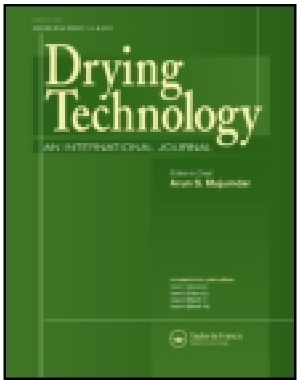

Drying Technology: An International Journal
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ldrt20

Pilot-Scale Radio Frequency Drying of Macadamia Nuts: Heating and Drying Uniformity

Yunyang Wang [a], Li Zhang [a], Mengxiang Gao [b], Juming Tang [c] & Shaojin Wang [c d]

[a] College of Food Science and Engineering, Northwest A & F University, Yangling, Shaanxi, China

[b] College of Life Science, Yangtze University, Jingzhou, Hubei, China

[c] Department of Biological Systems Engineering, Washington State University, Pullman, Washington, USA

[d] College of Mechanical and Electronic Engineering, Northwest A & F University, Yangling, Shaanxi, China

Published online: 22 May 2014.

To cite this article: Yunyang Wang, Li Zhang, Mengxiang Gao, Juming Tang & Shaojin Wang (2014) Pilot-Scale Radio Frequency Drying of Macadamia Nuts: Heating and Drying Uniformity, Drying Technology: An International Journal, 32:9, 1052-1059, DOI: 10.1080/07373937.2014.881848

To link to this article: http://dx.doi.org/10.1080/07373937.2014.881848

Drying Technology, 32: 1052–1059, 2014

ISSN: 0737-3937 print/1532-2300 online
DOI: 10.1080/07373937.2014.881848

Pilot-Scale Radio Frequency Drying of Macadamia Nuts: Heating and Drying Uniformity

Yunyang Wang,[1] Li Zhang,[1] Mengxiang Gao,[2] Juming Tang,[3] and Shaojin Wang[3,4]
[1]*College of Food Science and Engineering, Northwest A & F University, Yangling, Shaanxi, China*
[2]*College of Life Science, Yangtze University, Jingzhou, Hubei, China*
[3]*Department of Biological Systems Engineering, Washington State University, Pullman, Washington, USA*
[4]*College of Mechanical and Electronic Engineering, Northwest A & F University, Yangling, Shaanxi, China*

Hot air assisted radio frequency (HARF) heating holds potential to provide fast drying of Macadamia nuts with acceptable product quality. The goal of this study was to determine heating and drying uniformity of Macadamia nuts in a pilot-scale 27.12 MHz, 6 kW radio frequency (RF) system as influenced by container locations in the RF chamber, moving conditions, and with or without additional hot-air heating. Uniformity index values estimated by measured sample temperatures and weight changes over 12 compartments in the container were used for comparing heating and drying uniformity, respectively, between HARF- and RF-only treatments. Experimental results showed central heating in the HARF-treated four-layer tray and edge or corner heating in RF-alone-treated Macadamia nuts. Moving samples did not clearly improve heating and drying uniformity. The RF uniform drying was achieved with applied hot-air surface heating based on relatively small weight changes over 12 compartments in the container. The determined HARF heating and drying conditions are useful for further industrial applications.

Keywords Drying uniformity; Heating uniformity; Macadamia nuts; Radio frequency; Uniformity index

INTRODUCTION

Macadamia nuts (*Macadamia tetraphylla*) are native to Australia and planted commercially in Australia, Hawaii, South Africa, and South America. The world Macadamia kernel production was estimated to be 26,123 metric tons in 2007/2008 according to a report from the International Nut Council (INC). The fresh nuts need to be dried immediately to a moisture content of less than 1.5% on a dry basis (d.b.),[1] an essential postharvest operation to obtain a high recovery rate in cracking and maintain desired kernel flavor and texture in the final product.[2] Macadamia nuts have thick and hard shells; thus, they often require more than one month to complete industrial drying using hot air.[3] The process involves excessive handling of in-process materials and considerable costs. It is desirable to explore advanced technologies to speed up the drying process.

Electromagnetic energy at radio frequencies (RF) between 1 and 100 MHz has a unique ability to generate volumetric heating of moisture materials through agitation of water molecules and migration of charged ions.[4] RF energy has been studied to speed up drying for wood logs or sheets.[5–7] It has also been used in the food industry for the post-bake drying of cookies.[8] In those processes, RF field energy penetrates through the biomaterials placed in RF applicators, and the electromagnetic energy at RF frequencies is converted to thermal energy within the materials to evaporate water and increase internal water vapor pressure, thus dramatically increasing drying rates. By the same principle, it is also possible to directly couple RF energy into moist Macdamia nut kernels through the hard shells and convert it into thermal energy to remove internal moisture.[9]

