Nonuniform microwave heating of ready-to-eat chicken pies

A. Manickavasagan, D.S. Jayas* and R. Vadivambal

Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, Canada R3T 5V6. Email: Digvir_Jayas@umanitoba.ca

Manickavasagan, A., D.S. Jayas and R. Vadivambal. 2009. **Nonuniform microwave heating of ready-to-eat chicken pies**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada. **51**: 3.39–3.44. The temperature rise and distribution in ready-to-eat (RTE) chicken pie after microwave heating in three domestic ovens were studied. The RTE chicken pie was placed at seven different locations ("on turntable, at centre"; "on turntable, at edge"; "no turntable, at center"; and "no turntable, at corners" (1, 2, 3 and 4)) inside the microwave cavity and subjected to microwave treatment. The surface temperature of the pie was measured by an infrared thermal camera, and the internal temperature was measured by three thermocouples. The mean internal temperature was lower than the mean surface temperature at all locations in the cavity. An irregular heating pattern with hot and cold regions was observed on the surface and inside the pie. Nonuniformity (ΔT, the difference between maximum and minimum temperatures) was in the range of 31.6 to 130.5°C on the surface and 10.7 to 76.1°C inside the pie. The non-uniformity on the surface of the pie was significantly lower when the product was placed on the turntable. But the location of the pie in the microwave cavity did not have significant effect on internal nonuniformity. **Keywords:** ready to eat food, chicken pie, microwave heating, mean temperature, temperature nonuniformity, thermal imaging.

L'augmentation et la distribution de la température dans des pâtés au poulet prêts à manger (PAM) chauffés dans trois fours à micro-ondes domestiques ont été étudiées. Des pâtés au poulet PAM ont été placés à sept endroits différents (« sur le plateau tournant, au centre »; « sur le plateau tournant, sur le côté »; « sans plateau tournant, au centre »; et « sans plateau tournant, dans les coins » (1, 2, 3, et 4)) à l'intérieur de la chambre du four et ont été soumis au traitement micro-ondes. La température de surface du pâté a été mesurée à l'aide d'une caméra thermale à infrarouge et la température interne a été mesurée à l'aide de trois thermocouples. La température interne moyenne mesurée était plus faible que la température moyenne de surface peu importe la position des pâtés dans le four. Des patrons de chauffage irréguliers présentant des régions plus chaudes et plus froides à la surface de même qu'à l'intérieur des pâtés ont été observés. Les différences de température (ΔT, la différence entre les températures maximales et minimales) ont varié entre 31,6 et 130,5°C à la surface et entre 10,7 et 76,1°C à l'intérieur du pâté. Les différences de température à la surface du pâté étaient significativement plus faible lorsque le produit était placé sur le plateau tournant du four. Cependant, l'endroit où était placé le pâté dans la chambre du four n'a pas eu d'effet significatif sur les différences de température à l'intérieur. **Mots clés:** aliment prêt à manger, pâté au poulet, chauffage micro-ondes, température moyenne, différence de température, imagerie thermale.

INTRODUCTION

Changes in lifestyle and growth in income and purchasing power have resulted in the demand for ready-to-eat (RTE) food products globally. Ready-to-eat meals are one of the fastest growing sectors of the food industry in developed countries (Gehlar and Regmi 2005). Several food-borne illness outbreaks have been associated with the consumption of contaminated RTE foods. Microbiological investigations of RTE foods in many countries revealed that a significant percentage of RTE products were contaminated with pathogens. In Malaysia around 14% (of 112 samples) of RTE meat foods were contaminated with *Salmonella* spp. and 22% (of 76 samples) of RTE foods were contaminated with *Listeria monocytogenes* (Arumugaswamy et al. 1994; Arumugaswamy et al. 1995). About 20% (of 148) of the restaurants and 10% (of 444 samples) of RTE chicken dishes were infected by *Salmonella* spp. in Senegal (Cardinale et al. 2005). Quinones et al. (2000) found *Campylobacter* spp. in 27% (of 100 samples) of ready to eat chicken "tacos" in Mexico. In the United Kingdom, around 26% (of 3494 samples) of RTE foods were of unsatisfactory quality (due to high aerobic plate counts) during a microbiological investigation survey (Gillespie et al. 2000). *Listeria* spp. were found in 50% (of 34 samples) of RTE pork, 50% (of 18 samples) of RTE beef and 43.8% (of 16 samples) of RTE chicken products in New Zealand (Hudson et al. 1992 cited by Lake et al. 2002). Although the quality of the starting material is good, other factors such as handling, processing, transportation and storage could influence the microbiological composition of RTE foods at the consumer's table (Angelidis et al. 2006).

