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MICROWAVE DRYING KINETICS OF MUSHROOM SLICES

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Abstract

Drying is one of the mostly used food preservation techniques, which reduces moisture content sufficiently to prevent bacterial growth. One of the drying methods that gained popularity in recent years is microwave drying. Accordingly, in this study, microwave drying behavior of mushroom slices in various thicknesses was studied experimentally for various microwave power levels. In the study, 90W and 360W were selected as microwave power level, and 2mm, 4mm and 6mm were selected as slice thickness. During the experiment, the amount of moisture removed from the product was determined by weight measurements with a scale mounted to microwave oven. Experimental results show that microwave power has a significant effect on the drying rate of product and decreases the drying time considerably. The results also show that the effect of slice thickness is relatively small as compared with the microwave power level. The results also indicate that the Midilli et al. model is an appropriate model to describe the moisture content during microwave drying of mushroom slices. A color analysis was also conducted in this study in order to examine the effect of microwave drying on product quality in terms of color. The results show that there is a decrease in the color quality of the product due to the microwave drying.

Key words: *microwave drying, drying behavior, mushroom, modelling, color analysis*

1. INTRODUCTION

Because of the high level of the moisture content after harvest, food materials are generally dried using a proper drying method in order to be stored for a long period of time,. Traditionally used method in drying is hot air convective drying. However, drying with this method takes relatively long time, and therefore, the energy costs are in high levels. Drying time is high in this drying method because of drying mechanism. In convective hot air drying, drying mostly takes place with diffusion. In this method, heated drying air is sent on product. As a result of the heating, relative humidity decreases which increases moisture concentration difference between product and drying air. This concentration difference is the driving force for the moisture transfer with diffusion. In this drying method, moisture at the surface and places near surfaces of the product moves away quickly. In order drying to continue, the moisture inside the product needs to move towards the surface. This is, on the other hand, a long process and drying occurs depending upon internal resistance in this stage of drying. At this stage of drying, effect of the drying air conditions on drying rate is low. This increases the cost of energy because the drying air is heated continuously at every stage of drying. Both the long drying time and high energy costs gave way to the usage of other drying methods. One of these methods is microwave drying. In this drying method, microwave energy is sent to the product via magnetron. Water dipoles located in electromagnetic area in the product make twist movements of water molecules at a specific speed depending on the frequency. Friction forces that are formed due to this activity cause the product to be heated. Energy loss in this method is low because of the usage of energy just on water molecules. The mobility of water molecules increases as a result of heating and the water inside the product quickly moves away because of the pressure difference developing after the evaporation starts after a certain period of time. Because of this mechanism for moisture removal, microwave drying process of a product occurs in relatively short time and energy cost is much lower than convective air drying.

Microwave drying gradually gains popularity due to the advantages mentioned above. In parallel with this, there is an increase in the studies on this topic.

Microwave drying characteristics of various grains was studied by Xiurong et al. [1]. The results show that microwave method could be used as pretreatment of drying as it apparently shortens the heating time and increases the drying efficiency. The results also show that the activities of disbranching enzyme which has effects on the product quality decrease greatly when microwave drying is used for rice drying. On the other hand, microwave drying has little effect

on the cooking qualities and gelatinization of the rice. Xiurong et al. [1] also concluded that maize should be dried with the combination of microwave drying and hot air drying as the maize can absorb a great deal of microwave due to its high moisture content.

Microwave drying characteristics of pumpkin was investigated by Wang et al. [2] for different microwave power levels and pumpkin slice thicknesses. The experiments were conducted in two stages using the first and second stage power. The results show that the drying rate increases and the energy consumption decreases considerably with the increase of the microwave input power. The results also show that the thicker sample dries more quickly than the thinner sample during the first falling rate period, but the moisture removal rate for thin sample is slightly higher than the thicker sample for the second falling rate period. Wang et al. [2] also concluded that the first stage drying load-power should be higher for lower energy consumption and rehydration and second-stage drying load-power should be higher for lower rehydration and slightly lower for low energy consumption.

