Effect of far-infrared radiation assisted microwave-vacuum drying on drying characteristics and quality of red chilli

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Abstract Fresh red chilli (*Capsicum frutescens* L.) was dried using microwave-vacuum drying (MVD) and the far-infrared radiation assisted microwave-vacuum drying (FIR-MVD) method. The MVD was operated using the microwave power of 100, 200 and 300 W under absolute pressure of 21.33, 28.00 and 34.66 kPa. In terms of FIR-MVD, far-infrared power was applied at 100, 200 and 300 W. The effect of drying conditions, i.e., microwave power, absolute pressure and FIR power, on drying characteristics and qualities of dried product were investigated. It was observed that an increase in microwave power and FIR power with a decrease in absolute pressure could accelerate the drying rate. It was also found that FIR-MVD method required shorter drying time than MVD. Moreover, qualities, i.e., color changes, texture, rehydration ability and shrinkage, of FIR-MVD chilli were found to be better than those of MVD. Consequently, the optimum drying condition of FIR-MVD within this study was microwave power of 300 W under absolute pressure of 21.33 kPa with FIR power of 300 W.

Keywords Chilli · Drying · Far-infrared ·
Microwave-vacuum drying · Quality

Introduction

Dried chilli is one of spice products that used as condiments for flavoring and coloring in cuisines. Normally, the conventional drying method for chilli is sun drying, and remains the most practical method throughout chilli producing countries, which takes more than 5 days depending on weather conditions to obtain the required moisture content (4–11 % d.b.) (Phomkong et al. 2010). However, conventional drying method causes a major loss of qualities of the final product, due to the long drying time and direct exposure to the surroundings. Undesirable changes in the color attributes of the chilli may lead to a decrease in its quality and marketing value (Di Scala and Crapiste 2008; Santos and Silva 2008; Sigge et al. 1999). Some mechanical drying methods, i.e., heat pump drying and fluidized bed drying, have been applied to dry chilli in order to improve the quality of dried chilli and decrease the drying time, resulting in reduced quality of chilli as well as losses of volatile compounds, nutrients, and color (Pal et al. 2008; Alves-Filho et al. 2007; Yong et al. 2006).

As a result, the drying techniques which can reduce drying time and maintain qualities of dried chilli have been introduced to dry the product. Microwave drying (MW) technique has overcome the disadvantages of the conventional drying by reducing processing time that might improve the quality of final product. On the other hand, there are some research reported that the improper drying condition could reduce quality of product. Moisture accumulation at the surface during microwave heating, crispy surfaces become soggy and surface color development, is a problem. Therefore, the suggestion for reduction of surface moisture always point to increasing the surface temperature by additional heat source or applying vacuum condition. Microwave vacuum drying (MVD) was successfully applied in many dried agricultural products such as apple (Chong et al. 2013), carrot (Cui et al.

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2004; Arian et al. 2012), peach (Wang and Sheng 2006), shiitake mushroom (Kantong et al. 2012), sour cherry (Wojdyło et al. 2014), spinach (Ozkan et al. 2007) and Turmeric (Hirun et al. 2012).

Far-infrared radiation (FIR) has significant advantages over conventional drying. These advantages are higher drying rate, energy saving, and uniform temperature distribution giving a better quality product (Sandu 1986; Ratti and Mujumdar 2006; Kim et al. 2012; Ning et al. 2013; Mongpraneet et al. 2002). Many researchers reported that FIR could be combined with other drying techniques in order to obtain better quality of dried products and to reduce the drying time, such as FIR-convection drying (Itoh 1986; Afzal et al. 1999; Mongpraneet et al. 2002; Ning et al. 2013; Puente-Díaz et al. 2013), FIR-hot air impingement drying (Supmoon and Noomhorm 2013), FIR-vacuum drying (Mongpraneet et al. 2002), FIR-fluidized bed drying (Meeso et al. 2004), FIR-heat pump drying (Deng et al. 2011) and FIR-freeze drying (Lin et al. 2005, 2007).

Therefore, in this study, FIR was used as additional energy source to assist microwave-vacuum drying. Thus, the effects of operating parameters, i.e., Microwave power, FIR power and drying pressure, on the drying characteristics of chilli drying were investigated. Moreover, the physical properties, i.e., color changes, rehydration ability, texture and microstructure of dried chilli undergoing FIR-MVD process were also investigated.

