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Roasting Chilli (*Capsicum annuum* L.) Using Far-Infrared Radiation

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ABSTRACT: *Chilli (Capsicum annuum L.) is presently roasted using conduction heating in electrically-heated mechanical roasters. In this study, the possibility of using Far-Infrared (FIR) radiation heating for roasting chilli was investigated. The moisture content, temperature and colour variation of chilli pods at 3240, 3920, 5260 and 7188 W/m^2 FIR radiation intensities with different exposure times were measured. The colour of the factory roasted chilli pods prepared using a drum roaster at 120 °C for 25 min were 30.73(L^*), 9.33(a^*) and 48.51(b^*). These values were used as the standard and compared with the colour values of chilli roasted with FIR radiation. The factory-roasted colour of chilli pods was achieved in 60 s at the highest intensity of FIR radiation (7188 W/m^2) used in the experiment. The chilli temperature rose above 100 °C and the moisture content reached 9.02% (dry basis - db) at 60 s FIR exposure with 7188 W/m^2. At the radiation intensities of 3240, 3920, 5260 W/m^2, the factory-roasted colour of chilli was achieved at 124, 117, 107 s and the corresponding interpolated moisture contents were 8.38, 6.70 and 6.59% db, respectively.*

Keywords: *Chilli, drying, far-infrared, heating, roasting.*

INTRODUCTION

Chilli is an important spice and a potential cash crop in the world (Hossain *et al*., 2005). It has become an essential ingredient in Sri Lankan meals. Per capita consumption of chilli in the form of dry chilli is estimated as 2.32 kg per annum and the national annual requirement of dry chilli is around 42,634 MT. Fresh red chillies are perishable in nature and considerable amount of the produce is wasted due to lack of postharvest processing facilities. Drying is the most widely used primary method of food preservation (Gupta *et al*., 2002). Chilli is dried for making chilli powder and for both short and long term storage (Hossain *et al.*, 2005).

Dry roasting is a process by which heat is applied to dry food stuffs without the use of oil or water as a carrier. Dry roasting foods are stirred as they are roasted to ensure even heating and it can be done in a drying pan or wok (a common way to prepare spices in some cuisines or in a special roaster as it is used for coffee beans or peanuts). Roasting usually causes caramelization or Maillard browning of the surface of food, which is considered by some as flavor enhancement. It is done with adding various herbs, spices and sugars into drying pan and roasting until brown. The typical Sri Lankan flavor is due to heavy roasting of some

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species (cumin, coriander, black mustard and fenugreek) until they reach a rather dark colour. It is often said that Sri Lankan curries have a “darker” or “browner” flavor than Indian curies. Roasting or frying, practiced in Sri Lanka and India enhances the flavour (Takeda *et al*., 2007).

IR radiation is energy in the form of electromagnetic wave and lies in the wavelength range between 0.78 and 1000 µm (Ranjan *et al.,* 2002). It is more rapid in heat transfer than convection and conduction mechanisms (Yang *et al.*, 2010). IR radiation has received considerable attention lately because of its advantages in shortening drying time, high energy transfer rate, energy savings, and superior product quality compared to conventional heated air drying (Afzal *et al*., 1999 & Tan *et al*., 2001). The FIR wavelength lies in the wavelength range between 4−1000 µm (Von & Staack, 2008) and the FIR heat application can be classified into four major categories as baking, drying, thawing and pasteurization (Lam, 2009).

IR impinges on the material surface and penetrates in to the exposed material. The vibration is increased due to absorption of radiation and generates heat at surface and inner layers of the material simultaneously, which increases the heating rate (Sakai & Hanzawa, 1994 and Hebber *et al*., 2004). The maximum depth of IR penetration into agricultural produce has been found to be 18 mm (Sandu, 1986). Thus, the application of IR heating for achieving high drying rate should be focused on thin layer drying.

The objective of the research was to study the possibility of applying FIR radiation for roasting chilli and compare with industrial drum roasted chilli.

METHODOLOGY

Single layer of chilli pods (an unknown variety imported from India, average length 10.54 cm, width 1.31 cm and thickness 0.34 cm, bulk density 0.725 g/cm^3) were exposed to FIR radiation (450 – 500 °C surface temperature) produced by 15 cm x 5 cm electric ceramic emitter (660 W). The moisture content, temperature and the colour variation of chilli pods at 3240, 3920, 5260 and 7188 W/m^2 FIR radiation intensities with different exposure times were measured. The experiments were conducted at the Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya, Sri Lanka in 2013.

