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Chickpea Temperature Profile Development and its Implication under Microwave Treatment

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ABSTRACT: Non-uniform temperature distribution is the major concern during microwave processing. Generation of heat and temperature during microwave treatment is purely based on the material's intrinsic properties, therefore different material shows different behaviour. Microwave technology is often employed in legume crops for various reasons such as disinfestation, extraction, drying, roasting, pretreatment during milling operation etc. However, paucity of information on the microwave treatment and temperature behaviour, of legume crops are available. In the present study the temperature profile analysis and distribution are performed in the chickpea seeds at various power level (0– 800W) and treatment time (10 s – 50 s). A domestic-scale microwave at 2450 MHz was used for the experimental purpose to treat chickpeas. Surface temperature distribution was determined using an infra-red thermal sensor. The loss of moisture (% wet basis) from chickpea was correlated with the average surface temperature during microwave heating. A high positive correlation was observed (0.9) between the two parameters. Weighed amount of chickpea sample (50 g) was placed inside the microwave and treated at 0, 160, 320, 480, 640 and 800 W for 10 to 50s with 10 seconds of regular intervals. A temperature gradient was observed with each microwave treatment combination i.e. a non-uniform temperature distribution resulting into hot and cold regions within the treated sample. Results confirmed that power level and treatment time has a significant effect on the average surface temperature development ($p<0.05$). The study results proved that the temperature variation must be taken into consideration while designing any microwave system and the selection of microwave parameters (power level and treatment time) during experiments involving legumes.

Keywords: Microwave, power level, temperature profile, chickpea, surface temperature

INTRODUCTION

The conventional thermal food technologies, such as pasteurisation, sterilisation, drying and evaporation, can guarantee the microbiological safety or stability of products, but high temperature can negatively impact its nutritive constituents (Pereira & Vicente 2010; Zhang, 2018). These conventional methods require a longer time to reach a targeted temperature level as well as to achieve a given safety level (microbial death rate). However, processing food commodities at high temperatures for longer duration destroys the essential nutrients and produces some of the potentially harmful components like amines etc. (Guo, 2008; García-Baños, 2019; Puligundla, 2013). New age processing technologies treats the food by producing same effect at lower temperature in shorter period that help to maintain the product integrity.

In the recent past heat treatment employing microwave has become very popular and has been adopted commercially in the food processing operations at both industrial as well as domestic level. Microwave is being used in number of food processing operations such as drying, tempering, heating, thawing, cooking, blanching, baking, pasteurisation, sterilizing etc and plays a significant role in maintaining food quality and safety. One of the main advantages is significant reduction in cooking time and energy consumption. Heat treatment using microwave offers considerable advantages compared to any conventional heat treatment methods. In conventional heating system, mode of heat transfer from the surface to the centre is through convection and/or conduction process, which is time consuming as well as develops a temperature gradient. This temperature gradient between the surface towards core is minimum in case of microwave because heat generation (volumetric in nature) is achieved with in a short time as microwave penetrates deep inside the food (Pozar, 2009).

Microwaves is a form of electromagnetic waves between frequency range of 300 MHz to 300 GHz with corresponding wavelength of 1mm to 1m. Microwave frequencies permitted to be used for domestic and commercial purpose are 915 MHz and 2.45 GHz (Fu *et al.,* 2017; Metaxas and Meredith 2008). Microwave heating is a form of dielectric heating where electromagnetic energy is transformed into thermal energy as a result of molecular friction and dielectric loss factor of the material. Microwaves have been developed to operate in various fields, such as the food processing industry (Koné *et al.,* 2013), biological industry (Metaxas, 1991), agriculture industry (Grigory and Peter 2010) and mineral processing (Zhao *et al.,* 2015).

Nevertheless, microwave has taken an irreplaceable position yet its potential is being explored for other commercial applications such as insect disinfestation and assisting milling operations of grains. However, one of the issues associated with microwave heating is the challenge of maintaining uniform temperatures throughout the sample. A key concern with microwave heating is the development of non-uniform temperature zones within the sample (Vadivambal, 2010; Campañone and Zaritzky 2005).

Temperature variation during microwave heating has been studied during processes like pasteurisation, frozen and RTE foods production (Burfoot *et al.,* 1988; Lee *et al*., 2002; Sakai and Wang 2004; Manickavasagan *et al*., 2006a; Gunasekaran and Yang 2007; Geedipalli *et al.,* 2007). For cereals and oilseeds like wheat, barley, canola, rye, oats and sunflower seeds temperature variation has been reported (Manickavasagan *et al.,* 2006b; Vadivambal *et al.,* 2009). However not many results are published on the microwave treatment of pulses with respect to the temperature variation during microwave treatment. Since heat generation is purely a material property and each grain or legumes behaves differently therefore this study was conducted to evaluate the temperature and moisture behaviour of chickpea under microwave. The objective of the present study was (1) to determine the surface temperature distribution of microwave-heated chickpea seeds using an infrared thermal sensor, (2) to determine the maximum and minimum temperatures in the treated chickpea samples at different microwave power levels and exposure times, and (3) to determine the moisture loss during microwave heating in chickpea seeds.