Hot air assisted RF heating (HARF) may provide fast and volumetric drying of Macadamia nuts with acceptable product quality.[9–12] However, heating and drying non-uniformity is an important consideration in designing practical RF drying operations. A number of studies have been conducted on heating uniformity of agricultural products in RF systems. "Sweetheart" sweet cherries (*Prunus avium* L.) immersed in 0.15% saline water help to overcome the non-uniform heating within and among fruits as compared to direct treatments in air during RF heating.[13] With rotation and movement of fruit using a fruit mover, temperature distributions in oranges and apples are reduced from 4.9 and 9.6°C standard deviations

Correspondence: Shaojin Wang, Ph.D., Professor, College of Mechanical and Electronic Engineering, Northwest A & F University, Yangling, Shaanxi 712100, China; E-mail: shaojinwang@nwsuaf.edu.cn

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ldrt.

to less than 2.8 and 3.1°C, respectively, after an average temperature rise of about 30°C in 7.8 min RF heating.[14] Mathematical models based on normal distributions of product temperatures have been developed to describe treatment temperature–time ranges as a function of the number of mixings for soybean, lentil, and wheat.[15] The results suggest that increasing mixing number improves heating uniformity and expands the operation ranges for effective control of pests without causing adverse quality changes.[15] RF heating uniformity in legume samples is improved by adding forced hot air and back-and-forth movements on the conveyor.[16] Liu et al.[17] studied heating uniformity of white breads in a 6 kW pilot-scale RF system as affected by sample locations and orientations on the final temperature distributions. Until now, there have been no experimental reports on the RF heating and drying uniformity of Macadamia nuts as affected by sample positions, movement, and hot-air surface heating.

The general objective of this study was to explore the optimal operational conditions for pilot-scale RF drying of Macadamia nuts. Specific objectives of this study were: (1) to determine the effect of sample locations in the RF chamber and different sample positions inside a rectangular container on the heating and drying characteristics; and (2) to study the use of hot air to assist RF heating (HARF) and improve drying uniformity of Macadamia nuts under static and moving conditions.

MATERIALS AND METHODS

Materials

The raw material used in this study was hulled and pre-dried in shelled Macadamia nuts from the 2009 harvest season. The samples were provided by one of the major processors of Macadamia nuts in Hawaii, USA, and shipped to Washington State University, Pullman, WA, USA. To prevent moisture loss from the samples during transportation and storage, they were packed and vacuum-sealed into aluminum bags. Immediately after receipt, the packaged material was put into a refrigerator at 0–4°C until the time of the experiments. The moisture content of nuts was determined following the AOAC Official Method 925.40 with some modification. Two grams of the kernel flour were put into an aluminum container, which was placed in a vacuum oven set at 100°C under pressure of 21 kPa for 7 h. Weight changes in samples were used to calculate initial moisture content of the samples. The detailed procedure was described in Wang et al.[8] The measured moisture content was 10.6% d.b. for the given nuts.

Hot-Air-Assisted RF Heating System

A 6 kW, 27.12 MHz pilot-scale RF system (COMBI6-S, Strayfield International, Wokingham, UK) with an

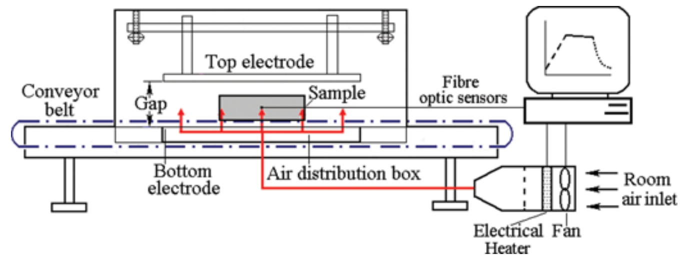

FIG. 1. Schematic view of the radio frequency (RF) unit showing the plate electrodes, conveyor belt, and the hot-air system with the fiber optic sensor to monitor the central temperature in the sample container.[16]

additional hot-air system (5.6 kW) was used to study the effect of sample positions on heating and drying uniformity of Macadamia nuts (Fig. 1). The dimension of the upper parallel-plate electrode was 71 cm × 52 cm. The configuration of the RF and hot-air heating systems was described in detail in Wang et al.[16] and our previous study.[18] The Macadamia nut samples were placed into a plastic container (25.5 cm L × 15.5 cm W × 11.0 cm H) standing on the ground electrode plate (Fig. 2). The container walls were constructed from a 12.7 mesh nylon screen with 0.14 cm openings (9318T27, McMaster-Carr Supply Company, Los Angeles, CA, USA) to allow hot air and moisture to move freely in and out of the samples. The hot-air system provided forced hot air at an air velocity of 1.0 m s^{-1} in the RF chamber through an air distribution box under the bottom electrode (Fig. 1).