In many countries, microwave ovens are commonly used to heat the RTE foods before consumption. Microwave ovens have become a common appliance in the kitchen and the market penetration is nearly 100% in the United States, Japan and Australia, over 80% in United Kingdom, and 55% in Singapore (Ryynanen et al. 2001; Statistics Singapore 2005). Microwave ovens are very efficient in quick reheating and cooking; however, an inherent problem associated with microwave heating is the nonuniform heating of products caused by an uneven spatial distribution of the electric field inside the microwave cavity. Another reason for non-uniform heating of heterogeneous food is due to the differences in dielectric properties of ingredients. A temperature difference (ΔT) of

60 to 80°C was measured in different food materials after microwave heating in domestic ovens (Fakhouri and Ramaswamy 1993; Goksoy et al. 1999; Ryynanen and Ohlsson 1996). As per the recommendation made by the Canadian Food Inspection Agency (2001), chicken must be heated to at least 85°C to prevent food-borne illness. Hence, the minimum temperature of chicken-based RTE foods after microwave heating must reach 85°C to kill the pathogens in potentially contaminated foods. In most of the published reports on heating patterns of domestic microwave ovens, the product was kept at the centre of the cavity, and thermocouples and fibre optic probes were placed at some locations in the food materials to measure the temperature. The objective of this study was to determine the mean temperature rise and nonuniformity in RTE chicken pie with thermal imaging after microwave heating by placing at different locations inside a microwave cavity.

MATERIALS and METHODS

Ready-to-eat chicken pies (200 g each) were purchased from a retail store. The chicken pies were composed of a wheat crust, chicken and vegetables (in cube shapes). The outer dimensions of the chicken pie were 12 cm diameter and 3 cm thickness. Each pie was kept in a freezer and taken out just before the experiment.

Three domestic microwave ovens were randomly selected and used in this study: 1. Proctor Silex, Model E 7017 NP-F, power 700 W (oven 1), 2. Goldstar, model GMS 1120W, power 1100 W (oven 2), 3. Panasonic, model NNH 765 WF, power 1200 W, (oven 3). The RTE pie was placed at seven different locations inside the microwave cavity (seven treatments) namely, "on turntable, at centre" (TC); "on turntable, at edge" (TE); "no turntable, at centre" (C); "no turntable, at corner 1" (C1); "no turntable, at corner 2" (C2); "no turntable, at corner 3" (C3); and "no turntable, at corner 4" (C4). For positions C, C1, C2, C3, and C4, the turntable was removed from the oven before placing the product. The pie was heated for 5 min in oven 1 and 4 min in ovens 2 and 3, at the maximum microwave power level (as per the recommendation on product label, 5 min in 700 W and 4 min in 1100 W ovens). The diameter and the speed of the turntables were 24.5 cm and 6.2 cm/s (4.8 rpm), 28.5 cm and 9.0 cm/s (6.0 rpm), 37.5 cm and 11.8 cm/s (6.0 rpm) for ovens 1, 2 and 3, respectively.