The drying characteristics of green peas were examined by Priyadarshini et al. [3] in a microwave dryer for microwave power levels of 20W, 40W, and 60W. The green peas were pretreated in the study with citric acid solutions and blanched with hot water before the drying experiments. The results show that the blanched samples dry faster than those in other pretreatments and rehydration capacity is higher for the pretreated samples. The results also show that sensory properties such as color, taste, texture, flavor, and appearance are in acceptable level for the water blanched sample product dried at microwave power level of 40W.

Microwave drying behavior of white onion slices was investigated by Kalse et al. [4] for various microwave power levels. The results show that drying times of onion slices at 0.25kW, 1.00kW, 1.50kW, and 2.25 kW level are 15.86h, 6.78h, 5.3h, and 3.2h. The results also show that there is no significant decrease in the quality of the dried product in respect to color, rehydration and water activity.

Microwave drying characteristics of cooked brown rice was investigated by Jaroenkit et al. [5] in the microwave power range of 280W to 320W. The results show that the optimum drying condition is at 300 W for 48min. The results also show that there is no change of crude protein, ash, crude fiber, and carbohydrate, but there is a little crude fat change after drying.

Microwave drying behavior of spinach leaves was investigated by Sharada [6] for four different microwave power levels ranging from 90W to 350W. The results show that the drying time takes a value from570s to 1350s depending on the microwave power level.

Darvishi et al. [7] studied the microwave drying characteristics of carrot slices for four different microwave power levels of 200W, 300W, 400W, and 500W and for slice thickness of 2.5mm. The results show that the drying rate increases rapidly first and then begin to decrease slowly as the drying proceeds.

Yan et al. [8] investigated the drying behavior of carrot pieces using different combined microwave drying model. The combined drying models used in the study are microwave-assisted vacuum drying, microwave–assisted freeze drying, and microwave-enhanced spouted bed drying. The results show that the drying rate is considerably higher for the product dried with the microwave-assisted vacuum drying and microwave-enhanced spouted drying than that dried with microwave-assisted freeze drying. The results also Show that the energy consumption takes its highest value when microwave-assisted freeze drying method is used.

In this study, the microwave drying behavior of mushroom experimentally examined in various microwave powers and various mushroom slice thicknesses. Also, a color analysis was performed in this study, and the effect of microwave drying on color quality of mushroom was specified.

2. MATERIAL AND METHODS

In this study, a commercially available microwave oven was used in order to investigate the drying behavior of mushroom slices. The microwave oven used in the experiments has 2450MHz frequency, 800W capacity, and 19L inner volume. Mushrooms used in the study were supplied from a local market and sliced in 2mm, 4mm and 6mm thicknesses. Mushroom slices used in the experiments was 20±1g. The moisture removed from the mushroom during drying was specified by weight measurement with a digital scale that has 620g capacity and ±0.001g accuracy. The dry mass of the mushrooms sliced in 2 mm, 4 mm and 6 mm thickness was also determined by keeping them in an oven at a temperature of 105° C for 24h. The results are given in Table 1.

Table 1. Dry weight of the mushroom slices for different slice thicknesses.

Thickness	Dry mass
2 mm	1.52 [g]
4 mm	1.54[g]
6 mm	1.56 [g]

In order to determine the moisture removed from the product, the weight measurements during drying performed via a scale were recorded on a computer at regular intervals by a software. In this study, experimental drying behavior of mushroom was determined for two different microwave powers (90W and 360W). Microwave drying process was continued until the moisture content of mushroom slices reaches to a specified value. In this study, also a color analysis for the product was conducted in order to see the effect of microwave drying on color quality of the product. The color measurements were performed using a Hunter Lab D25LT spectrophotometer.

3. RESULTS AND DISCUSSION

In this study, the drying behavior of mushroom slices, sliced at 2mm, 4mm and 6mm thicknesses were experimentally investigated at 90W and 360W microwave powers. The results were given based on the moisture content defined as follows:

$$m = \frac{M}{M_w} \tag{1}$$

where M and M_w are the instantaneous and initial mass of the mushroom slices.

