
Germination of wheat grains from uneven microwave heating in an industrial microwave dryer

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¹Department of Biosystems Engineering, University of Manitoba, Winnipeg, Manitoba R3T 5V6, Canada; and ²Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg, Manitoba R3T 2M9, Canada. *Email: digvir_jayas@umanitoba.ca

Manickavasagan, A., Jayas, D.S. and White, N.D.G. 2007. **Germination of wheat grains from uneven microwave heating in an industrial microwave dryer.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **49**: 3.23-3.27. Hot spots, produced on products due to the non-uniform heating pattern of microwaves, may be one of the important factors for the quality degradation of products during microwave treatment. In this study, the germination percentage of wheat samples collected from hot-spot and normal heating zones after microwave treatment was determined. Canadian hard red spring wheat samples (50 g in each experiment) at four moisture levels (12, 15, 18, and 21% wet basis) were subjected to microwave treatment at five power levels (100, 200, 300, 400, and 500 W) and two exposure times (28 and 56 s) in a laboratory scale, continuous type, industrial microwave dryer (2450 MHz). After microwave treatment, the samples were collected from the hot-spot and normal heating zones by viewing the live thermal images on the monitor of the data-acquisition computer of a thermal-imaging system. At all moisture and power levels, germination percentages were significantly ($\alpha=0.05$) lower for samples collected from hot spots than those from the normal heating zone. At 500 W for 28 s exposure, the germination percentage became zero in the hot-spot zones, whereas it was 4 to 33% in the normal heating zone. The germination percentage was near zero at 300 W for the samples collected from the hot spot, when the exposure time was increased to 56 s and the initial moisture content was 18 and 21%. At 400 and 500 W power and 56 s exposure, the germination percentage was almost zero for samples collected from both normal and hot-spot regions. **Keywords:** germination percentage, hot spot, microwave drying, thermal imaging.

Les points chauds causés par des patrons de chauffage aux micro-ondes non-uniforme peuvent être un facteur important de perte de la qualité des produits durant les traitements aux micro-ondes. Dans cette étude, le pourcentage de germination d'échantillons de blé provenant de zones de points chauds et de chauffage normal a été déterminé après que ces grains aient été traités aux micro-ondes. Des échantillons de blé dur roux de printemps canadien (50 g dans chaque essai) à quatre teneurs en eau différentes (12, 15, 18 et 21% base humide) ont été soumis à un traitement aux micro-ondes à cinq niveaux de puissance différents (100, 200, 300, 400 et 500 W) et deux durées d'exposition (28 et 56 s) dans un prototype de séchoir à micro-ondes industriel de type continu (2450 MHz). Après le traitement aux micro-ondes, des échantillons provenant des zones de points chauds et de chauffage normal ont été recueillis en observant en direct les distributions de température sur l'écran de l'ordinateur d'acquisition de données d'un système d'imagerie thermique. Les pourcentages de germination étaient significativement plus bas ($\alpha=0,05$) pour les échantillons prélevés dans les zones de points chauds comparativement aux zones de chauffage normal et ce, pour tous les niveaux de teneur en eau et de puissance.

Pour une puissance de 500 W et une durée exposition de 28 s, le pourcentage de germination était nul pour les zones de points chauds tandis qu'il variait de 4 à 33% dans les zones de chauffage normal. Le pourcentage de germination était près de zéro à 300 W pour les échantillons récoltés dans les points chauds lorsque le temps d'exposition était augmenté à 56 s et que la teneur en eau était comprise entre 18 et 21%. À des puissances de 400 et 500 W et pour une durée d'exposition de 56 s, le pourcentage de germination était presque nul pour les échantillons récoltés des zones normales et de points chauds. **Mots clés:** pourcentage de germination, point chaud, séchage aux micro-ondes, imagerie thermique.

INTRODUCTION

Heat generated within food materials during microwave treatment is utilized to obtain desired changes in the product. Microwaves have been used in grain research for various applications such as drying, accelerating seed germination, and insect disinfection. Borchers et al. (1972) reported that dielectric heat treatment improved the nutritive value of soybeans. Anthony (1983) determined that microwave and vacuum drying of cotton improved the marketing qualities of cotton seed oil. Dielectric-heat treatment increased or accelerated the germination of small-seeded legumes such as alfalfa, red clover, and arrowleaf clover (Nelson and Stetson 1985). Alfalfa-seed germination was improved by dielectric heating at 39 MHz (0.7 to 2.1 kV/cm) (Nelson 1976).