HARF Heating and Drying Uniformity in Macadamia Nuts at Different Positions in RF Chambers

The plastic container loaded randomly with 2 kg nuts was located on the bottom electrode at position 1 or 2 as

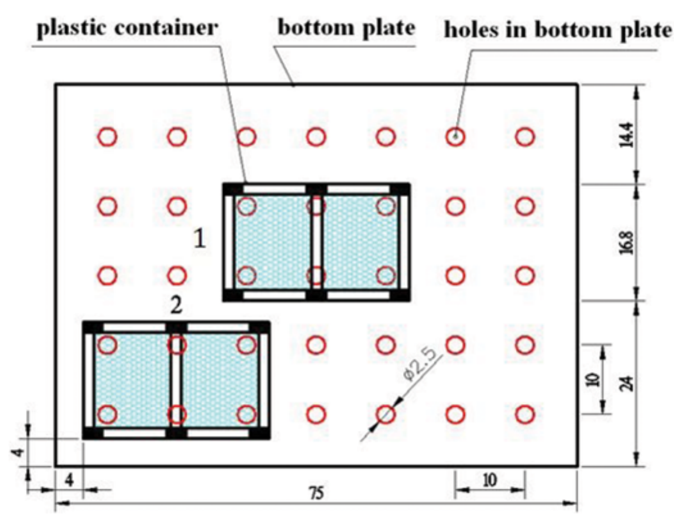

FIG. 2. Hole distributions for hot-air outlets and selected locations of the sample container placed on the bottom electrode plate (all dimensions are in cm).

shown in Fig. 2 to evaluate the influence of load locations on heating and drying uniformity. Electrode gap and hot-air temperature were adjusted to 15.5 cm and 50°C, respectively, which were the best parameters for RF drying as determined in the previous study.[9] The temperature of hot air in the RF chamber was measured using a fiber optic temperature measurement system (UMI, FISO Technologies Inc., Sainte-Foy, Quebec, Canada). Every 10 min, the RF machine was turned off and the container was taken out for surface temperature measurement using an infrared thermal imaging camera (ThermaCAM SC-3000, FLIR Systems, Inc., North Billerica, MA, USA) as quickly as possible. The container with sample was then weighed. After that, the container with samples was placed back into the RF systems and the power was turned on again. It took about 15 s for the process of taking infrared photos and weighing. The surface temperature drop during this period was less than 1°C. The average surface temperature of nuts was calculated using the Thermal CAM 2001 software. After 60 min, the drying was terminated.

Comparison of HARF Heating and Drying Uniformity in Macadamia Nuts Under Static and Moving Conditions

The plastic container loaded with 2 kg nuts was located at position 1 on the conveyor belt in touch with the bottom electrode. Electrode gap and hot air temperature were adjusted to 15.5 cm and 50°C, respectively. The temperature of hot air in the RF chamber was detected using the fiber optic sensor online. Tests were done with or without movement of the conveyor belt. The container movement started from the center to the right edge of the top electrode, moved back to the left edge, and then came back to the center at 0.56 m min^{-1} until the end of heating. Every 10 min, the RF power was turned off and the container was taken out. Surface temperature was mapped with the infrared thermal imaging camera as quickly as possible. Then, the container with samples was weighed. After that, the container was placed back into the RF systems and the power was turned on again. It took about 15 s for taking infrared photos and weighing. The surface temperature drop during this measurement period was less than 1°C. The average surface temperature of nuts was calculated using the software. After 60 min, the drying was terminated. Under static conditions, the container with nuts was placed at position 1. The other procedure was the same as described earlier.

HARF or HA Heating and Drying Uniformity of Macadamia Nuts Using Four-Layer Trays

To investigate HARF or HA heating and drying uniformity of Macadamia nuts at different heights from the bottom electrode, a tray made of Teflon divided into four layers and separated by a 12.7 mesh nylon screen with 0.14 cm openings was used to facilitate temperature mapping in the middle layers (Fig. 3). The tray layers were stacked on top of each other with 500 g nut samples in each. The stacked trays were supported by two slim bars to separate the bottom surface of the bottom tray 2 cm from the bottom electrode. The inner dimension of the stacked trays was the same as the container for drying nuts used by Wang et al.[9] The electrode gap was also set at 15.5 cm, which was the same as for the nut-drying experiments. The stacked trays with nuts were placed at position 1. Two tests with or without hot air at 50°C were made. Every 20 min, RF power was turned off and the trays were taken out for surface temperature mapping with the infrared thermal imaging camera, beginning with the top tray. The trays with samples were then weighed. After that, the trays with samples were stacked again and placed back into the RF machine, and the power was turned on again. It took about 30 s for the process of taking infrared images and weighing. The surface temperature drop during this period was less than 2°C. The average surface temperature of nuts was calculated from the imaging data. After 120 min, the drying was terminated.