METHODOLOGY

Sample Preparation. Chickpea (*Cicer arietinum*) samples of Kabuli variety were procured from the local market, New Delhi. Samples were cleaned and maintained at an initial moisture content of about 10 ± 0.5 % (wb) and used throughout the study.

Experimental Apparatus and Procedure. A Laboratory microwave (Model: P24YKA03, Industrial Microwave Systems, White, 230V-50Hz, 2450MHz, 28L convective oven, USA) having power levels of 160, 320, 480, 640 and 800 W was used at different time-intervals of 10, 20, 30, 40 and 50 seconds. Surface temperature was assessed using a non-contact digital type laser infrared thermometer with a temperature range of -50 ºC to 400 ºC. Temperature readings were noted from different points on the surface for further analysis.

50g of chickpea samples were used during each treatment combination and then weighed after the treatment to analyse the moisture loss. The treatment was conducted by placing the weighed sample into a microwave cavity and subjecting it to a selected power level for a specified duration. After the treatment, the surface temperatures of the samples were analysed at various locations and recorded. After cooling to ambient conditions, the samples were weighed, and the moisture loss was determined. From the recorded surface temperatures, the average temperature and the difference between the maximum and minimum temperatures were calculated for each treatment combination.

Statistical data analysis. The experiments were arranged based on a factorial design, and the effects of microwave power and treatment time on the average surface temperature and moisture loss percentage were evaluated using ANOVA at a 95% confidence interval ($p < 0.05$). Mean separation was conducted using Tukey's test. All the analyses were performed using the GLM procedure in SAS version 9.1 (SAS Institute, Inc. 2002).

RESULTS AND DISCUSSION

Effect of power level on average surface temperature. The average surface temperature of chickpea seeds presented in Table 2 represents the average of a minimum of 10 readings. The table provides an understanding of the average temperature achieved by the chickpea at various power levels and treatment times. The significance of the test was analysed using the analysis of variance test (Table 1), followed by Tukey's test to compare the means. The results showed that the average temperature (124.57±3.96°C) attained was higher at a higher power level (800W) and for a longer time, i.e., 50 seconds, and it was significantly ($p < 0.05$) higher than any of the other treatment combinations. The average surface temperature attained by the chickpea at 800W and 40 seconds was not significantly different from the temperature attained at the treatment combination of 640W and 50 seconds. Similar results were obtained at 480W for 50 seconds and 640W for 40 seconds. These results indicate that both the power level and treatment time have a significant effect on average temperature development. The average surface temperature of chickpea at 10 seconds of treatment time at all power levels remained below 45°C, although in some cases, the maximum temperature reached above 50°C. Surface temperature was more pronounced at higher power levels and treatment times (Fig. 1). At a fixed moisture content, the rise in temperature is attributed to changes in the dielectric behaviour of the chickpea.

Table 1: Analysis of Variance (ANOVA) results for change in surface temperature of chickpea during microwave treatment.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**24**	**43777.98095**	**1824.08254**	**91.33*****	**<.0001**
power	4	16774.96743	4193.74186	209.98***	<.0001
time	4	21078.51045	5269.62761	263.85***	<.0001
power*time	16	5924.50307	370.28144	18.54***	<.0001
Error	**50**	**998.60240**	**19.97205**		
Corrected Total	**74**	**44776.58335**			

* Significance level set at $p<0.05$. '***' represents highly significant level; Abbreviation: DF, degree of freedom

Table 2: Average surface temperature (mean ± SD) of chickpea at 9.9 % moisture content (wet basis).

Treatment Time (s)	Power level (W)				
	160	**320**	**480**	**640**	**800**
10	34.22 ± 0.66^{k}	40.52 ± 0.68^{hijk}	43.28 ± 4.47^{ghijk}	42.93 ± 3.60^{hijk}	42.02 ± 3.32^{hijk}
20	36.80 ± 0.89^{jk}	44.87 ± 3.09^{ghijk}	53.09 ± 9.67^{fghi}	52.38 ± 2.85^{fghij}	62.90 ± 2.76^{ef}
30	42.49 ± 2.83^{hijk}	56.39 ± 3.5^{fgh}	67.68 ± 6.26^{ef}	68.52 ± 2.29^{ef}	87.45 ± 2.00^{cd}
40	38.54 ± 0.57^{ijk}	59.30 ± 3.41^{fg}	78.32 ± 6.22^{ed}	87.86 ± 2.34^{cd}	105.32 ± 7.17^{b}
50	53.84 ± 0.04^{fghi}	63.61 ± 5.70^{ef}	93.89 ± 8.10^{bcd}	103.07 ± 6.67^{bc}	124.57 ± 3.96^{a}

