3-2013

Microwave drying kinetics and quality characteristics of corn

Songul Gursoy
Dicle University

Ruplal Choudhary
Southern Illinois University Carbondale, choudhry@siu.edu

Dennis G. Watson
Southern Illinois University Carbondale, dwatson@siu.edu

Recommended Citation

Gursoy, Songul, Choudhary, Ruplal and Watson, Dennis G. "Microwave drying kinetics and quality characteristics of corn." *International Journal of Agricultural and Biological Engineering* 6, No. 1 (Mar 2013): 90-99. doi:10.3965/j.ijabe.20130601.009.

Microwave drying kinetics and quality characteristics of corn

Songül Gürsoy[1], Ruplal Choudhary[2*], Dennis G. Watson[2]

(1. *Department of Agricultural Machinery*, *Faculty of Agriculture*, *Dicle University*, 21280, *Diyarbakir*, *Turkey*;
2. *Department of Plant, Soil and Agricultural Systems, MC* 4415, *Southern Illinois University*, *Carbondale*, *IL* 62901 *USA*)

Abstract: In recent years, microwave (MW) drying has gained popularity as an alternative drying method for a wide variety of food and agricultural products because of increasing concerns over product quality and production costs. However, the determination of drying kinetics that accurately describes microwave drying characteristics is crucial for the optimization of operating parameters, performance improvement of the drying system and product quality. The objective of this study was to investigate the drying kinetics and the quality characteristics of corn kernels, especially the effects of different initial moisture contents (18.3%, 26.3%, 34.3% and 42.3% db), MW power levels (70, 175 and 245 W) and exposure time (80 s and 120 s) on the drying kinetics, drying rate and various key quality parameters. The results indicated that the increased drying rate at higher power levels (P3, 245 W) reduced the drying time considerably but increased stress crack index and reduced germination. In addition, it reduced bulk density, true density and thousand grain weight (TGW). The germination rate of corn was the highest at MW power level P1 (70 W), with the lowest drying rate and observed to decrease with increase in initial moisture content. The reduction in exposure time decreased stress crack index and increased germination rate, bulk density and true density. The correlation analysis among drying rate, germination, stress-crack index (SCI), bulk density, true density and TGW showed that increasing drying rate could lead to an increase in SCI and decrease in germination, bulk density and true density.

Keywords: microwave drying, corn, stress-crack, germination, bulk density, true density
DOI: 10.3965/j.ijabe.20130601.009

Citation: Gürsoy S, Choudhary R, Watson D G. Microwave drying kinetics and quality characteristics of corn. Int J Agric & Biol Eng, 2013; 6(1): 90－99.

1 Introduction

Maize is one of the important cereals grown in most countries with total production exceeding 844 million tonnes. The United States is a major player in the world corn trade market, with approximately 20% of the corn crop exported to other countries[1,2]. Corn is used as the main ingredient in livestock feed and also processed into a multitude of food and industrial products including starch, sweeteners, corn oil, beverage and industrial alcohol, and fuel ethanol[2]. Corn is mostly harvested at 22% to 35% moisture content (wet basis) to avoid the risk of frost, insect, disease and kernel damage during harvest and to reduce the growing season where two or more crops are grown in a year. Sometimes, undesirable rain also forces farmers to harvest corn at high moisture level[3-5]. Corn harvested at high moisture content requires rapid drying for safe storage to prevent respiration, germination, mold damage and insect infestation. Artificial drying is a common practice for drying of cereal grains because it is rapid and weather-independent. In the artificial grain drying operation, the transfer of heat to seeds may be accomplished by convection (hot air), conduction (solids), or radiation (high frequency electromagnetic energy). In

Received date: 2013-01-10 **Accepted date:** 2013-03-09
Biographies: Songül Gürsoy, PhD, Assistant Professor, Research interests: Agricultural mechanization, seed properties, post-harvest crop processing, grain quality. Tel: +90 412 2488509, Fax: +90 412 2488153; Email: songulgursoy@hotmail.com. **Dennis G. Watson,** PhD. Associate Professor, Agricultural Systems, Southern Illinois University, Research interests: systems analysis, informatics, instrumentation. Tel: 6184536979; Email: dwatson@siu.edu.

***Corresponding author: Ruplal Choudhary**, PhD, Assistant Professor, Food and Bioprocess Engineering, Southern Illinois University. Research interests: microwave processing, nonthermal processing, nanotechnology, nondestructive testing, process automation. Tel: 6182031017, Fax: 6184537457; Email: choudhry@siu.edu.

a conventional drying process, heat flows from outside to inside of the grain by conduction with a gradual increase in temperature within the produce frequently with undesirable overheating of peripheral zones. The low thermal conductivity of biomaterials, energy efficiency and prolonged drying time are the major drawbacks of conventional hot air drying. Increased drying rates using higher air temperatures may result in overheating of grains. This causes stress cracking, lower test weight and discoloration of grains. Microwave use can minimize drawbacks of conventional drying by providing a fast and effective thermal process where heat is generated within the seed when microwave energy is applied. During microwave drying, the vapour pressure increases as the moisture inside the material approaches the boiling point and facilitates the transfer of moisture to the outside. Local pressure and temperature rise continues even though the loss factor of treated materials decrease with the reduction of moisture content[6-8]. Although these increases of pressure and temperature can speed up the drying process, they may cause side effects such as bio-value degradation, physical damages, and non-uniform temperature distribution in treated materials[9-12].

Quality has become a major concern in maize production and handling due to the increase of its use for human consumption and manufacture of industrial products[13]. The most frequently measured quality factors in the US grades and standards are test weight, broken corn and foreign material (BCFM), and heat-damaged grains[2]. Heat causes three detrimental effects within the kernel, which are starch gelatinization, protein denaturation and reduced germination occurring at 64-72°C, 55-65°C and 43-46°C, respectively; and they are especially severe when high moisture content kernels are dried[14-16].