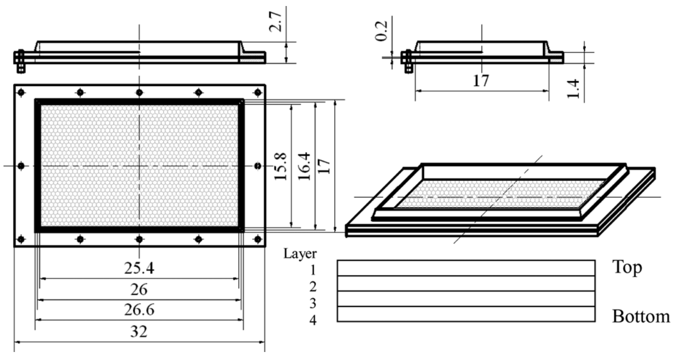

FIG. 3. Schematic view of one-layer tray for hot air (HA)-assisted RF heating and drying uniformity studies (all dimensions are in cm).

To compare the heating uniformity of nuts in four layers of the tray between HARF- and RF-only treatments, a heating uniformity index, λ, was introduced. The heating uniformity index has been applied to determine acceptable treatment conditions for walnuts and legumes.[16,22] It is defined as the ratio of the rise in standard deviation of product temperature to the rise in mean product temperature during treatment as follows:[15,20]

$$\lambda = \frac{\sqrt{\sigma^2 - \sigma_0^2}}{\mu - \mu_0} \tag{1}$$

where μ_0 and μ are initial and final mean almond temperatures (°C), and σ_0 and σ are initial and final standard deviations (°C) of almond temperatures over treatment time, respectively.

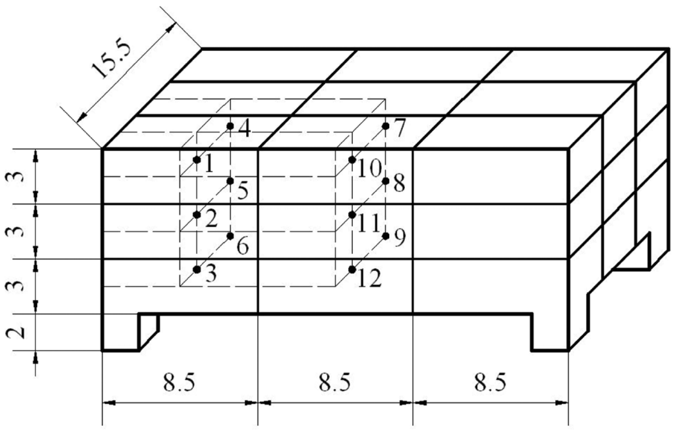

FIG. 4. Schematic view of 12 representative compartments with probe position in the compartment center for heating and drying uniformity experiments (all dimensions are in cm).

Heating and Drying Uniformity in Macadamia Nuts at Different Places of the Container

Experimental determination of the heating and drying uniformity within the bulk nut samples during HARF treatments was made as described in Wang et al.[9] for foams. The container with Macadamia nuts was divided into 27 compartments using plastic web sheets (Fig. 4). According to Jiao et al.,[19] the influence of the plastic web sheets inserted into samples on RF heating was negligible in their experiments for beans. A plastic container loaded with 2 kg nuts was located on the bottom plate at position 1. The electrode gap and hot air temperature were also adjusted to 15.5 cm and 50°C, respectively. Nuts filled in each of the representative compartments (#1 to 12) were weighed before heating. The central temperatures in each compartment were measured using the fiber optic temperature measurement system online. The sensors were inserted into the center of the nuts through the pre-drilled holes. The nuts fixed with sensors were located in the center of each compartment. Experiments were conducted to obtain temperature data as a function of time and compartment position. Due to the limited eight channels of the fiber optic system, two tests were conducted under the same conditions. During the first test, the temperatures of compartments 4, 5, 6, 7, 8, and 9 were measured, followed by the second tests for compartments 1, 2, 3, 10, 11, and 12. Channel one was used to detect the temperature of hot air. After 2 h, the RF power was turned off and the nuts in each compartment were weighed again to get the weight change of each compartment. The experiments were repeated three times for each test.

Statistical Analysis

Mean values and standard deviations were calculated from the replicates for each HARF- and RF-alone treatment. The mean values were compared and separated at a significant level of $P = 0.05$ with the least significant difference (LSD) *t*-test using the Excel variance procedure (Microsoft Office Excel 2003).