Material and methods

Material

Fresh red chilli (*Capsicum frutescens* L.) was procured from a local market then washed and graded prior to storage in a refrigerator at 5 °C. Initial moisture content of chilli was determined using AOAC method (AOAC 2000). It was found that the initial moisture content of chilli was 85.53 ± 0.04 % wet basis. Chilli was blanched using hot water at 90°C for 3 min. (Gupta et al. 2002) and then cooled in cold water and drained on a perforated tray prior to drying.

Drying experiment

A laboratory scale far-infrared assisted microwave-vacuum dryer (Fig. 1) was developed for the present study using a 2,450 MHz, 800 W microwave oven (Samsung, MW83Z-Y, Thailand). The power of microwave oven was calibrated using the standard procedure (IMPI 2-L test) (Buffler 1993). A 500 W far-infrared heater (Infrapara, ceramic element, A-500, Selangor, Malaysia) equipped with dryer, the radiation intensity was varied using voltage regulator. Temperature was measured with a fluoroptic probe (accuracy of 0.01 °C) connected with a control unit (Luxtron; Model M600, Santa

Clara, California, U.S.A.). Sample mass was measured by a load cell (Tedeia-Huntleigh; Model 1022, Singapore) connected to a weighing indicator (AND; Model 4329, Tokyo, Japan); the data was recorded continuously at 1-second time interval by a computer. The vacuum condition inside the chamber was generated and controlled with a vacuum pump (Busch, R5, Germany) equipped with a pressure regulator.

Approximately 50 g of the chilli was placed on the sample holder in a microwave dryer which having microwave leakage less than 0.5 W/m^2 . The magnetron was operated to generate three microwave power outputs 100, 200 and 300 W. A vacuum pump was switched on to evacuate the drying chamber to desired absolute pressures of 21.33, 28.00 and 34.66 kPa. FIR power was varied using voltage regulator to desired drying powers, i.e., 100, 200 and 300 W. The drying continues until the sample mass was constant. However, in order to prevent thermal damage, the maximum temperature of the sample was limited to 80 °C.

Drying characteristics

The effects of drying methods and drying conditions on drying characteristics were studied. The average moisture ratio (MR) was calculated using Eq. 1:

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (1)$$

where M is sample moisture content (dry basis), M_e is the equilibrium moisture content which is assumed to be zero due to the vacuum condition (Maskan 2000), and M_0 is the initial moisture content dry basis.

Color measurement

Surface colors of chilli were measured using a colorimeter (HunterLab, ColorQuest XE Plus, Reston, VA, USA). Color was expressed in CIELAB, i.e., L^* (whiteness or brightness), a^* (redness/greenness) and b^* (yellowness/blueness) coordinates, standard illuminant D65 and observer 10°. The colorimeter was calibrated against a standard white plate ($L^* = 91.7$, $a^* = -1.16$, $b^* = 1.06$) before color measurement. In addition, total color changes were calculated by Eq. (2):

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

$$\Delta L^* = L^* - L_0^* \quad (3)$$

$$\Delta a^* = a^* - a_0^* \quad (4)$$

$$\Delta b^* = b^* - b_0^* \quad (5)$$

Fig. 1 Schematic diagram of combination far-infrared and microwave-vacuum dryer

where L_0^* , a_0^* and b_0^* are initial color parameters of the chilli, ΔE^* is total color change.

Rehydration ability

The rehydration ratio, measuring in terms of mass ratio, was determined by immersing 2 g of dried chilli in 20 mL distilled water at 90 °C in a constant temperature water bath, soaking for 10 min, then drained on a perforated tray. Mass of dried and rehydrated chilli were measured by a digital balance (Sartorius; Model RC 250S, Germany) with an accuracy of ± 0.0001 g (Mongpraneet et al. 2002). The rehydration ratio was then calculated by Eq. (6):

$$\text{Rehydration ratio} = \frac{m_0}{m} \quad (6)$$

where m is mass of the dried chilli, m_0 is mass of the rehydrated chilli.