The surface temperature of RTE products was measured by an infrared thermal camera (Model: ThermaCAM ™ SC500 of FLIR systems, Burlington, ON, Canada; spectral range: 7.5 to 13.0 µm), 5 s after heating, and internal temperatures were measured by three thermocouples at 2 cm depth, 10 s after heating. One thermocouple (T2) was placed at the centre of the product and two thermocouples (T1 and T3) were placed near the periphery (Fig. 1). In all experiments, T1 was measured at the location that was facing the centre of the oven, and T3 was measured at the location that was facing the wall of the oven. From the acquired thermal images, average, maximum, minimum, and standard deviation of surface temperatures of the pie were extracted using ThermaCAM Researcher software (FLIR systems, Burlington, Ontario, Canada). The experiments were replicated three times in each oven and at all locations inside the microwave cavity.

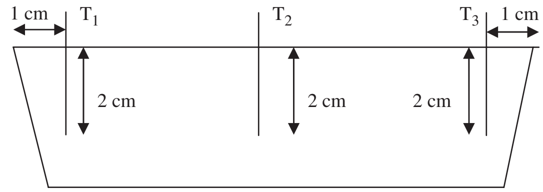

Fig. 1. Positioning of thermocouples (T1, T2 and T3) to measure internal temperatures of RTE pie after microwave heating.

Statistical analysis

The effect of location of the product inside the microwave cavity on mean temperature was analyzed using a factorial design [3 ovens $\times$ 7 locations $\times$ 2 depths (surface vs. internal)] by ANOVA. The effect of oven and location of the product in the microwave cavity on the surface and internal nonuniformity was analyzed by 2 factors model (3 ovens $\times$ 7 locations) separately using ANOVA. The differences within the levels under each variable were tested using the least significant difference (LSD) of comparison of means ($\alpha = 0.05$). General linear models (GLM) procedure in SAS (2002) was used for all statistical analysis.

RESULTS and DISCUSSION

In thermal imaging, the invisible 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 a temperature scale provided by the image processing software. Generally, in a thermal image, bright and dark colors represent high and low temperatures, respectively. A thermal image contained 320×240 pixels ($320 \times 240 = 76\ 800$ temperature values), out of that, the pie occupied approximately 35000 pixels. This means 35 000 temperature values were measured on the surface of each pie.

Temperature

The surface temperatures (obtained from thermal images) and internal temperatures (obtained from thermocouples) of the chicken pie after heating in domestic microwave ovens are given in Tables 1 and 2, and Table 3. The temperature ranges on the surface of the pie following microwave heating were 90.8 to 104.0°C, 65.9 to 105.4°C, and 84.1 to 106.7°C in ovens 1, 2, and 3, respectively. The mean internal temperature ranged from 49.5 to 78.4°C, 71.7 to 96.1°C, and 74.3 to 94.2°C in ovens 1, 2, and 3, respectively. There were no significant differences in mean surface and internal temperatures between different locations in the cavity. The mean surface temperature was significantly higher than internal temperature in all three ovens. This is probably due to poor penetration of microwaves in frozen foods.

Table 1. Temperature profile of a chicken pie after microwave heating for 5 min ($n = 3$) in oven 1.

	Surface temperature (°C)			Internal temperature (°C)		
Position*	Average	ΔT	SD	T1	T2	T3
TC	90.8 ± 1.8	31.6 ± 6.6	3.7 ± 0.4	64.8 ± 12.0	86.8 ± 4.8	75.7 ± 24.9
TE	92.4 ± 7.9	66.4 ± 23.7	11.3 ± 6.8	69.0 ± 23.2	48.1 ± 39.6	82.6 ± 2.2
C	95.7 ± 1.4	100.4 ± 38.5	14.1 ± 4.0	70.9 ± 17.3	23.1 ± 18.9	54.4 ± 42.5
C1	95.7 ± 10.7	130.5 ± 26.5	16.7 ± 2.7	83.0 ± 25.2	58.1 ± 15.5	89.1 ± 5.7
C2	104.0 ± 11.3	121.3 ± 12.1	23.0 ± 4.2	57.8 ± 34.8	30.6 ± 20.8	85.0 ± 4.2
C3	100.0 ± 2.4	118.6 ± 33.4	14.5 ± 1.9	96.5 ± 1.3	79.4 ± 4.7	75.1 ± 34.6
C4	94.5 ± 3.8	120.3 ± 47.3	17.4 ± 7.4	86.1 ± 10.2	60.3 ± 35.4	81.5 ± 16.4

*TC, on turntable, at center; TE, on turntable, at edge; C, no turntable, at center; C1, no turntable, at corner 1; C2, no turntable, at corner 2; C3, no turntable, at corner 3; C4, no turntable, at corner 4; T1, T2, T3, position of thermocouples.