Drying is a complex phenomenon which contains a combination of various drying mechanisms such as hydrodynamic flow, diffusion, and capillary flow. This makes the mathematical modeling rather difficult Furthermore, the complex structure of food materials imposes extra difficulties as far as the mathematical modeling is concerned. Therefore, empirical or semi-empirical models are generally used to describe the drying behavior of food materials. Midilli et al. model [9] defined below is one of the mostly used empirical models in drying modelling because of its success in predicting the drying behavior of food materials.

$$m = a\exp(-kt^n) + bt \tag{2}$$

where t is the drying time and a, k, n, and b are the drying constants. The Midilli et al. model was used in this study to predict the drying behavior of mushroom slices undergoing microwave drying.

In order to specify the effect of microwave drying on product quality, a color analysis was also conducted in this study. Three parameters used in the color analysis are L, which represents lightness, a, which represents redness, and b, which represents yellowness. L, lightness takes values between 0 (black) and 100 (white). Color density C and hue angle H were also calculated after measurements. They are defined as follows:

$$C = \sqrt{a^2 + b^2} \tag{3}$$

$$H = \arctan\frac{b}{a} \tag{4}$$

The following relations represent the change in the color parameters with respect to the fresh product:

$$\Delta a = a_{fresh} - a \tag{5}$$

$$\Delta b = b_{fresh} - b \quad (6)$$

$$\Delta L = L_{fresh} - L \quad (7)$$

Experimental drying behavior of mushroom slices for different microwave power levels and for the different slice thicknesses are shown in Figure 1 and 2. With the increase of the microwave power from 90W to 360W, a significant decrease in the drying time is seen depending on the increasing drying rate. 1450s - 1650s drying time for microwave power of 90W decreases to 330s – 390s for microwave power of 360W. This large decrease in the drying time with an increase at the microwave power level indicates that the effect of microwave power on drying is quite significant. As can be seen from the figures the effect of slice thickness on microwave drying rate is relatively low. It can also be seen from the Figures 1 and 2, the drying rate at the initial stage of the drying is relatively low, there is an increase at the later stage and towards the end of the drying it again begins to decrease. The reason for low drying rate at the initial stage of the drying is that microwave energy is used for the increase of the temperature of the product until the water inside the product reaches evaporation temperature. As a result of the pressure gradient developing with the beginning of evaporation at the later stages of drying, the moisture removes quickly from the product. The decrease at the drying rat towards the end of the drying is because of the fact that the moisture content of the product reaches low levels.

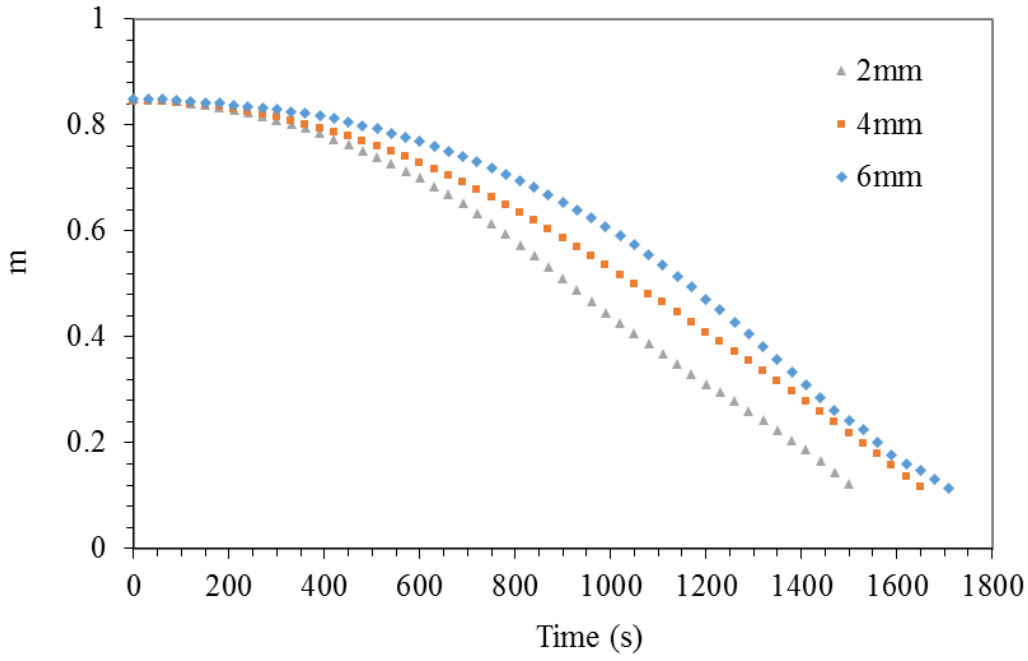


Figure 1. Variation of moisture content with drying time for microwave power of 90W.