Shrinkage coefficient

The shrinkage is a general term that has been used to describe loss of structure, which is analyzed in terms of the change of the volume of the sample (May and Perré 2002). Three chilli pods were used to determine shrinkage coefficient in each condition. Shrinkage coefficient was determined by liquid displacement method. Toluene (C_7H_8) was used instead of water because its surface tension is low, so that it fills even shallow dips in samples and its dissolution power is low (Özcan and Haciseferoğlu 2007). Each sample was placed into toluene that the weight was prior measured. Recording the change in weight of toluene, then calculated volume of product by Eq.(7):

$$V = \frac{m}{\rho} \quad (7)$$

where V is volume of sample (m^3), m is weight of toluene (kg) and ρ is density of toluene (862.27 kg/m^3). The volume of dried chilli was calculated by the same method. Then, the shrinkage coefficient was calculated using Eq.(8):

$$\text{Shrinkage coefficient} = 1 - \left(\frac{V}{V_0} \right) \quad (8)$$

where V is the volume of dried chilli (m^3) and V_0 is the volume of chilli before drying (m^3).

Texture measurement

Texture of dried chilli was measured as puncture force, which was a measure of the hardness of the product by a texture analyzer (TA-XT Plus; Stable Micro Systems, Surrey, England) using 2 mm cylindrical probe. The maximum force required to break the surface of dried chilli was recorded. The speed of 0.5 mm/s and penetration distance of 3 mm was used to measure the samples. The measured values were mean values of 3 measurements.

Scanning electron microscopy

The microstructure of chilli after drying was observed by scanning electron microscope (JEOL, JSM-5800, Tokyo, Japan) The microstructure of dried chilli was observed along the cross-section at the center of the piece. Samples were cut into small pieces by a sharp razor blade and mounted on aluminum stubs using conductive adhesive tape. Then, the sample was sputter-coated with gold and observed at 15 kV and $500 \times$ magnifications.

Statistical analysis

All experiments were performed in triplicate and the mean values with standard deviation were reported. The analysis of variance (ANOVA) and Duncan's multiple range test were used to establish the multiple comparisons of the mean values using the Minitab® 16 (Student version, Minitab Inc., PA, USA). Level of significance was considered at 95 % ($p=0.05$).

Results and discussion

Drying characteristics of chilli

The results showed that the plot of moisture ratio versus drying time of the chilli varied with microwave power, absolute pressure and FIR power. The effect of microwave power showed that the drying time of the chilli undergoing microwave power of 300 W (Fig. 2c) was shorter than those dried with lower microwave power of 200 (Fig. 2b) and 100 W (Fig. 2a). The increase in microwave power resulted in rapid

Fig. 2 Effect of absolute pressure on drying characteristics of chilli undergoing MVD at different microwave powers: (a) 100 W, (b) 200 W and (c) 300 W

heating, thus increasing the vaporization of moisture and increased vapor pressure inside the product that caused the diffusion of moisture towards the surface faster (Datta 2001; Sharma and Prasad 2004). Moreover, the absolute pressure

also had significant effects on the drying time. At microwave power of 300 W (Fig. 2c), the lower absolute pressure (21.33 kPa) provided shorter drying time. Similar results were found at other microwave power levels (Figs. 2a and 2b). The decrease in drying pressure reduced boiling point temperature of water that caused vaporization occurring at temperature lower than 100 °C and generated pressure gradient between surface and drying chamber which could accelerate the moisture diffusion to surroundings (Kaensup et al. 2002; Cui et al. 2004), consequently drying time reduced dramatically.

In terms of FIR-MVD, the drying time decreased with the increase in FIR power as expected (Figs. 3a–c) because during the FIR-MVD, additional thermal energy was brought with FIR. The extra thermal energy generated by FIR during FIR-MVD which caused much larger temperature gradients within the sample, an increase in radiation intensity led to an increase in drying rate. This result was consistent with those reported by Mongpraneet et al. (2002); Pathare and Sharma (2006); Nasiroglu and Kocabiyik (2009); Supmoon and Noomhorm (2013). The drying time and the percentage of drying time reduction at each drying condition were reported in Table 1.

Quality of dried chilli

Color

Figures 4–6 show the average value of the coordinates L^* , a^* , and b^* for MVD and FIR-MVD dried chilli. The measured initial values of the lightness (L_0^*), redness (a_0^*), and yellowness (b_0^*) of fresh chilli were in the ranges of 46.53 ± 1.52 , 60.95 ± 3.10 , and 41.15 ± 3.07 , respectively. The results of dried chilli undergoing FIR-MVD showed that microwave power level, absolute pressure level and FIR power level were the significant factors influencing the changes of lightness (Fig. 4), drying at higher microwave power and FIR power with lower absolute pressure showed lower changes of lightness value. Drying at lower microwave power and FIR power, chilli was dried at high temperature longer than that of products dried at higher microwave power and FIR power. FIR-MVD products became darker, it was probably due to a larger extension of the non-enzymatic browning reaction, especially at higher drying temperatures (Acevedo et al. 2008; Manzocco et al. 2000).