Table 2. Temperature profile of a chicken pie after microwave heating for 4 min ($n = 3$) in oven 2.

	Surface temperature (°C)			Internal temperature (°C)		
Position*	Average	ΔT	SD	T1	T2	T3
TC	93.9 ± 3.8	61.9 ± 14.2	7.4 ± 3.3	95.2 ± 3.4	85.3 ± 11.2	98.8 ± 4.7
TE	95.6 ± 2.7	60.0 ± 15.2	5.7 ± 1.2	92.8 ± 2.3	57.8 ± 43.6	92.6 ± 6.9
C	104.4 ± 3.6	62.8 ± 10.5	10.4 ± 3.3	97.1 ± 1.9	86.4 ± 13.1	90.5 ± 14.4
C1	105.4 ± 3.3	72.0 ± 7.0	13.6 ± 1.0	97.3 ± 0.2	75.2 ± 8.3	101.5 ± 1.9
C2	96.8 ± 11.7	88.0 ± 25.6	21.9 ± 4.2	68.5 ± 44.0	62.2 ± 31.7	84.4 ± 22.9
C3	65.9 ± 39.9	72.0 ± 8.4	13.0 ± 5.9	60.0 ± 54.1	35.3 ± 51.7	57.6 ± 47.5
C4	90.2 ± 8.8	106.4 ± 24.5	20.8 ± 6.3	97.6 ± 2.0	73.0 ± 19.5	56.7 ± 50.8

*TC, on turntable, at center; TE, on turntable, at edge; C, no turntable, at center; C1, no turntable, at corner 1; C2, no turntable, at corner 2; C3, no turntable, at corner 3; C4, no turntable, at corner 4; T1, T2, T3, position of thermocouples.

Temperature nonuniformity

Thermal images of a chicken pie after heating at various locations in the microwave cavity are shown in Fig. 2. The surface temperature values, min, max, max-min, avg, stdev, shown below each image indicates the minimum, maximum, difference between the maximum and minimum temperatures (ΔT), average and standard deviations of the temperature profiles within a selected region. At all locations in the microwave cavity, nonuniform temperatures were observed on the surface of the pie. The surface temperatures ranged between 31.6 to 130.5°C, 60.0 to 106.4°C, and 50.3 to 117.9°C for ovens 1, 2, and 3, respectively. The probable reason for the higher nonuniformity is the heat from the localized high temperature zone was not transferred to the low temperature region due to the poor conductivity of the material. Ryynanen

Table 3. Temperature profile of a chicken pie after microwave heating for 4 min ($n = 3$) in oven 3.

	Surface temperature (°C)			Internal temperature (°C)		
Position*	Average	ΔT	SD	T1	T2	T3
TC	89.9 ± 2.3	50.3 ± 6.4	7.4 ± 2.6	96.6 ± 1.5	87.0 ± 3.7	99.0 ± 1.3
TE	97.7 ± 0.1	64.7 ± 1.9	5.7 ± 0.2	95.4 ± 0.8	25.7 ± 16.6	102.0 ± 1.1
C	84.1 ± 8.2	117.9 ± 13.9	22.9 ± 0.9	97.9 ± 0.5	51.9 ± 7.1	95.8 ± 9.3
C1	105.5 ± 10.5	77.4 ± 39.9	23.2 ± 9.9	97.9 ± 0.9	52.8 ± 29.0	102.0 ± 5.3
C2	104.3 ± 10.9	58.8 ± 14.0	14.9 ± 1.2	98.2 ± 1.1	44.8 ± 14.2	100.0 ± 2.0
C3	99.0 ± 1.6	85.7 ± 17.2	12.2 ± 0.1	74.5 ± 22.1	42.2 ± 13.4	101.1 ± 2.3
C4	106.7 ± 1.2	75.5 ± 6.7	13.7 ± 4.1	97.1 ± 2.2	65.9 ± 23.2	113.0 ± 24.2