RESULTS AND DISCUSSION

HARF Heating and Drying Uniformity in Macadamia Nut at Positions 1 and 2

Figure 5 indicates that the average nut surface temperature at position 2 was much higher than that at position 1 after 30 min heating and drying by HARF. The average surface temperature reached more than 80°C and the maximum temperature went up to 94.7°C after 60 min RF heating. At these high temperatures, sweet smells came out of the nuts and the quality (peroxide value and fatty acid) of the nuts was degraded, as observed in Wang et al.[9] The test results suggest strong edge or corner heating, as the nut temperatures at position 2 were higher than those at position 1. This was consistent with the previous results obtained by foam experiments.[18] Nuts placed at position 2 lose more water than those at position 1 (Fig. 5). The tests suggested that electric field intensity was not uniformly distributed in the RF chamber. The RF field intensity might be higher towards the edge or corner of the electrodes. There was edge heating in the RF-heated nuts, especially at position 2. The successive drying experiments were then conducted at position 1.

Comparison of HARF Heating and Drying Uniformity in Macadamia Nut Under Static and Moving Conditions

Figure 6 shows nut temperature and weight changes at position 1 as a function of HARF heating under static and moving conditions of the conveyor. It was observed

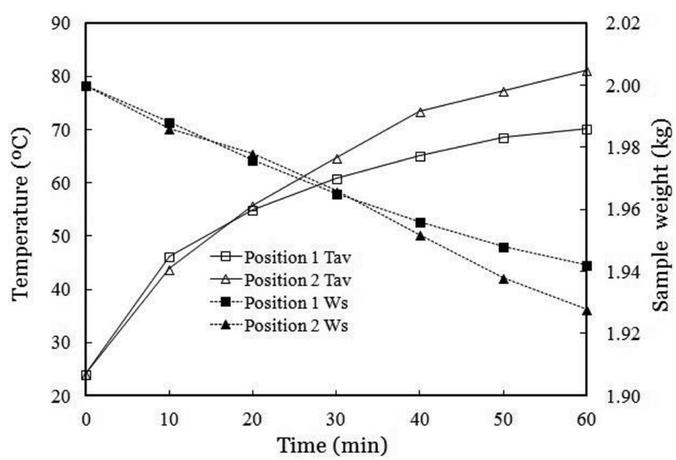

FIG. 5. Average surface temperature (Tav) and average weight (Ws) of nuts in the whole container as a function of HARF heating time at positions 1 and 2, the electrode gap of 15.5 cm, and hot-air temperature of 50°C.

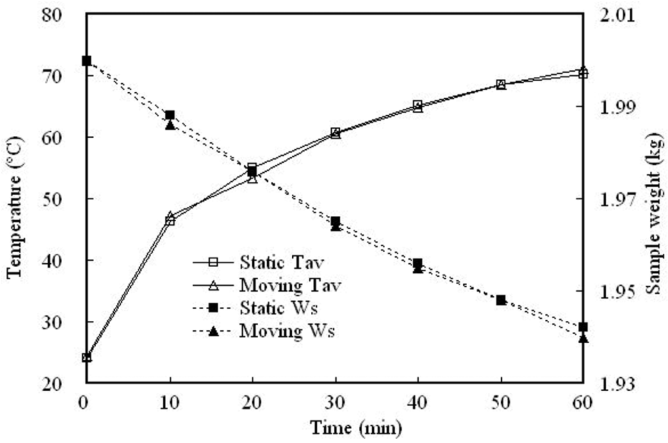

FIG. 6. Nut temperature and weight changes at position 1 as a function of HARF heating under static and moving conditions of the conveyor.

again that the sample temperature increased but the sample weight decreased with increasing drying time. Moving the nuts did not have noticeable improvement on HARF heating and drying uniformity, since there was no significant difference ($P > 0.05$) of measured sample temperature and weight between static and moving conditions. Thus, drying experiments could be done at static conditions to reduce the operational cost.

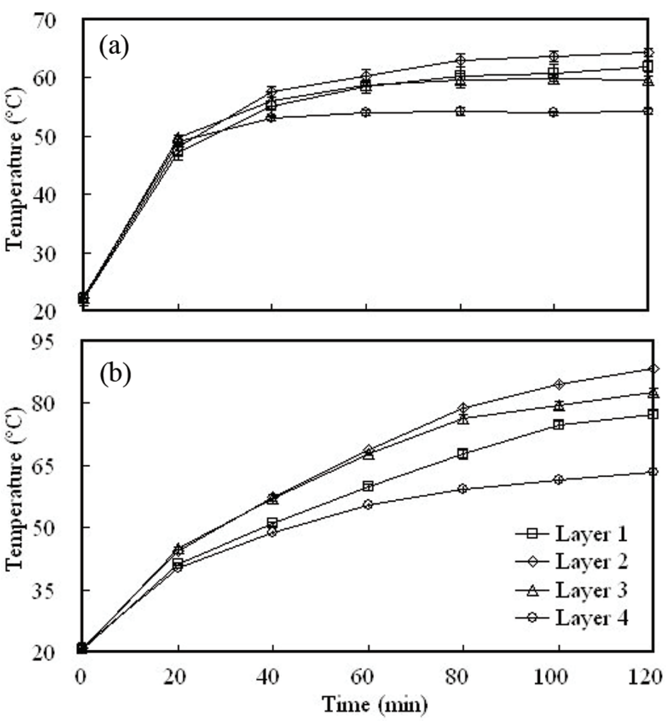

FIG. 7. Average surface temperatures of nuts in the four-layer tray at position 1 during (a) HARF drying at the electrode gap of 15.5 cm and hot-air temperature of 50°C; and (b) RF drying alone with the same electrode gap.