The changes of redness were shown in Fig. 5, the results revealed that that microwave power level, absolute pressure level and FIR power level were the significant factors influencing the changes of redness. Dried chilli undergoing FIR-MVD had higher redness value than that of fresh one. As a result of additional heat source of FIR, a higher drying temperature of FIR-MVD affected a larger increase of the redness. This could be due to the remaining of carotenoids and other components in the chilli together with the brown

Fig. 3 Effect of FIR power on drying characteristics of chilli undergoing FIR-MVD at microwave power of 300 W and absolute pressures of: (a) 21.33 kPa, (b) 28.00 kPa and (c) 34.66 kPa

pigments which generated due to the non-enzymatic browning reactions along drying process. It was also reported by Lee et al. (1991) that non-enzymatic browning in dried chilli was

Table 1 Drying time and percentage of drying time reduction of dried chilli at various FIR-MVD drying conditions

MW power (W)	Absolute pressure (kPa)	FIR power (W)	Drying time (min)	Drying time reduction (%)
100	21.33	0	125±5	46.12
		100	107±4	53.88
		200	98±2	57.76
		300	90±4	61.21
	28.00	0	167±5	28.02
		100	150±4	35.34
		200	134±3	42.24
		300	121±3	47.84
	34.66	0	232±5	-
		100	195±5	15.95
		200	181±4	21.98
		300	173±5	25.43
200	21.33	0	58±2	75.00
		100	43±2	81.47
		200	38±2	83.62
		300	34±1	85.34
	28.00	0	78±3	66.38
		100	53±2	77.16
		200	49±1	78.88
		300	40±2	82.76
	34.66	0	100±3	56.90
		100	77±3	66.81
		200	60±2	74.14
		300	52±2	77.59
300	21.33	0	50±2	78.45
		100	39±2	83.19
		200	35±2	84.91
		300	30±1	87.07
	28.00	0	58±3	75.00
		100	45±2	80.60
		200	38±2	83.62
		300	34±2	85.34
	34.66	0	78±4	66.38
		100	58±2	75.00
		200	54±2	76.72
		300	42±3	81.90

due to a Maillard reaction between reducing sugar and amino acid in pericarp. In terms of the effects of FIR power level on the changes of redness, although, the drying temperature of all FIR-MVD conditions were in the same range, drying at lower FIR power also provided higher changes of the redness due to the longer processing time.

Furthermore, FIR-MVD also provided a higher change of yellowness since non-enzymatic browning reactions were accelerated by a higher temperature. The effects of microwave

Fig. 4 Effects of microwave power and FIR power on the lightness changes of dried chilli undergoing FIR-MVD at absolute pressures of: (a) 21.33 kPa, (b) 28.00 kPa and (c) 34.66 kPa

power level, absolute pressure level and FIR power level on the changes of yellowness were significant (Fig. 6). In terms of total color change, the results changed from 3.75 to 12.99. It was observed that chilli dried a higher microwave power level,

Fig. 5 Effects of microwave power and FIR power on the redness changes of dried chilli undergoing FIR-MVD at absolute pressures of: (a) 21.33 kPa, (b) 28.00 kPa and (c) 34.66 kPa

FIR power level and lower absolute pressure level provided lower total color change. A shorter processing time reduced a brown pigment generation due to non-enzymatic reaction. The major color change in red pepper during drying was due to the

Fig. 6 Effects of microwave power and FIR power on the yellowness changes of dried chilli undergoing FIR-MVD at absolute pressures of: (a) 21.33 kPa, (b) 28.00 kPa and (c) 34.66 kPa

large increase in the content of brown pigment which were due to their high levels of reducing sugars and amino acids in fresh red pepper (Turhan et al. 1997).