Although microwaves have potential for many applications in the grain industry, they have not been used widely due to their adverse effects on various quality parameters. Walde et al. (2002) reported that microwave drying could reduce the power consumption in wheat milling industries, but was not suitable where the final products made from that flour needed to be soft in textural characteristics. Velu et al. (2006) dried maize (200 g samples) using microwaves and determined that the viscosity of the flour decreased with increasing drying time. It was stated that the alteration in structure of starch and protein increased with microwave drying time and caused the lower viscosity. Doty and Baker (1977) reported that increased ash content, increased dough strength, decreased β -amylase activity, increased flour viscosity, decreased loaf volume, and decreased external and internal loaf characteristics were the important degradation qualities due to microwave conditioning (625 W) of wheat (2 kg samples).



Fig. 1. Experimental setup. 1 - grain inlet, 2 - control panel, 3 - microwave chamber, 4 - conveyor, 5 - thermal camera, 6 - data acquisition system

It is difficult to determine the suitability of a microwave system for a particular application in the grain industry due to other quality deteriorations. Non-uniformity of heating during microwave treatment produces hot spots (localized elevated temperature), and this may be one of the important factors for the quality deterioration of grains. The non-uniformity (ΔT , the difference between maximum and minimum temperatures) of surface temperatures of wheat (50 g samples) after microwave treatment was found to be in the range of 62.9 to 69.5°C after exposing to 500 W for 56 s (Manickavasagan et al. 2006). Study on quality of the grain samples in the hot-spot and the normal heating zones after microwave treatment would help to understand the thermal degradation of bulk grain during microwave treatment. The objective of this research was to determine the germination percentage for wheat samples collected from the hot-spot and normal heating zones of bulk grain after microwave treatment.

MATERIALS and METHODS

Microwave treatment

A laboratory scale, continuous type, industrial microwave dryer (2450 MHz) operated at 230 VAC, 60 Hz, 23 A (Model No: P24YKA03, Industrial Microwave Systems, Morrisville, NC) was used in this study. The microwave dryer consisted of a conveyor-belt assembly, microwave applicator, fan, and a control panel (Fig. 1). The speed of the conveyor and the power output of the microwave generator could be adjusted to the desired level. The fan was on at all times during the experiments and the air inlet temperature was set at 30°C.

Canadian hard red spring wheat (obtained from the Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg, Manitoba) was conditioned to four different moisture levels (12, 15, 18, and 21% wet basis) and used in this study. In each experiment, a 50 g sample was spread on the conveyor and the top surface was made flat. Then the grain was allowed to enter the chamber where it was subjected to microwave treatment. The approximate volume of the grain sample on the conveyor

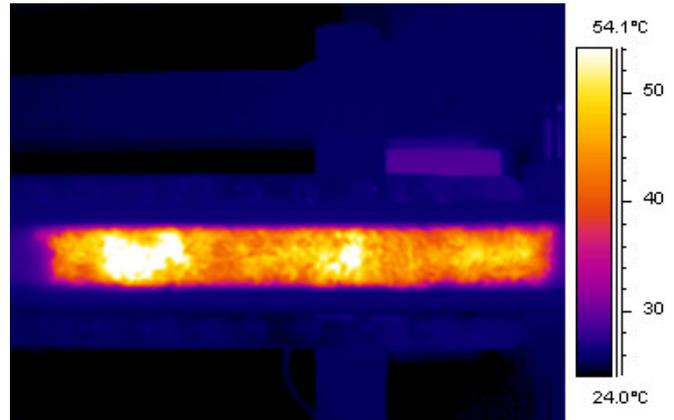


Fig. 2. Typical thermogram of wheat sample showing hot spot after microwave treatment.

during treatment was 300×30×10 mm (length of the belt × width of the belt × depth of grain on the belt). Two microwave exposure times were achieved by changing the speed of the conveyor. Microwave treatment was given at five power levels (100, 200, 300, 400, and 500 W) and two exposure times (28 and 56 s). A thermal camera (Model: ThermaCAM™ SC500, spectral range: 7.5 to 13.0 μm, FLIR Systems, Burlington, ON) was set to view the grain sample on the conveyor as soon as it came out from the microwave chamber after treatment in order to sample from the hot-spot and normal heating zones. Samples were collected using a spoon while viewing the live thermal images on the monitor of the data acquisition computer and the grain samples were stored in polyethylene bags separately for further analysis. The final moisture content after microwave treatment was measured for the wheat samples (bulk).

Thermal imaging

In thermal imaging, radiation pattern of an object (temperature) is converted into a visible image. The color of each pixel in a thermal image represents a temperature value which is given on the temperature scale (right side of Fig. 2). Generally, in a thermal image, bright and dark colors represent high and low temperatures, respectively. Because of non-uniform heating, hot spots were observed (as patches) at one or two locations on the surface of wheat samples after microwave treatment. Samples were collected from the hot spot and the remaining region, and subjected to a germination test.