Chilli samples

Dried and factory roasted chilli samples were procured from a leading spice processing factory at *Kundasale*, Sri Lanka. The dried chilli samples were obtained from unroasted bulk chilli stored at the factory. The samples were temporary stored in polythene pouches (gauge 200) in the laboratory for the experiments. Moisture content of the sample was 11% db.

Unroasted chilli sample (250 g) was roasted in 24 kW drum roaster (HENAN JINGXIN JXER 100, China) for 25 minutes. The roasted sample was used as the reference to achieve similar colour with FIR radiation roasting. FIR radiation roasting experiments were conducted with 12.19±1.16 g of unroasted chilli sample.

Experimental setup

The schematic diagram of the FIR chilli roasting setup is shown in Fig. 1. FIR was produced using 15 cm x 5 cm ceramic electric IR module with 660 W power mounted at the top of the apparatus. An aluminum reflective waveguide (30 cm height and 25.4 cm radius) surrounding the FIR emitter, guides the IR waves on to the sample, fairly a uniform distribution of IR across the cross section. A single layer of chilli (12.19±1.16 g) was exposed to FIR radiation by placing the sample under the FIR emitter, on 5 mm thick wooden sample tray (15 cm x 5 cm), at predetermined distances for 240 s. The required IR intensity was achieved by adjusting distance between the sample and the FIR emitter. The distance to achieve the required FIR intensities, 7188, 5260, 3920 and 3240 W/m^2 were determined at 10, 15, 20, 25 cm respectively. These intensities were selected as they were the practically important intensities nearly at 1000 W/m^2 intervals.

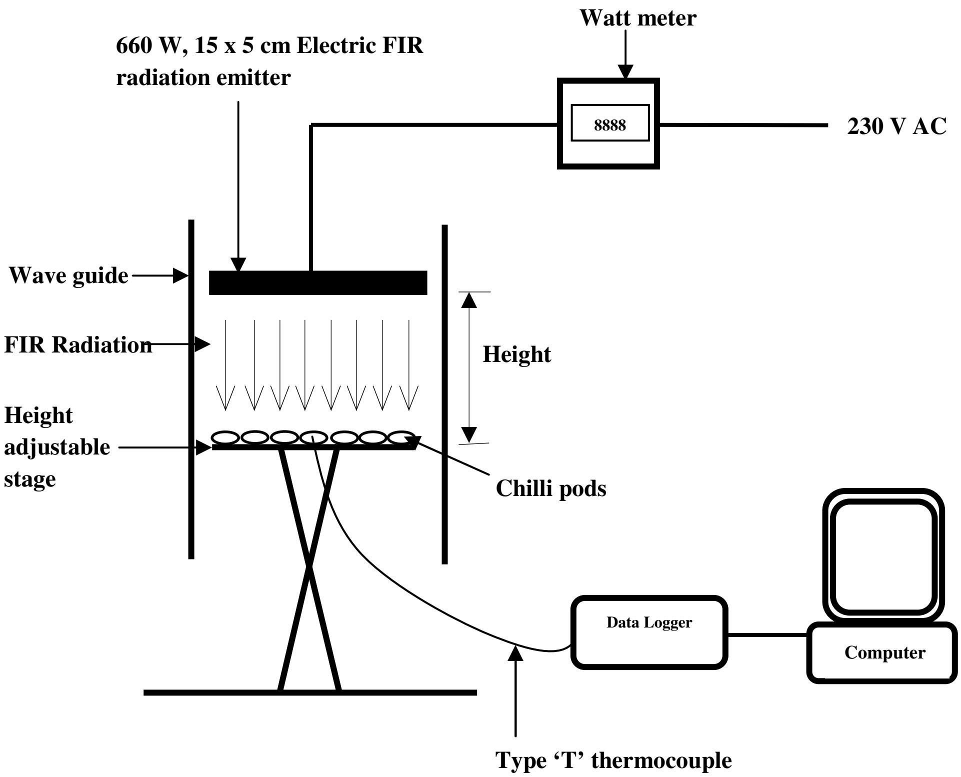

Fig. 1. Schematic diagram of the FIR chilli roasting setup.

