surface of the product and later flashed the moisture out by conventional heating-hot air.

2. Material and Methods

Agricultural products used in this study (rice grains and potato) were obtained from local farmer in Kendari during the rainy season 2018. The selected samples of potato were cleaned and sliced into thin layer-about 3mm of thickness. The grains and the sliced potatoes were stored at room temperature for 12hours until drying process. This process is intended to preserve its original quality and condition when the products just harvested.
forced through the products placed inside the heating chamber. Aluminum soda cans were holed and arranged in the absorber panel of 60cm width and 120 cm length.

Can collector is used to absorb heat from the sun and heat the air flow throughout the arranged cans. Air is entering to the bottom part of collector and experiencing heating inside the cans collector. Heated air is forced into the drying chamber by a small fan mounted on the top of collector. In order to evaluate the heating performance of the solar collector, temperature of air inlet and outlet were measured using K-Type Thermocouple.

A domestic microwave oven was used as the main energy source in this study. Electromagnetic wave from magnetron of the microwave was guided to the drying chamber by modifying the bottom part of microwave cavity. The driven electromagnetics can interact directly with the product inside the drying chamber to produce heat.

Experimental investigation on performance heating of the microwave-solar collector dryer was evaluated at different sample of materials and power input of microwave. Microwave used in this study is the microwave oven for domestic appliance with frequency of 2450MHz. Three levels of power heating scenarios were used - low, middle and high level. In order to investigate the temperature of the heating room and atmospheric temperature, K-Type thermocouple with 2 sensors cable were used. Moisture losses from samples dried was recorded by a means of digital balance at each 10 second intervals.

Experimental investigations were conducted at three different processes- natural drying at open sun (SUN), hot air coupled with microwave heating (MW+SUN), and microwave (MW). Drying rate is calculated based on the moisture reducing during a specific heating time for drying. Comprehensive analysis and descriptions on the experimental data are presented below.

3. Result and Discussion

Solar collector is one of the main heating sources for drying of the agricultural products in this study. Figure 2 shows the trend of hot air temperature produced from solar can collector (Tin) compared with the environment temperature (To) during experiment. Conditions of the sky was very clear along the time, however the blowing of wind was sometime come and affected the temperature of the hot air. It shows from the figure that the average temperature of hot air can reach around 60°C and it is hot enough for drying the agricultural products. Fluctuated trend at several points can reach 55°C and even lower is probably affected by the speed of the wind entering to the solar collector.

![Figure 2. The trend of hot air temperature produced (Tin) from solar can collector](image-url)
Moisture diffusion is mainly mass transfer of water content from inside to the surface material followed by evaporation process to the air. The change of moisture content with drying time of the three different heating processes of grain products can be seen in Figure 3. Moisture content escaped from product is expressed in mass reduction during drying time. Mass reduction was calculated based on the product mass recorded at the time divided by initial mass of the products. The lower mass reduction, the better the moisture evaporated from the products. It is clear that mass reduction of the moisture content decreases continuously during time heating. Comparing of the three heating schemes, it is revealed that combination drying of microwave and hot air (MW + SUN) is very effective drying scheme. In 60 minutes drying, the mass reduction can reach 68% while others heating schemes can reach 96% for Microwave (MW) and 98% for natural open sun drying (SUN).

Same trend of the three heating characteristics for potato slices can be shown in Figure 4. The moisture content of potato was very high in the initial state of drying which resulted in higher absorptions of microwave power and higher drying rate. It is also clear from the figure that moisture content escape rapidly from the product using MW+ SUN drying scheme following with MW and SUN drying. By 60 minutes drying time, the moisture reduction can be reduced to 68% in MW+SUN, 72% in MW and 96% in SUN respectively.
The particular structural of the product defines the volume, size and shape of the sample. Whenever the water content escaped from material, the unbalance pressure between inner and outer spaces is happened. This phenomenon can generate contracting stresses that leads to material shrinkage, changing in shape and sometimes cracking on the surface of the product [15]. Figure 5 shows the images of potato slices for two different heating, MW+SUN and SUN. Heat generated of microwave inside material tends to increase the inside pressure of moisture and pump the water to the surface and later evaporates to the air. The figure shows a shrinkage on the surface of potatoes dried by the SUN system. This characteristics may indicates the higher temperature at the surface than at the inner part of product. Higher surface temperature can increase the moisture evaporation from the surface and shrink the surface of product. It is totally different for heating product by microwave that generates heat inside material. The balance pressure between surface and inner part can inhibit the shrinkage. From previous figure can be seen that moisture content of product heated by MW + SUN is lower than heated by SUN that affect the shape and size of products.

Power of microwave drier has significant effect on the mass transfer of the moisture from the product. Figure 6 and Figure 7 show the mass reduction rate of the grain and potato for different power input during time drying. It is revealed that drying time can be reduced by increasing the power input of microwave. Thus, the higher power input can increase the heating rate of the product. These figures also shows that heating rate can be affected by the shape and size of material exposed microwave energy. Penetration depths of microwave is affected by the frequency of electromagnetic wave generated from magnetron of microwave. Microwave penetrates uniformly throughout the volume of product being

![Figure 5](image1.png)
**Figure 5.** The images of drying products at the two different heating schemes. A) is for MW+SUN and B) is for SUN heating

![Figure 6](image2.png)
**Figure 6.** Input power effect on the reduction rate of the moisture in the grain product

![Figure 7](image3.png)
**Figure 7.** Input power effect on the reduction rate of the moisture in the potato products
heated and this is called volumetric heating. It is contrasted with the traditional thermal heating which relies on conduction and convective heating from surface to the inner parts of the products. Combination of the two schemes can be a smart heating system for drying system of product.

4. Conclusions

Volumetric heating effect of microwave proposes the effective drying system for the agricultural crops. Combination of microwave and hot air heating schemes brings the new drying characteristics such as increasing the drying rate and improving the final quality. Power input can control the heating rate for microwave drying system and the shape of the product is the important thing to be mentioned.

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