*Average of three replications (for every replication average temperature is the mean temperature of 10 readings). Same letter after Mean±SD indicates non-significant difference

The dielectric constant, which is responsible for the storage of charge, for chickpea seeds is 2.60 ± 0.04 at 30°C (Oke & Baik 2022). Oke & Baik (2022). presented the dielectric constant of chickpea with changes in temperature and moisture content, demonstrating that at a fixed moisture content, the dielectric constant varies with temperature, ranging from 2.51 to 6.72 at 915 MHz. These dielectric constants depend on temperature, material moisture content, and the applied frequency of the microwave. The higher the dielectric constant, the faster the commodity will generate heat (Teseme, 2020; Xie *et al.*, 2019). Similarly, the average surface temperatures obtained by wheat and barley at 12% moisture content, 500 W, and 56 seconds were 108.8 and 117.5, respectively (Manickavasagan *et al.*, 2006a).

Moisture loss during microwave heating in chickpea seeds. Loss of moisture as a result of microwave irradiation of chickpea were analysed and ANOVA results are presented in Table 3. Test results indicates that both microwave power level and exposure time significantly influences the moisture loss.

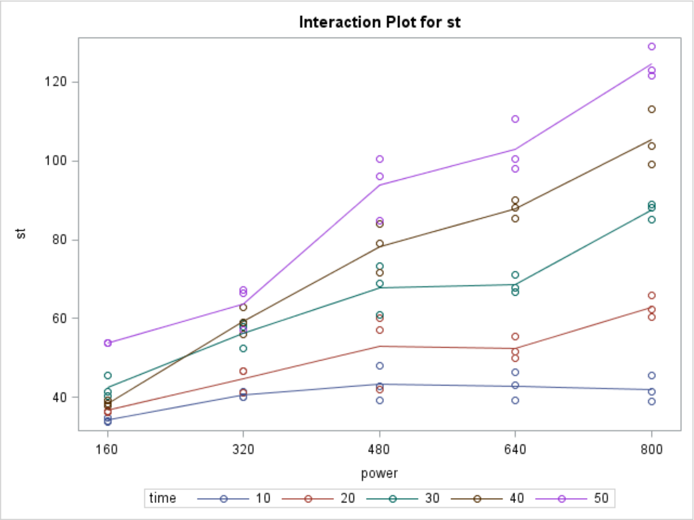

Fig. 1. Average surface temperature (st in ^{o}C) at different power level and treatment times of 10, 20, 30, 40 and 50s in chickpea.

Table 3: Analysis of variance for moisture loss from chickpea under microwave treatment.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**24**	**13.48142133**	**0.56172589**	**112.47*****	**<.0001**
power	4	3.97470133	0.99367533	198.95***	<.0001
time	4	4.31919467	1.07979867	216.19***	<.0001
power*time	16	5.18752533	0.32422033	64.91***	<.0001
Error	**50**	**0.24973333**	**0.00499467**		
Corrected Total	**74**	**13.73115467**			

'***' significance level at 0.01%

The percentage of moisture loss in chickpeas during microwave treatment is presented in Table 4. The moisture loss ranged from 0.019% to 2.106% during the experiment. The loss in moisture of chickpea seeds is primarily due to the increase in seed temperature, as the increase in surface temperature showed a significantly high positive correlation of approximately 0.9 with the moisture loss. This indicates that the higher the surface temperature, the greater the percentage of moisture loss. The correlation coefficients between moisture loss and average surface temperature at 160, 320, 480, 640, and 800 W were found to be 0.96, 0.98, 0.93, 0.95, and 0.83, respectively.

The moisture loss at 160, 320, 480, 640, and 800 W varied from 0.019% to 0.072%, 0.057% to 0.165%, 0.071% to 0.538%, 0.058% to 0.734%, and 0.064% to 2.106%, respectively, at different exposure times. Since the initial moisture content of chickpeas was relatively low, at 10 ± 0.5%, the moisture loss from the chickpeas was generally below 1%, except for the treatment combinations of 800 W for 50 seconds, where a moisture loss of 2.4% was observed. The heat required to remove moisture at lower moisture levels is higher, requiring more energy than at higher moisture levels. Therefore, higher moisture levels result in greater moisture loss (Vadivambal *et al.*, 2009; Teseme, 2020).

Table 4: Percentage moisture loss in chickpea seeds (mean ± SD) at different power level and exposure time.