The FIR heating device was turned on for 5 minutes to reach the working temperature before placing the samples. The intensity of FIR radiation was measured using OPHIR FL205A Thermal Excimer Absorber Head (Ophir Optronics Inc., Wilmington, Mass., U.S.A.) and the height adjustable stage was set to the required height depending on the radiation intensity.

Chilli pods were kept as a single layer on a wooden plate to avoid FIR reflection during the experiment. At the time of FIR exposure, temperature measurements and moisture content were recorded. Colour changes were measured using a single chilli pod.

Moisture variation with FIR radiation

The initial moisture content of chilli was 11% db and the weight loss of roasting sample under different FIR radiation intensities (3240, 3920, 5260 and 7188 W/m^2) was measured using an electronic balance (CTG 602B-600, CITIZEN SCALE Inc. USA) at predetermined time intervals (0, 60, 120, 180 seconds). Chilli pods (12.19±1.16 g) were spreaded on a wooden plate and kept on the height adjustable stage for FIR radiation exposure.

Temperature and colour variation of chilli exposed to FIR radiation

The temperature of chilli pods exposed to different radiation intensities were measured and recorded using T-type thermocouples inserted into three pods in each trial. Thermocouples were connected to a data logger (TC-8, OMEGA, Japan) and the data logger was connected to a computer as shown in Figure 1. The temperature measured and recorded in 1 s interval up to 240 s.

The colour change of chilli pods roasted with FIR radiation was measured using a Chroma meter (Minolta CR 300, Japan). Three replicates were used and average values were recorded. The colour of the factory roasted chilli sample obtained from the leading spice processing factory at *Kundasale* was measured and the L*a*b* values obtained from 20 chilli pods were averaged. The values were used as the standard roasted colour of chilli and compared with the FIR roasted chilli colour.

RESULTS AND DISCUSSION

Moisture removal under different drying treatments

Table 1 shows the variation of moisture content during FIR roasting chilli at different radiation intensities. The moisture removal of chilli during FIR heating showed a linear relationship (Fig. 2) with time contrast to convectional drying shows logarithmic drying characteristics. Rate of drying increased with increasing radiation intensity.

Table 1. Moisture content and rate of drying with different radiation intensities.

Time (t), s	3240 W/m2		3920 W/m2		5260 W/m2		7188 W/m2	
	MC	dMC/dt	MC	dMC/dt	MC	dMC/dt	MC	dMC/dt
0	11.00±0.00	0.00	11.00±0.00	0.00	11.00±0.00	0.00	11.00±0.00	0.00
60	10.08±0.01	0.02	8.59±0.02	0.04	8.78±0.01	0.04	9.02±0.02	0.03
120	8.69±0.02	0.02	6.66±0.01	0.03	5.67±0.02	0.05	6.24±0.01	0.05
180	6.84±0.01	0.03	4.73±0.01	0.03	3.45±0.01	0.04	2.68±0.02	0.06

MC (Moisture content %, dry basis), dMC/dt (Moisture removal rate)