Stress cracks are being successfully used as an indirect test of degree of protein denaturation and starch gelatinization, and the germination percentage is indication of protein denaturation and starch recovery[16]. Stress cracks are considered as an important quality indicator to determine the severity of damage occurred during drying because it can lead to increase in broken grain and fine material during subsequent handling and decrease in corn dry milling performance[17,18]. In general, the formation of stress cracks is associated with rapid drying of grain at high temperatures. Watkins and Maier[19] reported that temperature during drying has a significant effect on the development of stress cracks. They determined that while stress crack percentage was 77% in corn dried at 37.8°C, and it was 99% at 71.1°C. Weller et al.[20] found that stress cracks increased significantly with increase in initial moisture content at the drying air temperatures of 49°C, 71°C and 93°C.

Several researchers have investigated the microwave drying of corn, and the safe temperature limits for drying. Nair et al.[21] studied to determine an optimum microwave drying method for corn kernels to achieve maximum germination and minimum drying time. They found that 4 W/g fixed power resulted in the minimum drying time but 0% germination. Gunasekaran[22] investigated the effect of both pulsed and continuous operation of power on drying corn in a commercial microwave oven. Microwave power levels of 10 W/g and 20 W/g of wet grain resulted in rapid drying with good production quality as determined by visual observation. Shivhare[10] stated that water vapour and temperature inside the kernel would increase when they were subjected to microwave radiation. The mechanism of heat generation inside the particle prevents case hardening but may lead to swelling, cracking, discoloration and reduced germination of grain depending on the level of microwave power used. It is therefore important to know the effects of different microwave power levels and inlet air condition on product quality. Shivhare et al.[23] determined that germination of corn was inversely related to microwave power and increased with air velocity. They recommended a power level less than 0.25 W/g for seed-drying purposes. Chung and Furutani[24] reported that microwave power level and the initial moisture content of nuts had significantly affected the quality of nuts in microwave drying of macadamia nuts. They found that the quality of nuts was reduced at high microwave power. Vicaş and Ioan[25] studied the effect of temperature, power and humidity on germination of corn seeds. They stated that using an air stream is important to eliminate the water from seed bed and avoid the hot spots. They determined that the lowest MW power level (0.02 W/g ≤0.2 W/g ≤ 0.5 W/g per 10 minutes) had the highest rate of germination. Vicaş and Palade[26] stated that a constant temperature and humidity has a good influence on the germination rate of corn seeds. The high MW power level may lead to the high temperature areas and the low rate of germination. Manickavasagan et al.[27] reported that the grain temperature during MW treatment increased with power level and exposure time, and non-uniformity of heating produced hot spots (localized elevated temperature). They determined that the germination percentage of wheat was significantly decreased with increasing power level, exposure time and initial moisture content. Campaña et al.[28] stated that germination capacity was inversely related to initial moisture content of wheat and final temperature during MW drying. Nofsinger et al.[29] studied the effect of microwave energy on the microbial population and germination of corn as a function of initial moisture content and temperature of the heated grain mass. They determined that the germinability of corn was substantially reduced at 55°C and zero at 70°C. Velu et al.[30] investigated the dry milling characteristics of corn grains dried from different initial moisture content (IMC) in a domestic microwave oven. They determined that the alteration in structure of starch and protein increased with microwave drying time and caused the lower viscosity. They suggested that the effects of microwave drying on various physico-chemical properties of grains needs to be assessed.

The objective of this study was to evaluate the effect of different initial moisture content (18.3%, 26.3%, 34.3% and 42.3% db), MW power level (70, 175 and 245 W) and exposure time (80 and 120 s) on the drying kinetics, drying rate and various key quality parameters such as germination, stress-crack index (SCI), bulk density, true density and thousand grain weight (TGW) of corn grains, and determine correlations among these parameters.

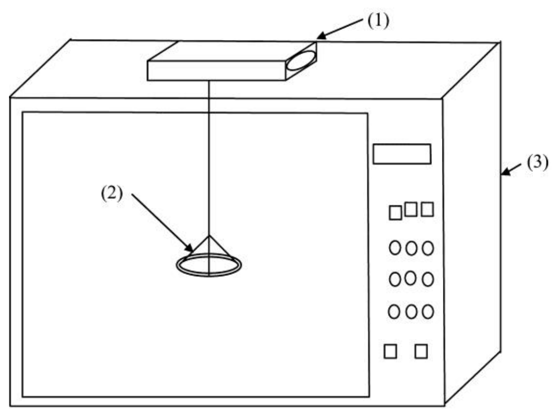
2 Materials and methods

2.1 Materials

The corn used in this study was "yellow" corn obtained from Southern Illinois University Farms in Carbondale, IL. The initial moisture content of corn at arrival time was determined as 10.3% dry basis (db) according to the standard ASABE Method (1990). The corn was remoistened with addition of a calculated amount of water to obtain the desired moisture content levels of 18.3%, 26.3%, 34.3% and 42.3% (db). The rewetted corn was then kept in a temperature-controlled refrigerator at (4±0.5)°C for 5-7 days in order to get the uniform moisture content inside the grain kernels.

2.2 Drying equipment and drying procedure

A domestic MW oven (GE, JES 1334, Turntable MW oven, Malaysia) with a frequency of 2.45 GHz was used to study the drying of corn seeds. It had 1 550 W of rated power and 910 W of absorbed power at the MW power level P10. A drying pan made of a Teflon petridish with 50 mm diameter and 15 mm height was suspended from a digital balance into the MW by a fine fishing wire to acquire its weight at different time intervals during drying (Figure 1). The absorbed power was measured by the method of temperature elevation of water contained in two one-liter beakers given by Buffler (1993). Before starting the MW drying experiment, the absorbed power of the MW was determined at three levels: (1) MW power level P1 of 70 W; (2) MW power level P2 of 175 W; and (3) MW power level P3 of 245 W.