Treatment Time (sec)	**Power level (W)**				
	160	**320**	**480**	**640**	**800**
10	0.019±0.001^{g}	0.057±0.007^{g}	0.071±0.020^{g}	0.058±0.008^{g}	0.064±0.006^{g}
20	0.029±0.001^{g}	0.061±0.009^{g}	0.093±0.050^{g}	0.138±0.034	0.199±0.043^{defg}
30	0.055±0.020^{g}	0.122±0.022^{fg}	0.171±0.039^{defg}	0.214±0.021^{defg}	0.428±0.109^{cd}
40	0.056±0.004^{g}	0.144±0.020^{fg}	0.358±0.105^{cdef}	0.417±0.140^{cde}	0.721±0.120^{b}
50	0.072±0.053^{g}	0.165±0.031^{efg}	0.538±0.138^{bc}	0.734±0.036^{b}	2.106±0.185^{a}

*Each value is the average of three replications. Mean±SD followed by same letter (a, b, c, d, f, g) are non-significant

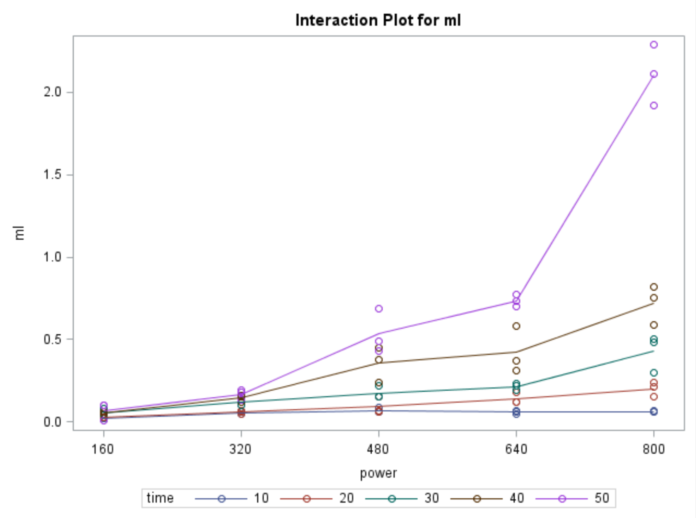

Fig. 2. Figure shows the increased moisture loss (ml in %) with increased microwave power levels at treatment times of 10, 20, 30, 40 and 50s in chickpea.

Maximum and Minimum Temperatures. The temperature variation during microwave treatment can be better perceived by examining the difference between the maximum and minimum temperatures within the sample, as presented in Table 5, for a given treatment combination. The largest difference between the maximum and minimum temperatures was observed at 50°C in the chickpea batch subjected to 640 W for 40 s of treatment time. On the other hand, the smallest temperature difference was recorded as 7.8°C at 160 W for 20 s. This temperature difference, which is the gap between the maximum and minimum temperatures, indicates the presence of temperature variation within the chickpea sample. Temperature rarely remains uniform but varies at different spots within the sample, signifying non-uniform temperature distribution under microwave heating.

This will aid in comprehending the temperature response of chickpeas to dielectric treatment and in choosing the treatment parameters to preserve product integrity. It is essential to exercise utmost care to ensure that the minimum temperature is attained while avoiding exceeding the maximum safe temperature, depending on the specific application.

Table 5: Existence of minimum and maximum temperature in chickpea at different power level and treatment time.

Exposure time (s)	Power level (W)	Minimum temperature	Maximum temperature
10	0	27.1	27.8
	160	30.2	41
	320	36.5	48.4
	480	36.3	56.3
	640	39	50.3
	800	36.2	48
20	160	33	40.8
	320	33	52.1
	480	40.8	66.3
	640	41.3	72.6
	800	54	74.1
30	160	34	51.6
	320	50.2	63.2
	480	60.2	82.1
	640	53	77.5
	800	73.8	98.2
40	160	42.5	67.5
	320	44.7	84.8
	480	60.2	94.3
	640	56.2	106.2
	800	88	128
50	160	42.5	67.5
	320	50.9	76.3
	480	71.2	105.6
	640	80.6	127.4
	800	109	138

CONCLUSIONS

The present study has demonstrated a significant temperature disparity in chickpea seeds during microwave treatment. The temperature variation is observed at all power levels and treatment times. However, the temperature difference is more pronounced at higher power levels and treatment durations than at lower levels. This increase in temperature is attributed to the elevated dielectric constant of chickpeas at higher temperatures. This variation can be minimized but not entirely eliminated. The loss in moisture content remains negligible up to 40 seconds of treatment with less than 1% loss at all power levels. Non uniform temperature distribution is because at some point temperature increased to very high and at some points temperature was significantly lower. Therefore, it is suggested that caution should be exercised with respect to the maximum temperature development during grain processing. This is because the quality of the grain may be compromised due to the elevated temperatures at certain locations, even if the average temperature falls within an acceptable range.

FUTURE SCOPE

The study could be expanded through additional experimentation to corroborate and extend the current results by utilizing data analysis technique to enhance the depth and precision of the research.

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Conflict of Interest. None.

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