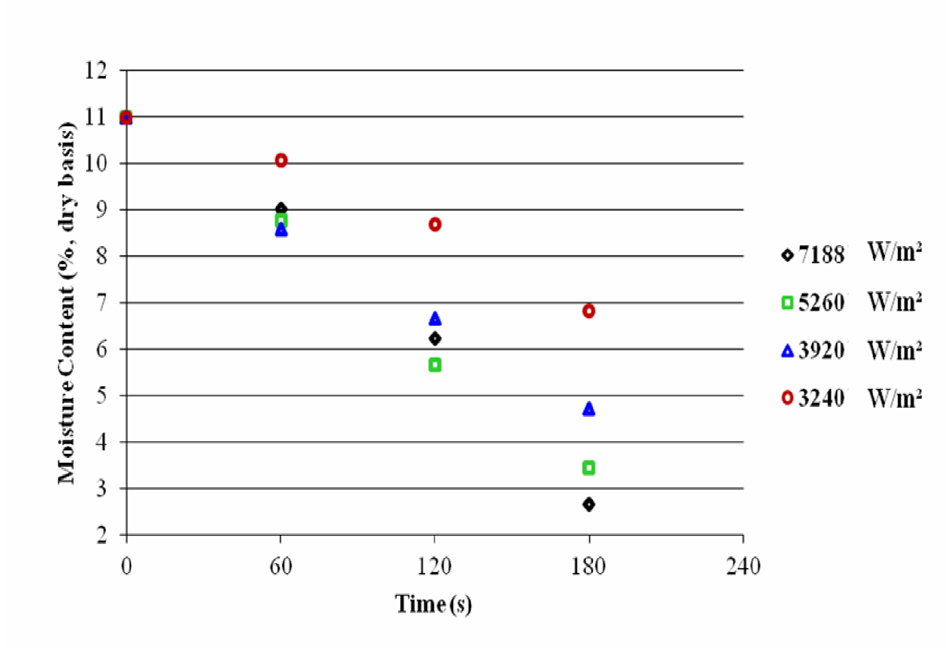

Fig. 2. **Relationship between average chilli moisture content and FIR heating time under different radiation intensities.**

Temperature of chilli samples

Temperature of chilli is an important factor in roasting. Application of high temperature short time (HTST) method is advantageous in achieving faster roasting. The variation of chilli temperature with FIR exposure under different radiation intensities is shown in Table 2 & Fig. 3. Roasting took place above 100 $^{\circ}$C. At 3240 W/m^2 FIR intensity chilli did not reached 100 $^{\circ}$C even at 240 s exposure time. According to the results, 7188 W/m^2 would be the best FIR radiation intensity in industrial applications as it increased the temperature at 100 $^{\circ}$C within 60 s which had a faster rate. There was a practical difficulty to achieve higher FIR radiation intensity due to space limitations. The distance between the FIR emitter and the sample was 10 cm at 7188 W/m^2 FIR radiation intensity and that would be the practically minimum distance allowing safe handling under FIR radiation application for chilli roasting.

Table 2. **Variation of chilli temperature with heating time under different radiation intensities.**

Time (s)	Temperature (°C)			
	3240 W/m^2 25 cm*	3920 W/m^2 20 cm*	5260 W/m^2 15 cm*	7188 W/m^2 10 cm*
0	24.80±0.00	24.80±0.00	24.80±0.00	24.80±0.00
60	68.85±8.28	80.77±7.98	86.55±4.31	100.03±4.6
120	80.56±5.94	88.27±4.67	96.51±0.24	108.82±7.46
180	88.48±4.53	96.25±3.42	100.81±2.79	120.97±7.79
240	92.87±3.85	101.47±5.18	108.01±3.75	132.25±7.62

*Distance between FIR emitter and the chilli sample

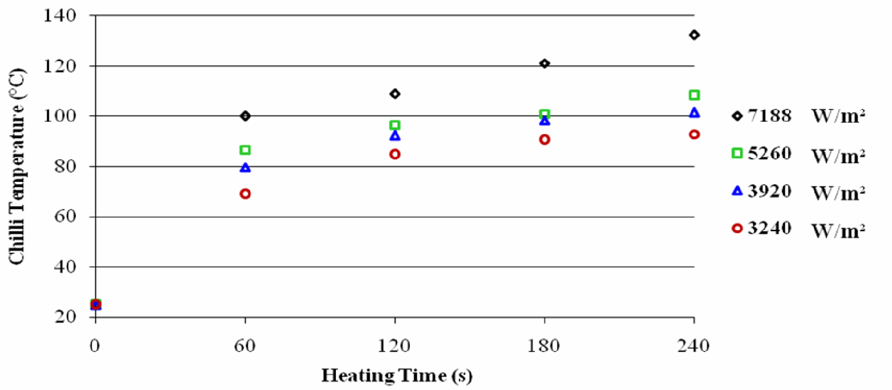

Fig. 3. Relationship between chilli temperature and heating time under different radiation intensities.

Colour of chilli with FIR radiation

Colour of chilli pods has been considered as an indicator of degree of roasting and the variation of lightness (L*), redness (a*) and yellowness (b*) values were compared with drum roasted factory sample (Table 3). L* a* b* values were decreased during the course of FIR radiation exposure. Fig. 4 shows the colour change of chilli with FIR radiation intensity at 7188 W/m^2. Factory roasted colour values (L* a* b*) for chilli are named as L* (standard), a* (standard) and b* (standard) and are drawn as horizontal lines in the Fig. 4 for comparison purposes. The L* (standard), a* (standard) and b* (standard) values obtained were 30.73 (L*), 9.33 (a*) and 48.51 (b*). The similar values could be obtained in 7188 W/m^2 FIR radiation intensity within 60 s. At 3240, 3920, 5260 W/m² radiation intensities, factory roasted colour of chilli was achieved at 124, 117, 107 s respectively.