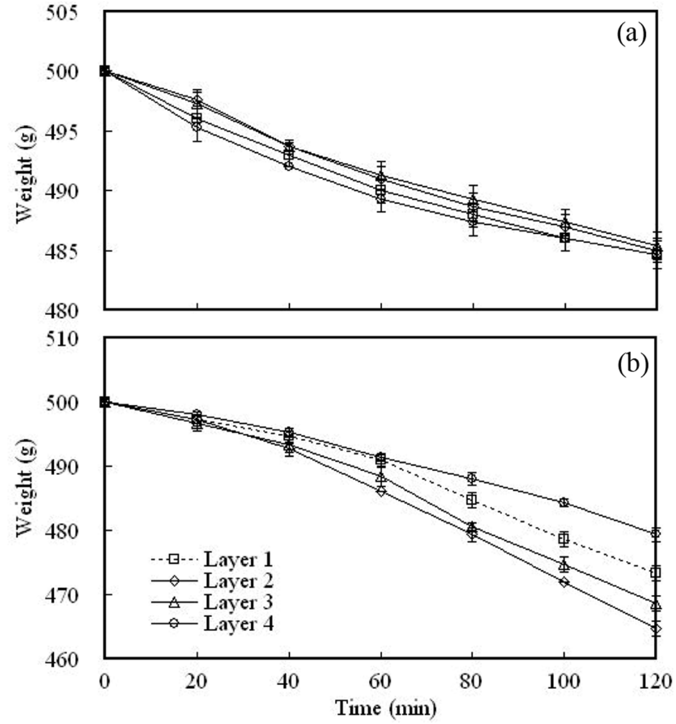

FIG. 8. Weight change of nuts in the four-layer tray during (a) HARF drying with the electrode gap of 15.5 cm and hot-air temperature of 50°C; and (b) RF drying alone at position 1 with the same electrode gap.

HARF Drying and Heating Uniformity in Macadamia Nuts Using Four-Layer Trays

Figure 7 shows the average surface temperature of nuts in the four-layer trays (Fig. 3) during HARF- and RF-alone drying for an electrode gap of 15.5 cm and hot-air temperature of 50°C. Nut temperatures in layer 2 were the largest, followed by layers 3, 1, and 4 during RF heating. Nut temperatures of the middle two layers were higher than those of the top and bottom layers, suggesting the center layer heating pattern of the RF heating of nuts. This was in good agreement with previous test results using RF heating of polyurethane foams.[18] Similar results were also reported when doing experiments on RF-heating uniformity of water and walnuts.[18–23] The average surface temperature of layer 2 heated by RF alone reached more than 80°C and the maximum temperature went up to 102°C after 100 min of RF heating (Fig. 7a), which was too high for the drying of nuts due to the negative effects on nut quality. With the HARF heating, the average surface temperatures of nuts reached no more than 65°C all through the 120 min of drying (Fig. 7b).

Figure 8 shows that weight changes of nuts in the four-layer trays dried both by RF alone and HARF, which were in good correspondence with the temperature changes in Fig. 7 over the 120 min drying period. Tray 2 lost 36 g water as compared to 21 g water loss in tray 4 without

TABLE 1
Comparisons of HARF and RF heating uniformity indexes (mean ± SD over three replicates) of nuts as a function of heating time at four layers (L1–L4) of the tray and position 1

Time (min)	HARF				RF alone			
	L1	L2	L3	L4	L1	L2	L3	L4
20	0.090 ± 0.012	0.097 ± 0.020	0.074 ± 0.005	0.100 ± 0.014	0.144 ± 0.014	0.151 ± 0.006	0.152 ± 0.007	0.202 ± 0.016
40	0.094 ± 0.005	0.095 ± 0.009	0.089 ± 0.003	0.111 ± 0.008	0.138 ± 0.006	0.163 ± 0.006	0.161 ± 0.002	0.218 ± 0.017
60	0.093 ± 0.012	0.100 ± 0.018	0.101 ± 0.010	0.113 ± 0.008	0.157 ± 0.009	0.171 ± 0.007	0.187 ± 0.006	0.236 ± 0.009
80	0.102 ± 0.005	0.108 ± 0.017	0.105 ± 0.010	0.119 ± 0.011	0.156 ± 0.002	0.176 ± 0.003	0.192 ± 0.003	0.241 ± 0.010
100	0.114 ± 0.007	0.112 ± 0.018	0.112 ± 0.016	0.127 ± 0.013	0.167 ± 0.005	0.175 ± 0.001	0.187 ± 0.002	0.251 ± 0.011
120	0.114 ± 0.003	0.123 ± 0.017	0.115 ± 0.003	0.124 ± 0.010	0.179 ± 0.013	0.178 ± 0.005	0.191 ± 0.002	0.223 ± 0.006