*TC, on turntable, at center; TE, on turntable, at edge; C, no turntable, at center; C1, no turntable, at corner 1; C2, no turntable, at corner 2; C3, no turntable, at corner 3; C4, no turntable, at corner 4; T1, T2, T3, position of thermocouples.

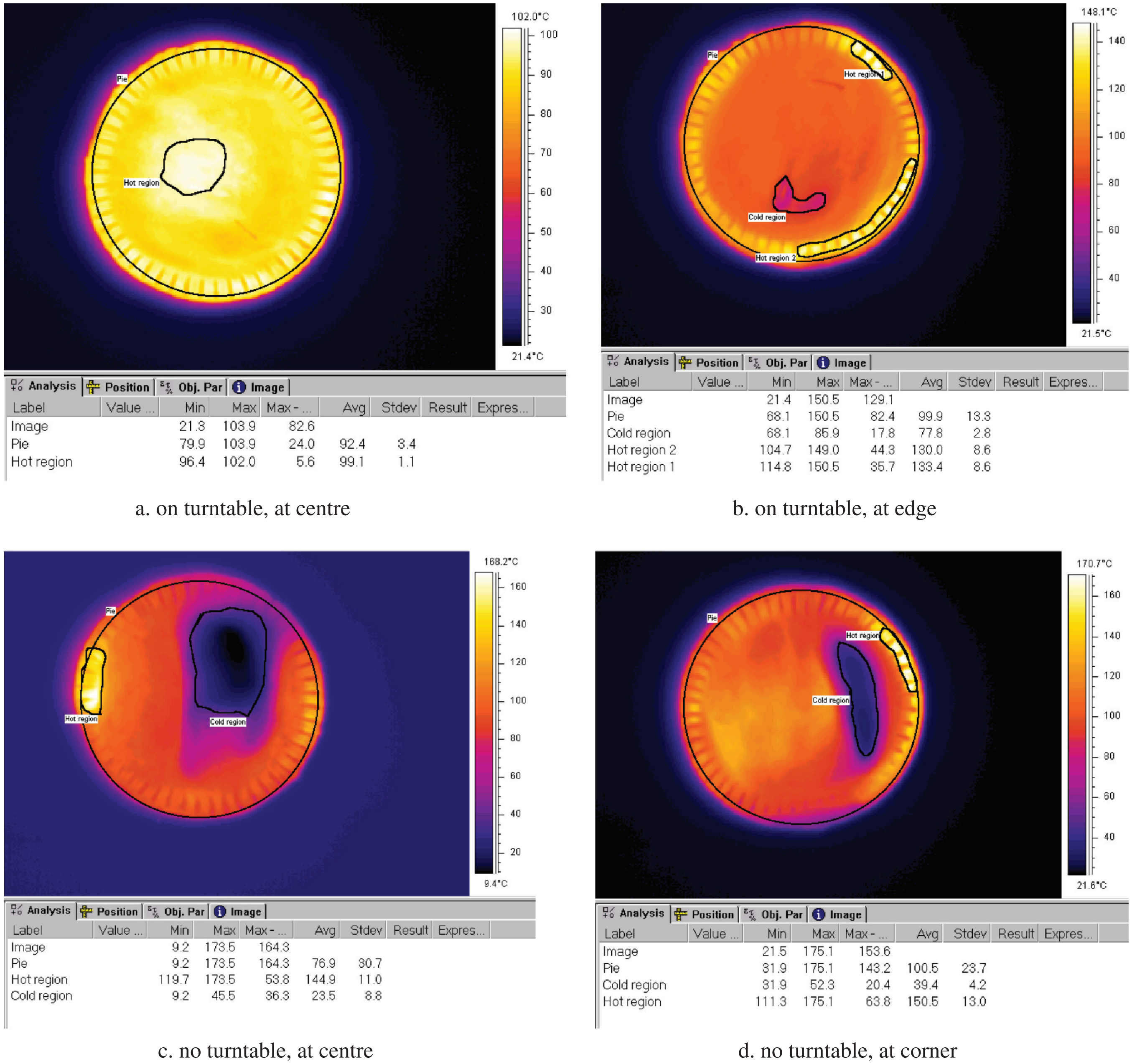

Fig. 2. Thermal images of a pie after microwave heating by placing at different locations inside microwave cavity.

and Ohlsson (1996) stated that a temperature difference of 70°C in mashed potato was obtained after microwave heating, and that might be due to the compact structure and the poor conductivity of the product.

The nonuniformity on the surface of the pie was significantly lower when the product was heated on a turntable. While the products are in constant movement within the microwave cavity, different parts of the product receive average electric field intensity over a period of time and uniform heat is produced in the product (Feng and Tang 1998). There was no significant difference on the level of surface temperature nonuniformity between the locations without turntable. The surface nonuniformity was higher in oven 1, and there was no difference in the level of nonuniformity between ovens 2 and 3.

Several researchers have studied microwave heating patterns, and the location of hot and cold spots on different shapes of foods using mathematical models (Zhou et al. 1995; Vilayannur et al. 1998; Campanone and Zaritzky 2005). Campanone and Zaritzky (2005) observed hot spots at the centre of the sphere in spherical foods, nonuniform radial distribution with the highest temperatures at the surface and the centre for cylindrical foods, and hot spots in corners of cubes and brick-shaped products. Vilayannur et al. (1998) studied the size and shape effect on the nonuniformity of temperature distribution in microwave heated food using a finite element model, and reported that for brick-shaped products, hot spot appeared at the corners and cold spot developed at the geometric centre. In our study, when there was no turntable during heating, a distinct cold region was observed for the products in all replications. The entire periphery of the pie was slightly hotter than the remaining area when the products were