Germination test

The germination test was conducted for the samples collected from the hot-spot and normal heating zones. It was not possible to conduct baking quality tests since the quantity of sample collected from the hot spot was small (about 10 to 15 g from 50 g of the microwave-treated sample). However, to detect quality degradation of grain due to high temperature, a germination test can be used because it is a sensitive, simple, and reproducible test and the results are reasonably correlated with baking tests (Ghaly and Taylor 1982).

Wheat kernels (25 seeds) were placed on Whatman no. 3 filter paper in a 90-mm diameter Petri-dish saturated with 5.5 mL of distilled water. The Petri-dishes were covered with a polyethylene bag and kept at 25°C for 7 d. The germinated seeds were counted on the seventh day and germination percentage

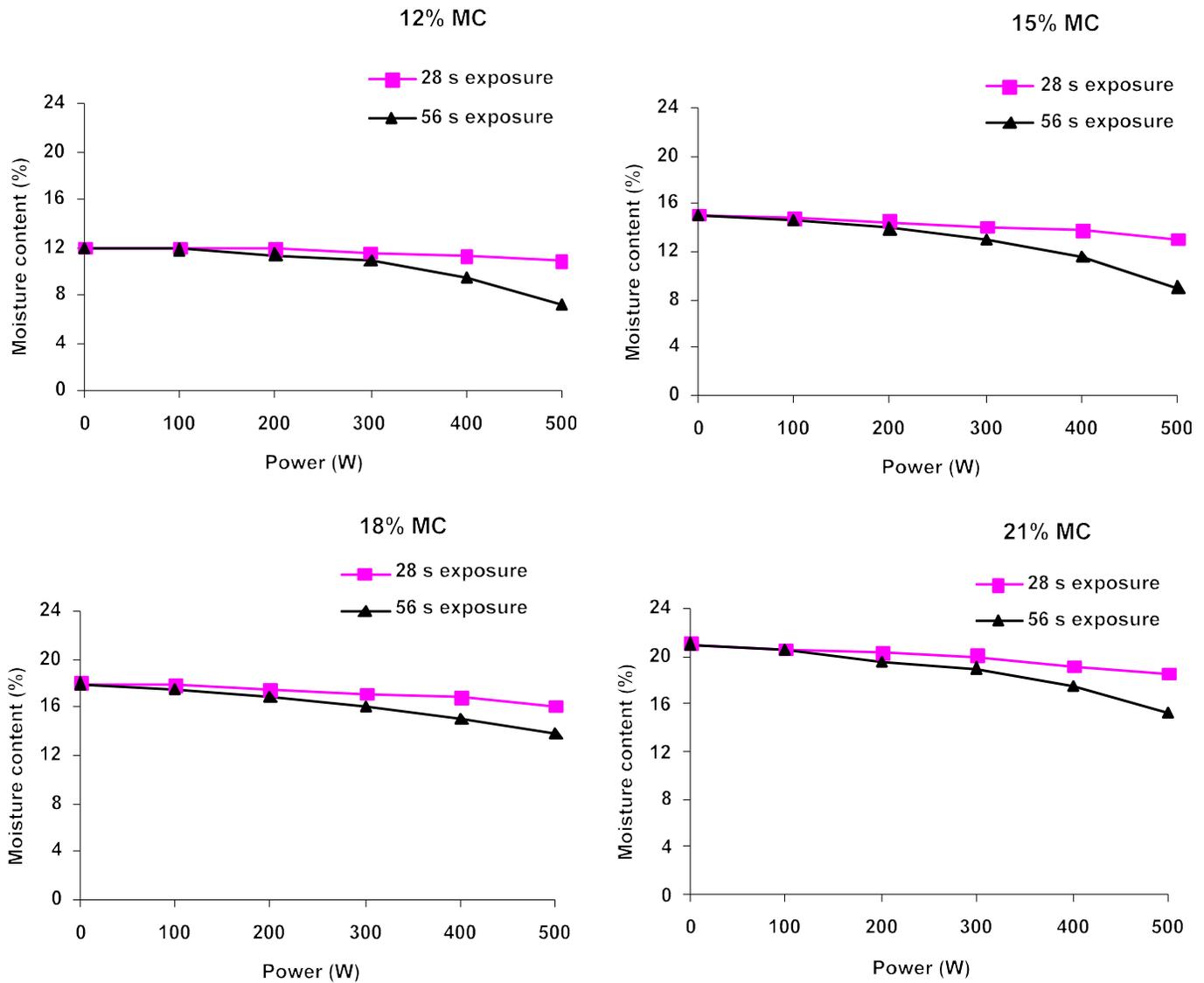


Fig. 3. Final moisture content of bulk wheat samples after microwave treatment.

was calculated. Wheat samples were subjected to the germination test on the next day after microwave treatment. The entire experiment was replicated three times.