(1) electronic balance; (2) plate (teflon) D =70 mm; (3) domestic MW oven

Figure 1 Depiction of microwave drying apparatus used in this investigation

The experiment included 24 treatments consisting of three MW power levels (P1, P2 and P3), two exposure time (80 and 120 s) and four initial moisture contents (18.3%, 26.3%, 34.3% and 42.3% db), and the experiment was replicated three times. In each experiment, a sample of about 20 g was put in drying pan.

After the MW drying process, the warm samples were placed in paper bags and cooled at room temperature for later kernel quality evaluation[15].

2.3 Drying kinetics

The moisture content change of each sample was calculated according to the loss of mass and the initial moisture content value at intervals of 20 s. The drying kinetics was represented by reduced moisture content versus drying time. The drying rate of corn was calculated using Equation (1).

$$\text{Drying rate} = (M_{t+dt} - M_t) / dt \qquad (1)$$

where, drying rate is the quantity of moisture removed per unit time per unit dry matter (g H_2O/g dry matter/s); M_t is the moisture content at a specific time (g H_2O/g dry matter); M_{t+dt} is the moisture content at $t+dt$ (g H_2O/g dry matter); t is the drying time (s).

2.4 Quality properties

2.4.1 Germination test

From each drying treatment, 25 grains were placed in a petri plate with filter paper and 15 mL of water was added. After seven days, the number of germinated seeds was counted. To remove the variability of germination among fresh samples, germination of dried samples was normalized as Equation (2).

Normalized germination of dried corn=

$$\left(\frac{\text{germination of dried corn}}{\text{germination of corn before drying}}\right) \times 10 \qquad (2)$$

2.4.2 Stress crack test

Stress crack analysis was done on fresh and dried samples. One hundred kernels of each corn sample were individually examined using 10 × magnification microscope for single, multiple and checked (intersecting) stress cracks. A stress crack index (SCI) was calculated using Equation (3)[31].

$$SCI = 1\times(SCK) + 3\times(MCK) + 5\times(CK) \qquad (3)$$

where, SCI is stress crack index, %; SCK is single cracked kernels, %; MCK is multiple cracked kernels, %; CK is checked (intersecting) kernels.

2.4.3 Bulk density, true density, thousand grain weight, and equivalent diameter

Bulk density was determined as the ratio of mass to the occupied volume by pouring a known mass into graduated cylinder and reading the volume after gently tapping the cylinder twice. To determine true density which is the ratio of mass sample of grains to its pure volume, the toluene displacement method was used[32]. Thousand grain weight (TGW) was measured by counting 100 seeds and weighing them in an electronic balance with an accuracy of 0.001 g and multiplying by 10 to give mass of 1 000 grains[33]. The measurement of length, width and thickness was performed on 50 randomly selected kernels for each level of initial moisture content sample, including the dry corn. The equivalent diameter was calculated by the method suggested by Shivhare[10].

$$Dp = 2\times\left(\frac{3\times(T\times W\times L)}{2\times(T\times W + T\times L + L\times W)}\right) \qquad (4)$$

where, Dp is equivalent diameter, mm; T is thickness of corn grain, mm; W is width of corn grain, mm; T is length of corn grain, mm.

The average values of SCI, bulk density, true density, TGW and equivalent diameter before drying the corn for each level of initial moisture content sample are given in Table 1.

Table 1 Some properties of corn for each initial moisture content before drying

Initial moisture content/% db	SCI^a /%	Bulk density /kg · m^{-3}	True density /kg · m^{-3}	TGW^b /g	Dp^c /mm
18.3	34	690.7±17.5	1214.4±31.4	359.8±0.2	7.4±0.7
26.3	36	635.7±29.8	1201.5±25.0	398.1±2.2	7.6±0.8
34.3	33	625.4±22.9	1196.1±12.8	429.5±1.6	7.7±0.6
42.3	32	624.9±22.3	1191.9±14.8	473.8±1.5	8.0±0.9

Note: [a] stress crack index; [b] thousand grain weight; [c] equivalent diameter.

2.5 Statistical analysis

The SAS statistical software package version 9.1 was used for statistical analyses (SAS Institute Inc., Cary, NC). The Pearson Correlation Coefficients between the variables were calculated using the Proc Corr of SAS software.

3 Results and discussion

3.1 Drying kinetics

The microwave drying curves of the moisture content versus drying time of corn at different MW power levels are shown in Figure 2 for 18.3%, 26.3%, 34.3% and

42.3% (db) initial moisture contents. It could be seen that as the microwave power level increased the moisture content of corn significantly decreased. The loss of moisture content was significantly higher at power level P3 (245 W) than at power levels P1 and P2. At the power level P1 (70 W), loss of moisture content was very low. The difference in moisture contents between power levels increased with increase in time. The difference between power levels was lower in 34.3% and 42.3% (db) than in 18.3% and 26.3% (db) initial moisture contents. Comparing the loss of moisture content versus drying time at different initial moisture content for P1, P2 and P3 power levels, while the moisture loss of corn at initial moisture content of 42.3% (db) was higher than that at the lower initial moisture contents for P1 and P2 power levels, it was significantly lower than that at 18.3%, 26.3% and 34.3% initial moisture content for P3 (Figure 3). This contradictory trend can be explained as a charring effect and loss of volatile matters from corn kernels because of intense heating at higher power level (P3) after depletion of water molecules in corn kernels.