using hot air (Fig. 8b). There was less than 1 g difference in water loss between the four trays after 120 min drying when assisted with hot air (Fig. 8a). Heating uniformity indexes of each tray dried by HARF were lower than those of trays dried by RF alone (Table 1). Thus, when assisted by hot air, RF heating and drying became much more uniform in both the horizontal and vertical directions. Gao et al.[24] obtained similar results when doing experiments on heating uniformity of almonds in RF treatments. Although there was a temperature difference in the four-layer tray, the weight loss was almost the same when drying by HARF. Hot air acted as a mixing medium, which mainly blew to both the bottom and top trays, and took the vaporized water away from the surface of the nuts while it cooled the surface sample. Thus, gradient of moisture content between the center part and the outer parts of samples in the container was formed by water vaporizing from the inner parts but reduced by additional surface hot-air heating. In this way, temperature distributions in the sample became even. In general, hot air was an effective factor for RF uniform heating and drying of nuts.

The heating and drying process of nuts in HARF systems can be divided into two stages. In stage I, the sample temperature was lower than the hot-air temperature when the sample was heated both by RF and hot air. Water in samples vaporized in an increasing rate over the initial heating time and then slowed down. The RF energy coupled in samples was rather intense due to the high loss factor of samples with high initial moisture content.[8] Temperature of the samples rose steadily at a high speed. In stage II, the sample temperature exceeded the hot-air temperature. Hot air served as the medium to carry the vapor away from the surface of the sample and absorbed some RF energy at the same time. RF energy was the only source of thermal energy for water vaporizing. However, there was still net energy accumulation in the samples, which caused a gradual increase in temperature.

RF and microwave heating have been widely used for drying perishable agricultural products after harvesting. Microwave-assisted or -enhanced combination drying methods have improved heating uniformity and product quality. However, those methods are difficult to use for treating bulk materials due to their limited penetration depth,[25] and have been tested in small-scale units. RF drying has major advantages over microwave treatments, such as better heating uniformity and larger sample loads[9,11] because of the greater penetration depths, as indicated in this study. RF drying has unique heating characteristics in which the sample temperature is relatively stable and slightly decreases due to reduced RF power absorbed in the sample caused by the removed moisture content.

Heating and Drying Uniformity of Macadamia Nuts at Different Locations

Figure 9 illustrates the measured center temperatures of 12 compartments during HARF heating of nuts. The largest temperature difference appeared after 72 min heating between 82.2°C in compartment 8 and 66.3°C in compartment 12. After that, temperatures in all compartments gradually went down. This was probably caused by reduced thermal energy conversion from RF energy as the nut samples dried out.

Temperatures in compartments 8, 5, 4, 11, and 7 were higher than those of compartments 2, 9, 3, and 12. Temperatures in the middle layers or near the center of the container were higher than those located away from the center. The center heating of HARF was observed again in this case, which is in good agreement with the above results in the four-layer trays and the previous results of HARF heating of polyurethane foam.[15] Corresponding to the observed temperatures, compartments 7, 8, and 10 had maximum weight changes but compartments 3, 9, and 12 had minimum weight changes (Fig. 10). According to statistical analysis, there was no significant difference of weight changes among most of the compartments ($P > 0.05$), but

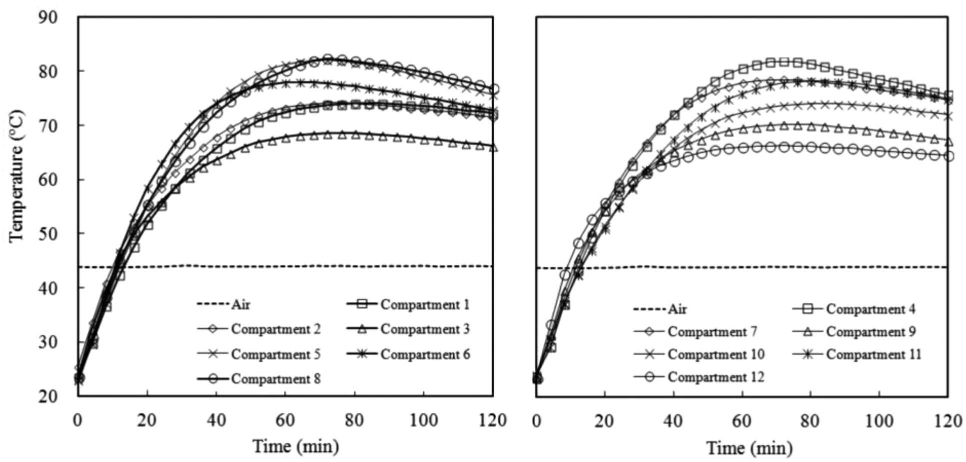

FIG. 9. Measured center temperatures of nuts located at the 12 compartments of the container at position 1 during HARF heating.