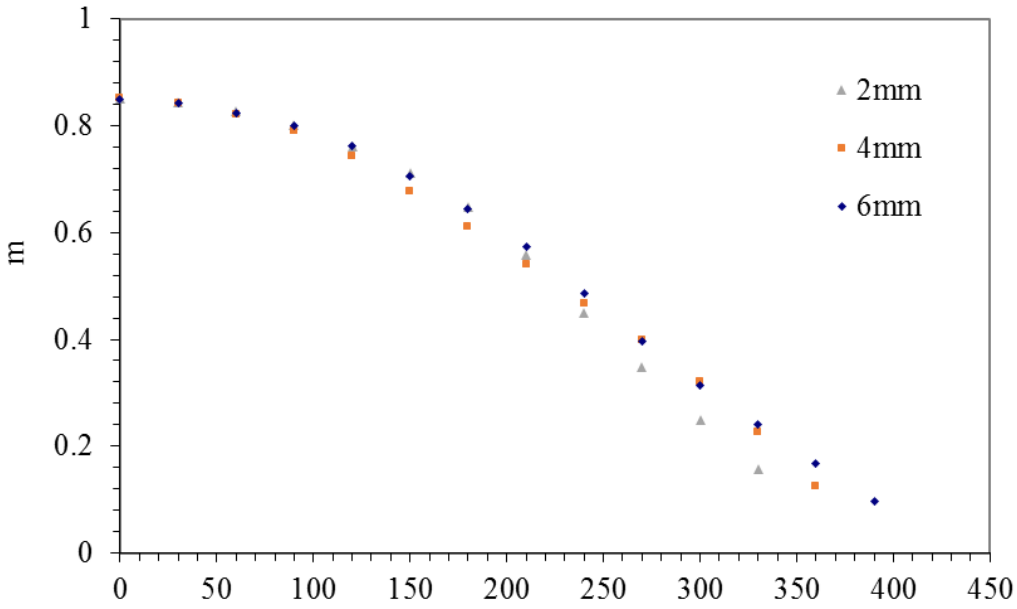


Figure 2. Variation of moisture content with drying time for microwave power of 360W.

The regression analysis results of the Midilli et al. model are shown in Table 2 and Figures 3 and 4 for various values of the slice thickness and microwave power level. As it can be observed that the root mean square deviation (rmse) has low values, which means that the Midilli et al. model predicts the microwave drying behavior of mushroom slices well. As it can also be seen from Figures 3 and 4 that the model yields the higher deviations between experimental and predicted moisture contents at the beginning and at the end of drying. These are the drying periods with low drying rates. However, overall agreement of predictions with the experimental and predicted values is very well. As it can be observed from Figures 3 and 4, an increase is seen at the deviation with the increase of microwave power level.

The color parameters of the dried mushroom and fresh slices are given in Table 2 for microwave powers of 90W and 360W and for slice thicknesses of 2mm, 4mm, and 6mm to make a comparison on color quality of the material. As it can be seen from Table 2, a relatively small change at the brightness and color is observed in the mushroom slices due to the microwave drying.

Table 2. The regression analysis results.

m. p.	thickness	a	k	n	b	rmse
90	2	0.78955	2.40427×10^{-2}	0.48714	-1.13882×10^{-3}	1.90×10^{-2}
	4	0.81753	1.66648×10^{-2}	0.53581	-1.10000×10^{-3}	2.64×10^{-2}
	6	0.78361	2.61536×10^{-2}	0.47016	-1.09088×10^{-3}	1.87×10^{-2}
360	2	0.75701	7.33884×10^{-2}	0.45706	-5.91345×10^{-3}	3.68×10^{-2}
	4	0.93755	-1.13200×10^{-8}	2.89502	-1.60010×10^{-3}	3.34×10^{-2}
	6	0.94326	-1.90832×10^{-7}	2.43886	-1.43171×10^{-3}	3.85×10^{-2}