The drying rate versus moisture content of corn at different initial moisture contents are shown in Figure 4 for power levels P1 (70 W), P2 (175 W) and P3 (245 W). The loss of moisture content and drying rate were very low for P1 and P2 compared with P3 power level. At power level P1, drying rate increased with increase in the moisture content, but loss of moisture content is very low. Drying rate was higher at 42.3% (db) than at the other initial moisture contents. At power level P2, an initial unstable drying rate period was observed until it stabilized and an increasing trend was observed towards the end of the microwave heating. The drying rate curves at P3 power level showed that the drying rate increased with initial drying process and then decreased after peak point at all initial moisture content. This might be due to the loss of moisture in product caused a decrease in the absorption of microwave power and resulted in a fall in the drying rate as the drying progressed.

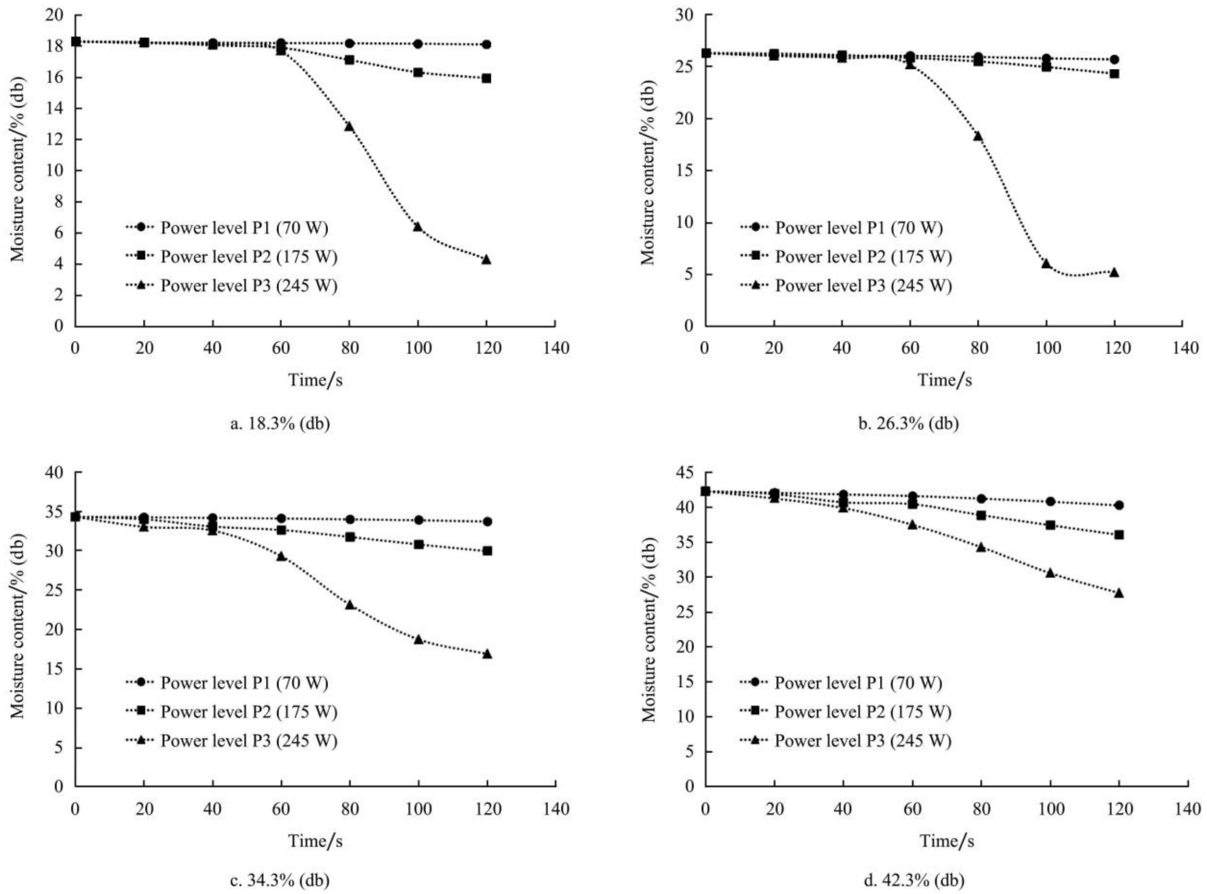


Figure 2 Variation of moisture content with drying time of corn kernels at different power levels at 18.3% (db), 26.3% (db), 34.3% (db) and 42.3% (db) initial moisture contents (exposure time is 120 s)