Rehydration ability

Rehydration ability of products depends on structural changes of food material during drying, which produces shrinkage and collapse (Kaymak-Ertekin 2002). Fig. 7 presents the rehydration ratio for each condition studied. The statistical analysis showed that microwave power and absolute pressure affected the rehydration ratio significantly ($p < 0.05$) while the different levels of FIR power had no significant ($p > 0.05$) effect on the rehydration ability. The rehydration ratio increased as the microwave power and FIR power increased, while absolute pressure decreased. In terms of microwave power, when higher microwave power was applied, the larger heat generation inside chilli occurred. This creates a large vapor pressure inside materials allowing rapid moisture transfer to surroundings and preventing structure collapse. In addition, when lower absolute pressure was applied, the rehydration ratio increased. This could be due to the fact that a large vapor pressure inside the chilli was higher than drying chamber resulting in a force that prevented the structure collapse during drying. Therefore, the less collapsed structure and the greater porous structure formation could enhance the rehydration ability of chilli. Regarding the effect of FIR power on the rehydration ratio of chilli, when FIR was applied to the process, it could enhance the rehydration ability. A shorter drying time and quicker moisture diffusion could prevent the structure collapse and raise the porous structure inside chilli. Thus, the chilli could be heightened its ability to re-absorb water during rehydration. The maximum rehydration ratio was 1.49 ± 0.01 at microwave power of 300 W, absolute pressure 21.33 kPa and FIR power 300 W. In addition, improper drying condition leads to the collapse of structure which is known as a barrier to re-absorb the water. The samples dried at lower microwave power, FIR power and higher absolute pressure reduced their rehydration ability. This could be explained due to cellular structure collapse during drying that resulting in the obstruction of water diffusion through the product during rehydration process (Jayaraman et al. 1990; Krokida and Maroulis 2001). Fortunately, the use of the optimum condition of FIR-MVD could prevent the collapsed structure and enhance puffing phenomena that influenced water absorption. This shows the advantage of FIR when combined with MVD.

Textural property

Figure 8 shows effect of drying condition on the hardness of dried chilli. The results showed that drying with FIR-MVD required lower maximum force for breaking dried product than those of MVD products (data is not shown). Statistical analysis showed that microwave power and absolute pressure affected the hardness of chill significantly ($p < 0.05$). On the other hand, the level of FIR power had no significant difference on the hardness of chilli. The hardness reduction could

Fig. 7 Effects of microwave power and FIR power on the rehydration ability of dried chilli undergoing FIR-MVD at absolute pressures of: (a) 21.33 kPa, (b) 28.00 kPa and (c) 34.66 kPa

be explained due to the greater amount of porous structure formation inside product during drying resulting in the expansion of product that caused product easier to break. In case of

Fig. 8 Effects of microwave power and FIR power on the hardness of dried chilli undergoing FIR-MVD at absolute pressures of: (a) 21.33 kPa, (b) 28.00 kPa and (c) 34.66 kPa

MVD, chilli dried undergoing higher microwave power and lower absolute pressure represented lower hardness. During drying process, when chilli absorbed microwave energy and

Fig. 9 Effects of microwave power and FIR power on the shrinkage coefficient of dried chilli undergoing FIR-MVD at absolute pressures of: (a) 21.33 kPa, (b) 28.00 kPa and (c) 34.66 kPa

generated heat, then the evaporation and vaporization occurred inside chilli and transferred to the drying chamber resulted in a vapor pressure difference. Simultaneous phenomenon of pressure reduced by applied vacuum condition in

drying chamber, the pressure difference was increased and then caused an expansion of chilli's internal structure (Giri and Prasad 2007). So, the chilli represented a puffing structure. In terms of effect of FIR power, when FIR was applied to drying process, the extra heat source from FIR could increase the surface temperature. Therefore, the surface moisture evaporation occurred faster and chilli could retain its internal structure, so it tends to the reduction of hardness compared with those of MVD. The hardness of dried product decreased as microwave power and FIR power increased while absolute pressure decreased. The hardness was found to be the lowest on the drying condition of microwave power 300 W, absolute pressure 21.33 kPa and FIR power 300 W. The texture, in terms of the hardness, is one of the important properties which can be related to rehydration ability. The softer texture (low

Fig. 10 Microstructure of chilli undergoing MVD: (a) 300 W at 21.33 kPa; (b) 100 W at 21.33 kPa; and (c) 100 W at 34.66 kPa

hardness) showed the more possibility to the more water absorption (Giri and Prasad 2007; Therdtai and Zhou 2009).