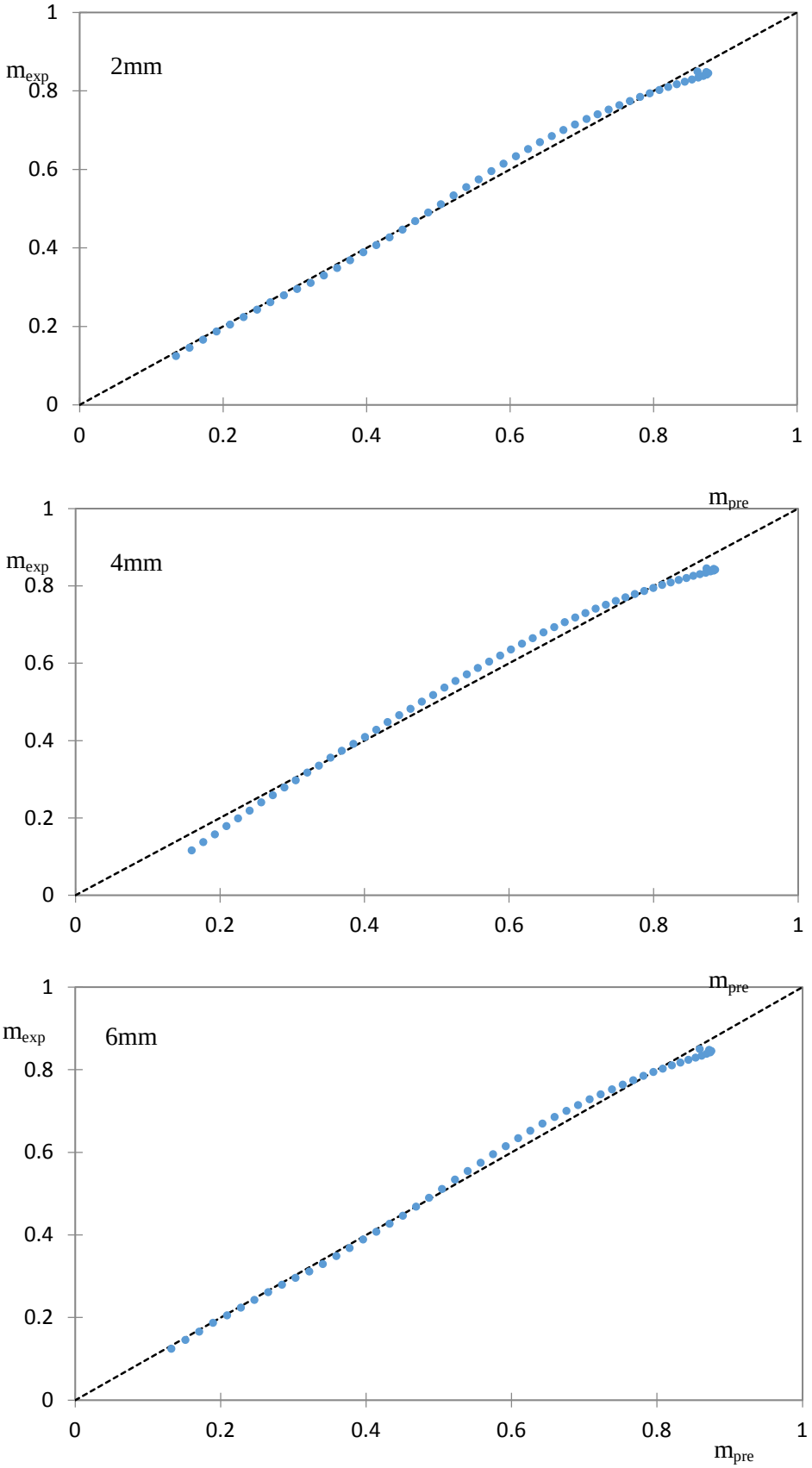


Figure 3. Experimental and predicted moisture contents for microwave power of 90W.