Statistical analysis

The effect of moisture content, microwave power, and sample location in 50 g bulks on the germination percentage at each exposure time was analyzed by the analysis of variance (ANOVA) method using a factorial experimental design (4 moisture content \times 6 power (control, 100, 200, 300, 400, and 500) \times 2 sample locations (hot-spot and normal heating zones)). The differences within the levels under each variable were tested using the least significant difference (LSD) method of comparison of means. The general linear models (GLM) procedure in SAS (version 9.1) (Statistical Analysis System, Cary, NC) was used for all statistical analysis. For the germination percentage, the statistical significance between the samples collected from the hot spot and the normal heating zone at each power level was tested using an independent t test ($\alpha=0.05$).

RESULTS

The moisture content of the bulk samples after microwave treatment is given in Fig. 3. Since the microwave treatment and exposure time were the same for all the grains (with different initial moisture content), the samples were at different final moisture contents. When the microwave power was 100 W, the moisture loss was in the range of 1 to 1.9% at 28 s exposure and 1.7 to 3.9% at 56 s exposure. When the power level was increased to 500 W, the moisture loss was 9.7 to 12.9% and 23.9 to 40.4% when the exposure time was 28 and 56 s, respectively.

The germination percentages of samples collected from the hot-spot and normal heating zones after microwave treatments are shown in Figs. 4 and 5. Sample location (hot spot vs normal heating zone) had a significant effect on the germination percentage. The germination percentage was lower for the samples which were collected from the hot spot region than those from the normal heating zone, except for two treatments:

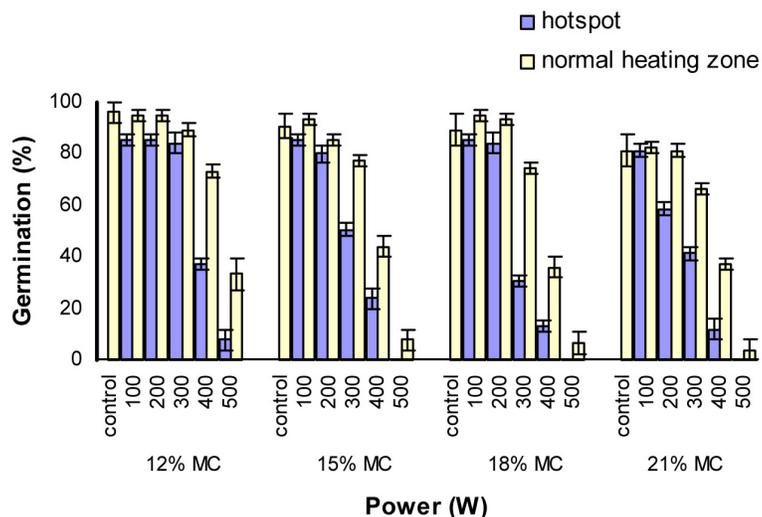


Fig. 4. Germination percentages of wheat samples collected from the hot-spot and the normal heating zones after heating for 28 s in an industrial microwave dryer.

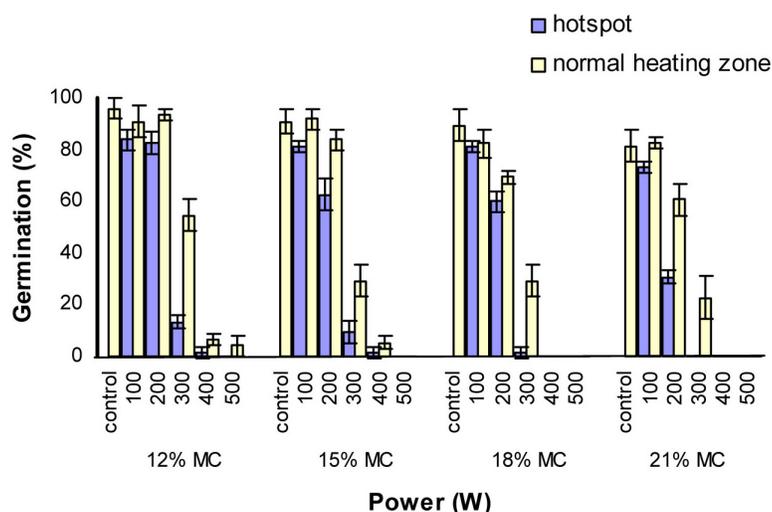


Fig. 5. Germination percentages of wheat samples collected from the hot-spot and the normal heating zones after heating for 56 s in an industrial microwave dryer.