Table 3. Variation of L*a*b values with FIR exposure time at different radiation intensities.

Time (s)	3240 W/m²			3920 W/m²			5260 W/m²			7188 W/m²		
	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
0	34.83	14.19	64.80	34.83	14.19	64.80	34.83	14.19	64.80	34.83	14.19	64.80
60	33.56	14.80	60.74	32.63	13.12	56.41	32.03	10.88	52.86	30.93	5.59	46.07
120	30.85	9.64	47.50	31.82	10.16	52.09	30.39	4.63	43.53	29.58	1.27	39.62
180	29.17	3.89	38.90	29.41	4.52	40.25	29.51	1.48	39.37	29.39	1.03	38.97
240	27.80	1.28	33.65	28.72	1.32	36.78	29.88	1.10	40.55	29.58	1.48	39.59

Standard deviations for L*, a* and b* were in the range of 3.00-0.21, 6.75-0.09 and 15.34-0.60 respectively.
Standard (factory roasted) L*, a* and b* values were 30.73±1.76, 9.33±3.74 and 48.5±8.22 respectively.

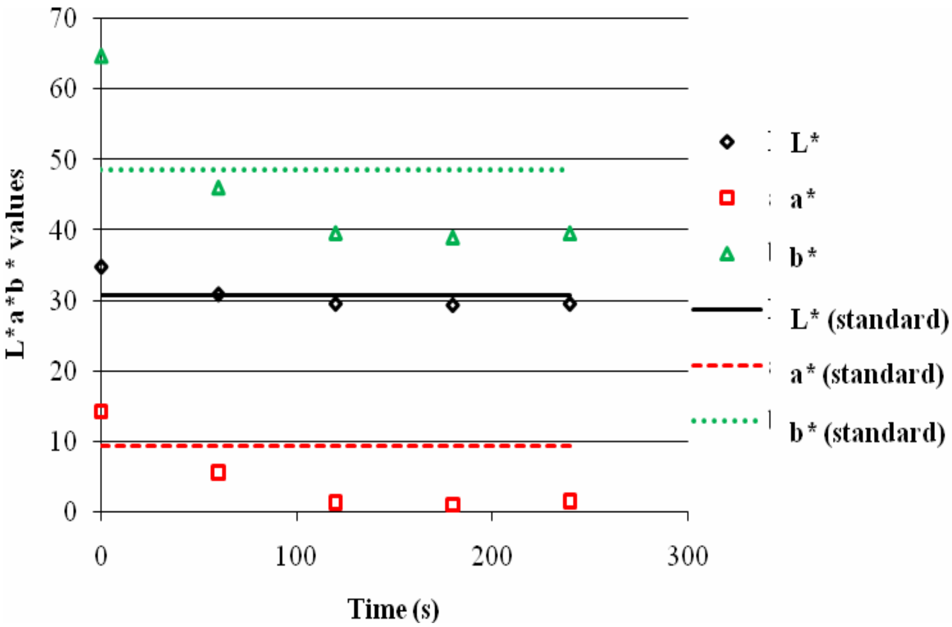

Fig. 4. L*a*b values with time and standard L*a*b values at 7188 W/m^2 FIR radiation intensity.

CONCLUSION

The obtained results indicated that FIR radiation can be effectively used in roasting chilli. The highest FIR intensity used in this trial was 7188 W/m^2 and futher increase of intensity was restricted by the space limitation between FIR emitter and the sample. Rosting time required to achieve factory roasted chilli in the drum roaster (HENAN JINGXIN JXER 100, China) was 25 minutes and the similar colour and moisture content were achieved when the chilli was exposed to 7188 W/m^2 FIR radiation intensity for 60 s. At 3240, 3920, 5260 W/m^2 radiation intensities the factory roasted colour of chilli was achieved at 124, 117, 107 s and the corresponding interpolated moisture contents were 8.38, 6.70 and 6.59% db, respectively. Therefore, it could be concluded that FIR radiation could be effectively used in roasting chilli. Further studies are required for improvement of the quality of roasted chilli with FIR radiation before applying the technology at industrial scale.

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