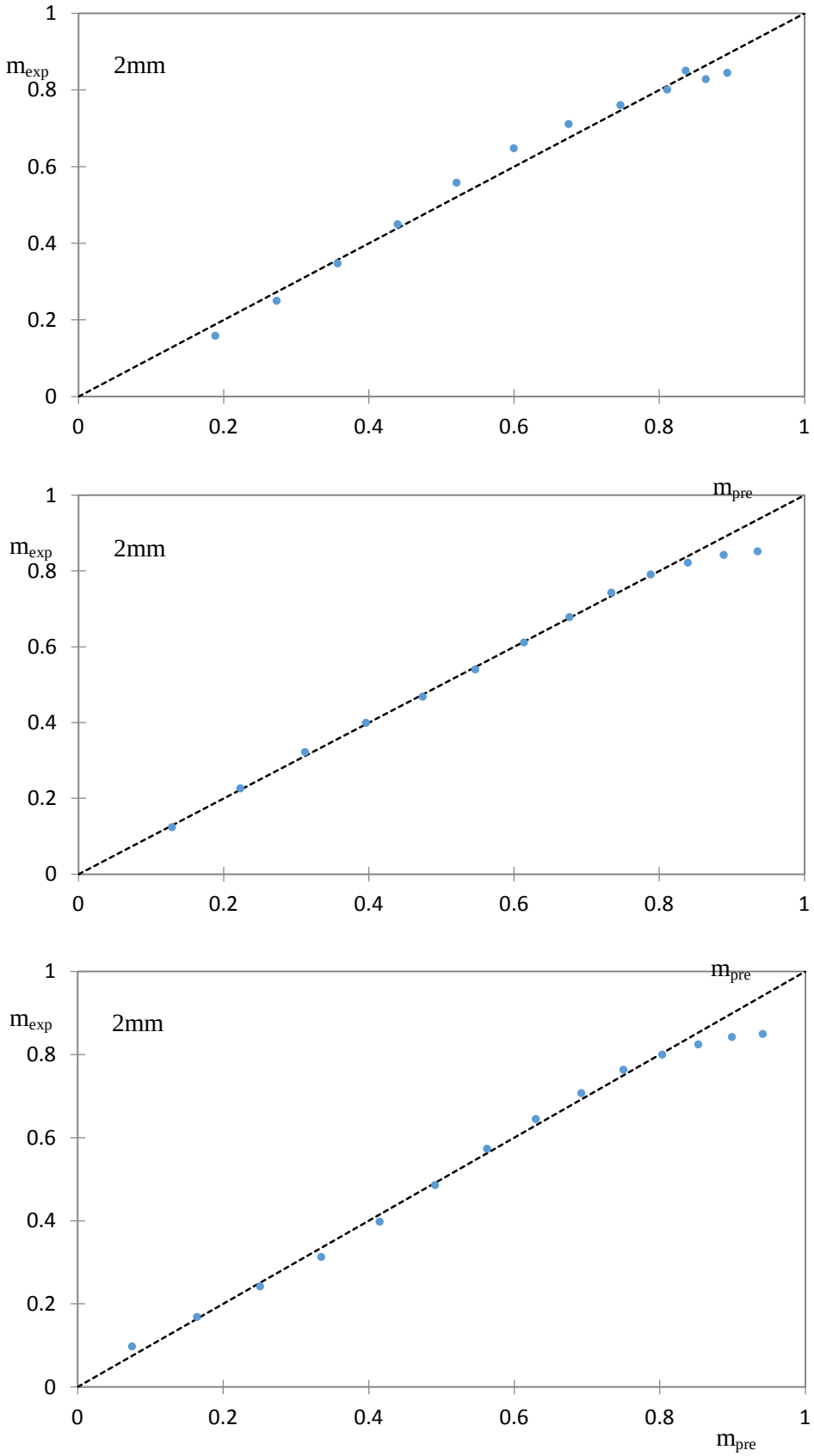


Figure 4. Experimental and predicted moisture contents for microwave power of 360W.

Table 2. The color parameters for microwave powers of 90 W and 360 W.

m. p.	thickness	L	a	b	C	H
fresh	-	83.96	4.06	11.64	12.83	70.78
90[W]	2 [mm]	45.44	10.11	32.55	32.44	71.85
	4 [mm]	50.15	9.86	29.64	31.24	71.59
	6 [mm]	59.53	9.09	27.57	29.03	71.76
360[W]	2 [mm]	53.83	15.69	37.22	40.39	67.14
	4 [mm]	60.12	13.60	38.49	40.83	70.53

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