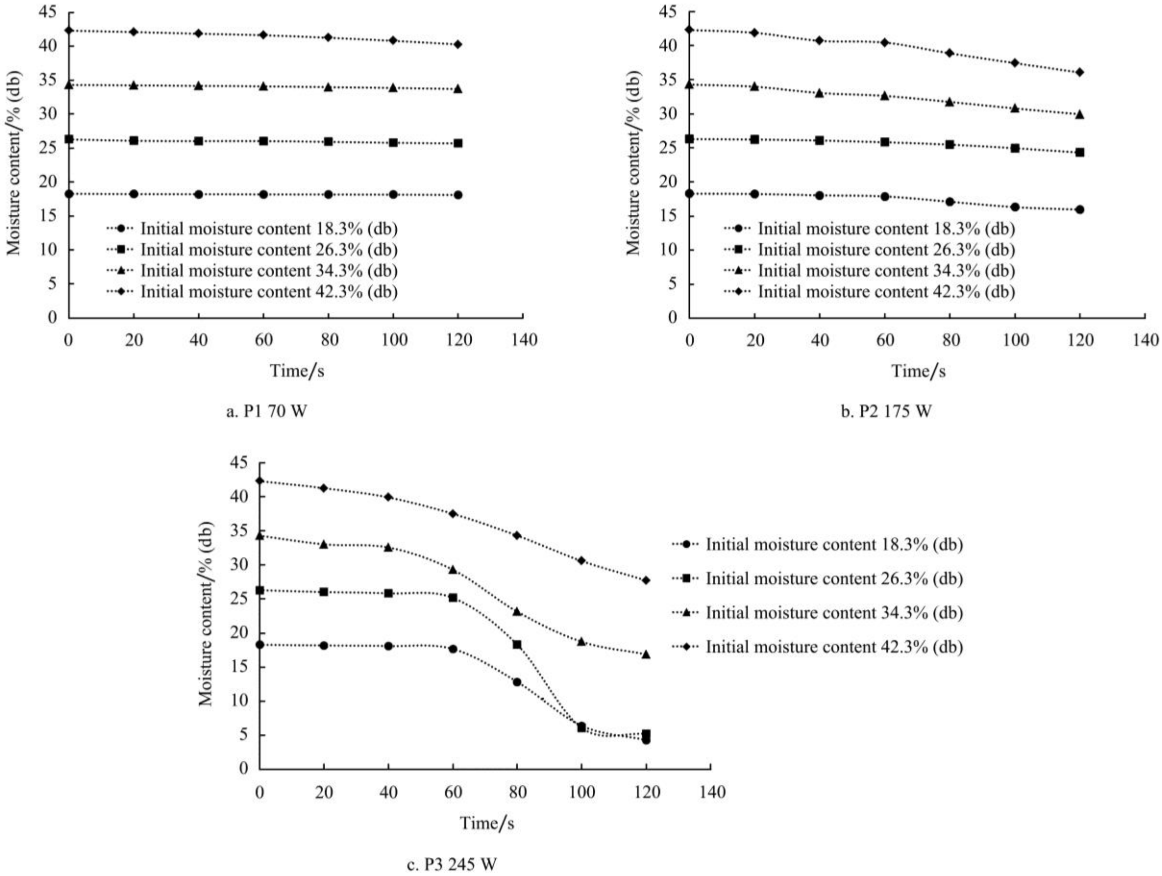


Figure 3 Variation of moisture content with drying time of corn kernels at different initial moisture contents at P1 70 W, P2 175 W and P3 245 power levels (exposure time is 120 s)

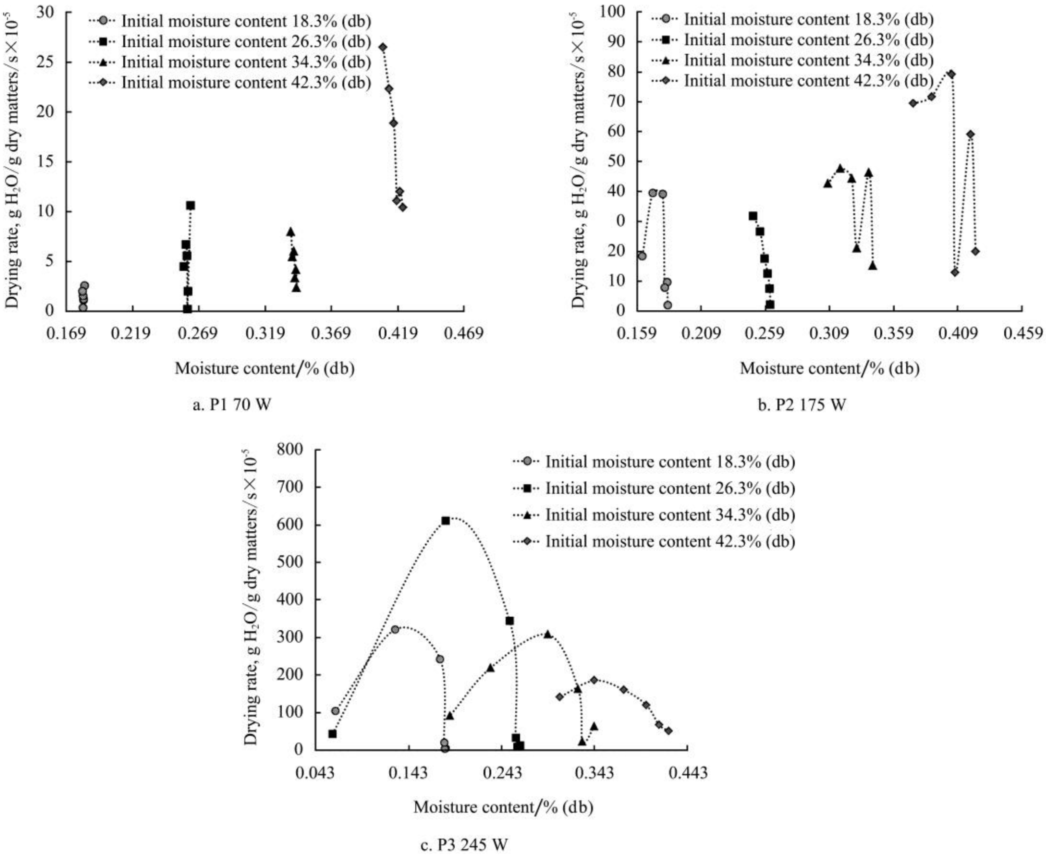


Figure 4 Effect of different initial moisture content on drying rate of corn kernels at 18.28 % (db) at MW power levels P1 70 W, P2 175 W and P3 245 W (exposure time is 120 s)

3.2 Quality evaluation

The effects of MW power level, initial moisture content and exposure time on germination rate of corn kernels are shown in Table 2. While only the MW power level P1 (70 Watt) had germination for all moisture content levels and exposure times, the germination rate was zero at P3 (245 W). At P2 (175 W) power level, when the exposure time was 120 s, the germination rate was zero for all initial moisture content except 18.3%. The increase in exposure time and initial moisture content decreased the germination rate of corn. This can be explained that the increase of water vapor pressure and temperature inside the grain might lead to reduced germination of corn depending on the level of MW power used[10]. Manickavasagan et al.[27] stated that the continuous increase in temperature during MW treatment with power level and exposure time might result in a decrease in germination percentage of grain. They stated that the microwave power level and exposure time would be the important factors while using microwaves for seed processing. This indicated that the high power level and long exposure time would not be recommended for safe drying of corn kernels.