Shrinkage

Shrinkage is usually expressed by the ratio between the volume of the sample before and after drying. The presence of shrinkage can be used to describe the occurrence of collapse or loss of structure, and in particular a drastic decrease in porosity in dehydrated materials (Yan et al. 2008). The results of shrinkage coefficient were shown in Fig. 9. It was observed that shrinkage of FIR-MVD dried products were lower than those of MVD dried products. This result could be explained that MVD dried products lost their internal structure due to the collapse of cell during drying. On the other hand, the generation of porous structure and the expansion of FIR-MVD dried product during drying resulting in lower shrinkage of final product. The shrinkage found to be decreased with an increase of microwave power and FIR power, while a decrease of absolute pressure. The minimum shrinkage coefficient was 0.0218 ± 0.0005 , which was found in the chilli dried undergoing microwave power 300 W, absolute pressure 21.33 kPa and FIR power 300 W.

Microstructure

Figure 10 shows microstructure of chilli dried at different drying conditions. The pack-damaged chilli tissue was mostly found in MVD dried products. On the other hand, the

expanded internal structure was more pronounced in FIR-MVD dried products. In terms of MVD, drying at higher microwave power is able to maintain the internal structure of chilli and provide more porous structure. MVD at 200 W with 21.33 kPa (Fig. 10a) generated more porous structure compared with MVD at 100 W with 21.33 kPa (Fig. 10b). This is because the increasing of microwave power tends to increase evaporation rate that prevent the shrinkage and case hardening (Therdtai and Zhou 2009). Moreover, absolute pressure also had effect on the microstructure of dried chilli, when lower absolute pressure applied the microstructure exhibited more porous and inhibited collapsed structure. MVD at 100 W with 21.33 kPa generated the numerous porous and less collapsed structure (Fig. 10b) compared with MVD at 100 and 28.00 kPa that clearly showed a collapsed structure (Fig. 10c). This could be explained by the fact that drying at lower absolute pressure generates a larger vapor pressure difference between chilli and the drying chamber, which accelerates moisture transfer from chilli to the surroundings. This phenomenon can prevent the collapse of structure and also increases the expansion of internal structure. In terms of FIR-MVD, dried chilli undergoing FIR-MVD (Fig. 11) had more porous and less collapsed structure than those of MVD (Fig. 10). It is because the rapid evaporation and moisture transfer from chilli to the surrounding which occurs along drying process. These occurrences resulted in both retained and developed the porous structure within chilli and thus generated puffing structure (Nathakaranakule et al. 2010). The microstructure of FIR-MVD dried products validated

Fig. 11 Microstructure of chilli undergoing FIR-MVD: (a) MW 300 W, FIR 300 W at 21.33 kPa; (b) MW 300 W, FIR 100 W at 21.33 kPa; (c) MW 300 W, FIR 300 W at 34.66 kPa; and (d) MW 100 W, FIR 300 W at 34.66 kPa

those previous mentioned results of physical properties, i.e., rehydration ratio (Fig. 7), hardness (Fig. 8) and, shrinkage coefficient (Fig. 9) of dried chilli which decreased shrinkage and hardness while increased rehydration ability of products. The chilli dried at microwave power 300 W, absolute pressure 21.33 kPa and FIR power 300 W (Fig. 11a) presented more expansion of internal structure and greater porous structure formation than those of other conditions of FIR-MVD.

Conclusion

Conventional drying method causes a major loss of qualities of dried chilli. In this study the far-infrared assisted microwave-vacuum drying technique was proposed for drying red chilli. The drying characteristics of FIR-MVD showed that the drying parameters, i.e., microwave power, FIR power and absolute pressure levels, had effect on drying time. The result showed that drying at higher microwave power, higher FIR power and lower absolute pressure the drying time decreased. Moreover, the effects of drying conditions on the changes of color, texture, shrinkage, rehydration ability and microstructure were also investigated. Drying chilli at higher microwave power, higher FIR power and lower absolute pressure provided lower changes of all color parameters (L^* , a^* , b^* and ΔE) as well as shrinkage coefficient and hardness were also found to be lower, while rehydration ability was found to be higher. Consequently, the optimum condition for drying chilli in this study was at microwave power of 300 W under absolute pressure of 21.33 kPa with the applied FIR power of 300 W.

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