placed on the turntable, and distinct hot regions were observed on some areas on the periphery, when the products were placed in the oven without a turntable. Some hot regions were observed in the centre of the product while placing the product at the centre of the turntable. The size and location of the hot and cold regions varied during replications for each treatment. It was also observed that the area of the cold region was large and more predominant than hot regions.

The internal temperature difference ranged between 21.3 and 54.4°C, 10.7 and 40.9°C and 12.0 and 76.1°C for ovens 1, 2, and 3, respectively. The location in the microwave cavity did not have any significant impact on the internal temperature nonuniformity in all three ovens. The internal nonuniformity was lower in oven 2 and there was no difference between ovens 1 and 3. From the three internal temperature measurements, (T1, T2, and T3), the temperature at the centre (T2) was lower than the temperature near the periphery.

CONCLUSIONS

The temperature rise and distribution in RTE chicken pies were determined after heating in domestic microwave ovens. Nonuniformity was observed on surface and internal temperatures of the pies after heating in all three microwave ovens. The temperature nonuniformity was significantly lower when the products were placed on a turntable and there was no significant difference between the locations without turntable. The temperature measured at three locations inside the product was irregular with each of them recording minimum and maximum in different treatments. Similarly, thermal images showed various sizes of hot and cold regions at various locations. Although the nonuniformity of heating was smallest when the pie was placed at the center of the turntable, the ΔT was in the range of 31.6 to 61.9°C.

ACKNOWLEDGEMENTS

We thank the Canada Research Chairs program and the Natural Sciences and Engineering Research Council of Canada (NSERC) for their partial financial assistance and Ms. U. Nithya, Ms. G. Sathya and Mr. V. Chelladurai for their help in experiments. We thank Dr. N.D.G. White of Agriculture and Agri-Food Canada for reviewing this manuscript.

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