Table 2 Germination rate of corn at different initial moisture contents dried with microwave (%)

Exposure time /s	Initial moisture content/% db	Power level		
		P1 (70 W)	P2 (175 W)	P3 (245 W)
120	18.3	62.5	13.9	0
	26.3	41.7	0	0
	34.3	13.9	0	0
	42.3	6.9	0	0
80	18.3	90.3	20.8	0
	26.3	97.2	13.9	0
	34.3	62.5	6.9	0
	42.3	13.9	0	0

The severity of stress cracking in the MW dried corn was assessed using a stress crack index. Figure 5 showed the effects of MW power level, initial moisture content and exposure time. The P3 (245 W) power level resulted in higher SCI than P1 (70 W) and P2 (175 W) power level at all initial moisture content and exposure time. It was also noticed that the increase in initial moisture content caused an increase in SCI. This increase can be due to the penetration of MW energy into the sample and creation of a large vapor pressure difference between the core and the surface of kernels.

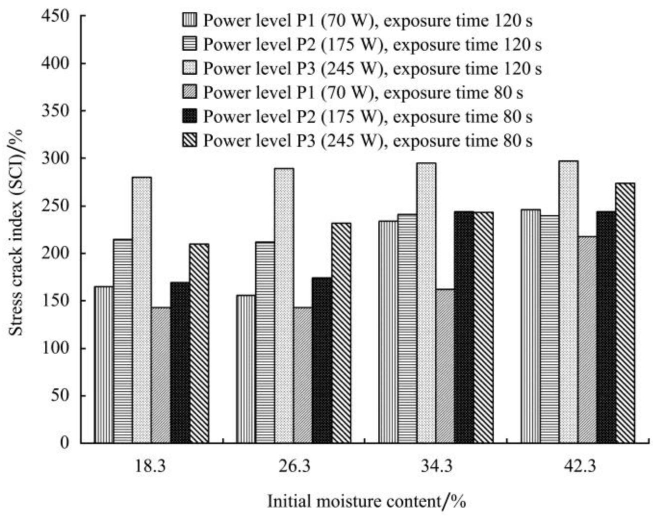


Figure 5 Effects of power level, exposure time, initial moisture content on stress crack index (SCI) in corn

The effect of microwave drying on the true density of corn at different initial moisture content is shown in Figure 6. The highest power level P3 (245 W) decreased the true density of corn. Density is frequently used as an indirect indicator of the corneous endosperm content in corn. This is based on the fact that corneous endosperm is very dense, whereas floury endosperm is full of micro fissures or void spaces, and therefore less dense[31]. This effect could be a result of expansion and cracking of endosperm due to the higher drying rate of P3 power level.

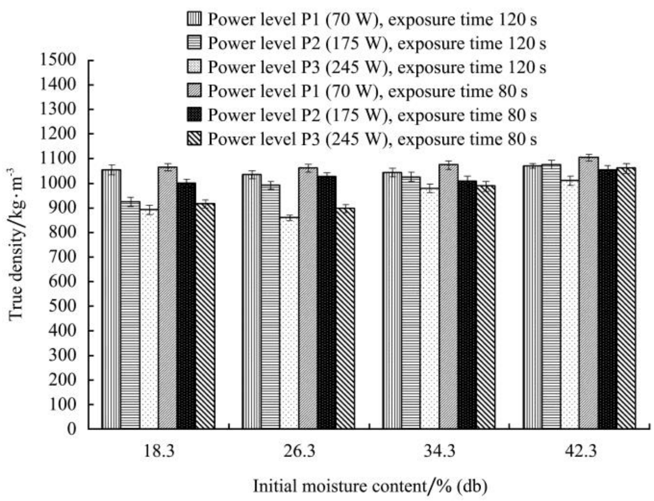


Figure 6 True density of corn at different initial moisture content dried with microwave

The variations in the bulk density of corn at different initial moisture content dried with microwave are given in Figure 7. The P3 (245 W) power level decreased the bulk density of corn at all initial moisture content and exposure time. Shivhare[10] also reported the bulk density of corn reduced with higher microwave power. The bulk density of corn at 42.3% initial moisture content after MW drying was higher and the difference between power levels was lower than that at the other initial moisture content. Similar to the true density, the effect of power level on endosperm might lead to decrease in bulk density.

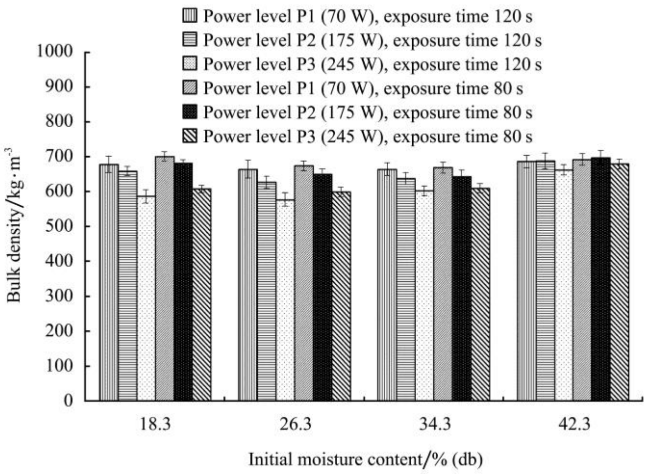


Figure 7 Bulk density of corn at different initial moisture content dried with microwave

Figure 8 shows the effect of microwave drying on TGW of corn at different initial moisture content. The TGW decreased with increase in MW power level but did not change significantly with exposure time. The TGW at the higher initial moisture content (34.3% and 42.3%) was higher than that at 18.3% and 26.3% (db). This might have resulted from higher loss of moisture at lower initial moisture content. Kirleis and Stroshine[31] reported that TGW was not affected by the microwave drying. However, in the present study, we found significant change in TGW due to microwave drying at different power levels.