21% moisture content grain at 100 W power and 28 s exposure time, and for 18% moisture content grain at 100 W and 56 s exposure time. In these two treatments, there were no significant differences in the germination percentages of samples collected from the normal and hot-spot regions. The difference in germination between samples from the hot-spot and the normal heating zones was less at lower-power levels and increased as the power level increased. When the exposure time was 28 s at 500 W, the germination was almost zero in the hot-spot zone except for 12% moisture content grain, whereas it was 4 to 33% for samples collected from the normal heating zone. The germination percentage was almost zero at 300 W for the samples collected from the hot spot, when the exposure time was increased to 56 s and the initial moisture contents were 18 and 21%. At 400 and 500 W power levels when the exposure time was 56 s, the germination percentage was near zero for

samples collected from both normal and hot-spot regions (except for 12% moisture content).

Microwave exposure time and power level had a significant effect on the germination percentage of wheat. Germination percentage decreased with increasing power level and exposure time. Germination percentage of wheat after microwave treatment was significantly decreased with increasing initial moisture content.

DISCUSSION

The variations in the germination percentage of wheat samples collected from the hot-spot and normal heating zones which were subjected to the same microwave treatment were determined. The wheat samples were just heated up and not much drying was observed at the lower power levels as the treatment time was less than one minute. Fanslow and Saul (1971) reported that moisture removal was small in the first 60 s during microwave drying of corn. They also stated that 31 to 56% of microwave power was consumed for moisture removal and the remaining power was utilized to raise the temperature of the grain and air. In our study, the moisture removal was higher at the higher power levels.

The exposure time and initial moisture content had a significant effect on the germination percentage. Ghaly and Touw (1982) evaluated the level of heat damage to wheat samples in a small batch fluidized-bed rig, and determined that the effects of temperature and initial moisture content were highly significant, but exposure time had little effect on quality deterioration of wheat. The variation in the effect of exposure time on the damage between microwave heating and convection heating is because of the continuous increase in temperature during microwave treatment. The grain temperature during microwave treatment increased with power level and exposure time. In another study at our lab using the same microwave drier, the average temperature, maximum temperature, and ΔT on the surface of the wheat bulk (50 g samples) after exposing to five power levels (100, 200, 300, 400, and 500 W) and two treatment times (28 and 56 s) were determined (Manickavasagan et al. 2006). The ΔT increased with the microwave power levels, and ranged from 9.7 to 67.7°C when the wheat samples were treated between 100 and 500 W power levels. The maximum temperature on the surface of the grain bulk was also increased with power levels and exposure time. It was in the range of 37.5 to 117°C and 44 to 131°C at 28 and 56 s exposure times, respectively. In correlation with these results, the germination percentage decreased with increasing microwave power levels in both hot-spot and normal heating zones. The germination percentage was essentially determined by grain temperature. Nelson (1976) also reported that optimum germination response was related to elevation of seed temperature during dielectric-heating and was about 75°C for alfalfa seed of 6 to 7% moisture content. If the temperature exceeded this optimum level, the high temperatures damaged

seed viability. Shivhare et al. (1992) 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. Hence, the microwave power and exposure time would be the important factors while using microwaves for seed processing. So, while using microwaves for seed-drying or processing, arrangements must be made to reduce the temperature in the hot spot in order to retain the germination ability at lower microwave power levels.

Although the temperature generated in the high moisture wheat was lower than that in the low moisture wheat, the high moisture grain was more heat-sensitive and hence a lower germination percentage was observed in high moistures at all power levels. Moisture content determines the rate at which seed can absorb energy from RF electric fields and the capability of seed to retain its viability at higher temperature (Nelson 1976). Campana et al. (1993) also stated that germination capacity was inversely related to initial moisture content of wheat and final temperature during microwave treatment.

CONCLUSION

The germination percentage of wheat samples present in the hot spot region was significantly lower than that of the normal heating region in almost all moisture and power levels. Microwaves are not suitable for the drying of wheat which is to be used as seeds, even at low power levels, unless some provisions are made to ensure uniform heating. Apart from germination, the other quality parameters which are sensitive to heat are also expected to be affected more in the hot-spot zone than the remaining bulk grain. While evaluating the quality changes of grain after microwave treatment, testing grain in the hot-spot zone would yield more realistic information about the damage due to microwave treatment rather than mixing and testing the whole bulk grain.

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