The variations in the equivalent diameter of corn at different initial moisture content dried with microwave are given in Figure 9. The equivalent diameter was increased with increasing in MW power level. The equivalent diameter was higher at 18.3% and 26.3% than initial moisture content at 34.3% and 42.3%. This might be resulted from the swelling phenomenon of starch due to gelatinization of corn at the lower initial moisture content during microwave drying.

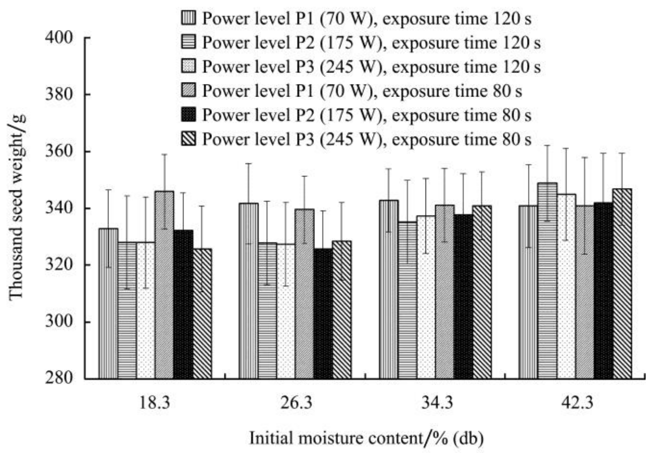


Figure 8 Thousand grain weight of corn at different initial moisture content dried with microwave

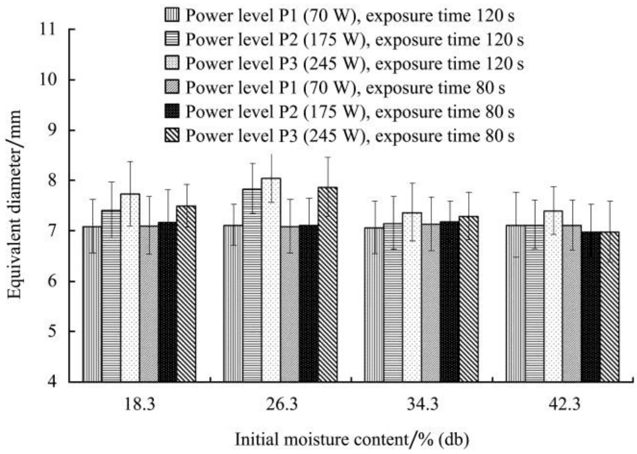


Figure 9 Equivalent diameter of corn grain at different initial moisture contents dried with microwave

The correlation coefficient among the drying and quality parameters of corn dried in microwave conditions are presented in Table 3. While drying rate showed highly significant and positive correlation with SCI and equivalent diameter, it was negatively correlated with germination rate, bulk density and true density. This means that the increase in drying rate may lead to an increase in SCI and equivalent diameter, and a decrease in germination, bulk density and true density. There was no correlation between drying rate and TWG. The SCI had a significant negative correlation with germination rate, bulk density and true density and positive correlation with equivalent diameter. This showed that an increase in the SCI could lead to decreases in germination, bulk density and true density. SCI was not correlated with TGW, while bulk density showed highly significant and positive correlation with true density, TGW and germination rate; it had negative correlation with drying rate, SCI and equivalent diameter.

Table 3 Correlation coefficients among drying rate (DR), germination rate (GR), stress crack index (SCI), bulk density (BD), true density (TD), thousand grain weight (TGW), equivalent diameter (Dp) parameters undergoing microwave drying

	DR	GR	SCI	BD	TD	TGW
GR	-0.5368^{***a}					
SCI	0.7244***	-0.7983***				
BD	-0.7449***	0.4534^{*b}	-0.4651*			
TD	-0.6230***	0.4228*	-0.3907*	0.8606***		
TGW	-0.1757ns^{c}	0.2267ns	0.0328ns	0.6409***	0.7368***	
Dp	0.5830***	-0.3980*	0.4013*	-0.8469***	-0.8666***	-0.6335***

Note: a***, significant at the 0.001 probability, b*, significant at the 0.05 probability; ^{c}ns, not significant.

4 Conclusions

While the higher MW power level increased the loss of moisture content, it significantly reduced the quality parameters. The increase in microwave power level, initial moisture content and exposure time caused a decrease in germination rate, bulk density and true density of corn, and an increase in SCI. The increase in drying rate resulted in an increase in SCI and equivalent diameter, and a decrease in germination, bulk density and true density. Therefore, for microwave drying of corn, it is essential to optimize the power level & initial moisture content for balancing the time of drying and sacrifice in quality of corn. This study will greatly help the corn grain and seed industry in choosing drying parameters for optimizing their microwave drying process.

Acknowledgements

The authors would like to thank the Dicle University for providing financial support for Songul Gursoy's visit to Southern Illinois University, Carbondale, IL, USA. Corn seeds were provided by SIU Farms, Carbondale.

[References]

[1] FAO. FAOSTAT. Food and Agriculture Organization of the United Nations, 2010; Roma, Italy.

[2] USDA. United States Standards for Corn. 1996; Available online: http://www.gipsa.usda.gov/fgis/standards/810corn.pdf.

[3] Wall J S, James C, Donaldson G L. Corn proteins: Chemical and physical changes during drying of corn. Cereal Chemistry, 1975; 52 (6): 779-790.

[4] Herter U, Burris J S. Preconditioning reduces the susceptibility to drying incury in corn seed. Canadian Journal of Plant Science, 1989; 69: 775-789.

[5] Elikhani Z. Zeolites as particulate medium for contact heating and drying of corn. The thesis submitted to the Faculty of Graduate Studies and Research of McGill University, Québec, Canada. 1990.

[6] Bengtsson N E, Ohlsson T. Microwave heating in the food industry. Proceedings of the IEEE, 1974; 62(1): 44–55.

[7] Zhou L, Puri V M, Anantheswaran R C. Effect of temperature gradient on moisture migration during microwave heating. Drying Technology, 1994; 12(4): 777-798.

[8] Odjo S, Malumba P, Dossou J, Janas S, Béra F. Influence of drying and hydrothermal treatment of corn on the denaturation of salt-soluble proteins and color parameters. Journal of Food Engineering, 2012; 109(3): 561-570.

[9] Sale A J H. A review of microwave for food processing. International Journal of Food Science & Technology, 1976; 11(4): 319-329.

[10] Shivhare U S. Drying characteristics of com in a microwave field with a surface-wave applicator. PhD. thesis, Macdonald Campus of McGill University, 1991.

[11] Gunasekaran S. Pulsed microwave and vacuum drying of food materials. Drying Technology, 1999; 17(3): 395-412.

[12] Reyes A, Cerón S, Zůňiga R, Moyano P. A comparative study of microwave-assisted air drying of potato slices. Biosystem Engineering, 2007; 98: 310-318.

[13] Good D L, Hill L D. Illinois and the world corn market. Illinois Research, 1992; 34(1-2): 3-7.

[14] Weller C L, Paulsen M R, Steinberg M P. Correlation of starch recovery with assorted quality factors of four corn hybrids. Cereal Chemistry, 1988; 65(5): 392-397.

[15] Peplinski A J, Paulis J W, Bietz J A, Pratt R C. Drying of high-moisture corn: Changes in properties and physical quality. Cereal Chemistry, 1994; 71(2): 129-133.

[16] Paulsen M R, Hofing S L, Hill L D, Eckhoff S R. Corn quality characteristics for Japan markets. Applied Engineering in Agriculture, 1996; 12(6): 731-738.

[17] Paulsen M R, Hill L D. Corn quality factors affecting dry milling performance. Journal of Agricultural Engineering

Research, 1985; 31: 255-263.

[18] Montross M D, Bakker-Arkema F W, Hines R E. Moisture content variation and grain quality of corn dried in different high-temperature dryers. Transactions of the ASAE, 1999; 42(2): 427-433.

[19] Watkins A E, Maier D E. Thin layer drying rates and stress cracking of white food corn hybrids. ASAE Paper No. 97-6065, 1997.

[20] Weller C L, Paulsen M R, Steinberg M P. Stress crackıng and breakage susceptibility as affected by moisture content at harvest for four yellow dent corn hybrıds. Transactions of the ASAE, 1990; 33(3): 863-869.

[21] Nair G R, Li Z, Gariepy Y, Vijaya R. Microwave drying of corn (*Zea mays* L. ssp.) for the seed industry. Drying Technology, 2011; 29(11): 1291-1296.

[22] Gunasekaran S. Drying corn using continuous and pulsed microwave energy. Drying Technology, 1990; 8(5): 1039-1047.

[23] Shivhare U S, Raghavan G S V, Bosisio R G. Microwave drying of corn II. Constant power, continuous operation. Transaction of the ASAE, 1992; 35(3): 951-958.

[24] Chung M T M, Furutani S C. Microwave Drying of Macadamia Nuts. Applied Engineering in Agriculture, 1989; 5(4): 565-567.

[25] Vicaş S, Ioan M. The drying process of corn seeds in the microwave field. Analele Universităţii din Oradea, Fascicula Protecţia Mediului, XVI, 2011; 191-197.

[26] Vicaş S M, Palade P A. The drying processes of corn seeds in microwave field. Analele Universită Ńii din Oradea Fascicula: Ecotoxicologie, Zootehnie si Tehnologii de Industrie Alimentară, 2010; 1278-1286.

[27] Manickavasagan A, Jayas D S, White N D G. Germination of wheat grains from uneven microwave heating in an industrial microwave dryer. Canadian Biosystem Engineering, 2007; 49(3): 23-27.

[28] Campaña L A, Sempé M E, Filgueira R R. Physical, chemical and baking properties of wheat dried with microwave energy. Cereal Chemistry, 1993; 70: 760-763.

[29] Nofsinger G W, Van Cauwenberge J E, Anderson R A, Boathast R J. Preliminary biological evaluation of the effect of microwave heating on high-moisture shelled corn. Cereal Chemistry, 1980; 57(6): 373-375.

[30] Velu V, Nagender A, Prabhakara Rao P G. Rao D G. Dry milling characteristics of microwave dried maize grains (*Zea mays* L.). Journal of Food Engineering, 2006; 74: 30-36.

[31] Kirleis A W, Stroshine R L. Effects of hardness and drying air temperature on breakage susceptibility and dry-milling characteristics of yellow dent corn. Cereal Chemistry, 1990; 67(6): 523-528.

[32] Mohsenin N N. Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers, New York, 1980.

[33] Seifi M R, Alimardani R. Comparison of moisture-dependent physical and mechanical properties of two varieties of corn (Sc 704 and Dc 370). Australian Journal of Agricultural Engineering, 2010; 1(5): 170-178.