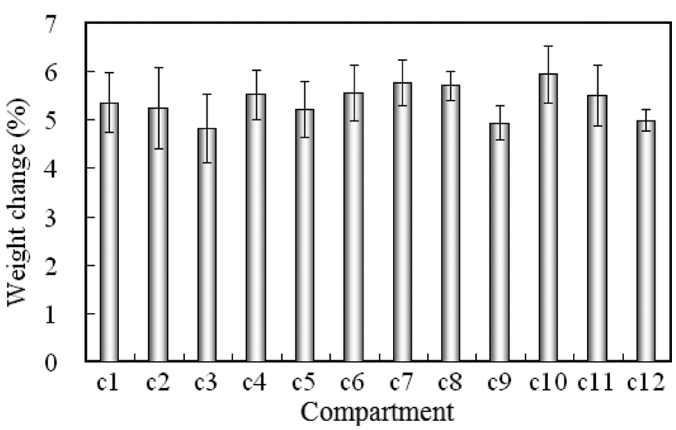

FIG. 10. Weight change of nuts located at the 12 compartments of the container during HARF heating at position 1.

the weight change in compartment 8 was significantly lower than that in compartments 9 and 12 ($P < 0.05$), suggesting uniform drying of nuts by HARF in most parts of the container except for compartment 8.

CONCLUSIONS

Experiments with nuts showed that the electric field intensity was not uniformly distributed in the RF chamber. The RF field intensity was higher at the edge or corner of the RF chamber than that at the center part. Under the given experimental conditions, moving samples on the conveyor did not provide noticeable improvement on the heating and drying uniformity of HARF treatments. There appeared to be a strong center heating pattern in nut samples in the four-layer tray with HARF treatments. Heating uniformity indexes of each layer dried by HARF were lower than those by RF alone. Hot air acted as a mixing medium and improved RF heating and drying uniformity in nuts. The detailed temperature and weight changes in 12 compartments within a container confirmed central heating but relative uniform drying. This uniformity study may provide potential RF heating and drying applications for other nut products.

ACKNOWLEDGMENT

We thank Island Princess Macadamia Nut Company in Hawaii, USA, for providing pre-dried macadamia nut kernels.

FUNDING

This research was conducted in the Department of Biological Systems Engineering, Washington State University (WSU), supported by grants from the WSU Agricultural Research Centre, and partially provided by the general program (Grant No. 31171761) of the National Natural Science Foundation of China, Fundamental Research Funds for the Central Universities (Grant No. ZD2013016), and a seed grant from Yangling International Academy of Modern Agriculture.

REFERENCES

1. Wall, M.M.; Gentry, T.S. Carbohydrate composition and color development during drying and roasting of macadamia nuts (*Macadamia integrifolia*). *LWT-Food Science and Technology* **2007**, *40*(4), 587–593.
2. Nagao, M.A. *Farm and Forestry Production and Marketing Profile for Macadamia Nut (Macadamia integrifolia and M. tetraphylla)*; Permanent Agriculture Resources: Holualoa, Hawaii, 2011.
3. Silva, F.A.; Marsaloli, A.; Maximo, G.J.; Silva, M.; Goncalves, L.A.G. Microwave assisted drying of macadamia nuts. *Journal of Food Engineering* **2006**, *77*(3), 550–558.
4. Ramaswamy, H.; Tang, J. Microwave and radio frequency heating. *Food Science and Technology International* **2008**, *14*(5), 423–427.
5. Huang, R.; Wu, Y.; Zhao, Y.; Lu, J.; Jiang, J.; Chen, Z. Factors affecting the temperature increasing rate in wood during radio-frequency heating. *Drying Technology* **2013**, *31*(2), 246–252.
6. Lazarescu, C.; Avramidis, S. Radio-frequency heating kinetics of softwood logs. *Drying Technology* **2011**, *29*(6), 673–681.

7. Koumoutsakos, A.; Avramidis, S.; Hatzikiriakos, S.G. Radio frequency vacuum drying of wood. I. Mathematical model. *Drying Technology* **2001**, *19*(1), 65–84.
8. Koral, T. Radio frequency heating and post-baking. *Biscuit World Issue* **2004**, *7*(4), 1–7.
9. Wang, Y.; Li, Y.; Zhang, L.; Gao, M.; Tang, J.; Wang, S. Temperature and moisture dependent dielectric properties of macadamia nut kernels. *Food and Bioprocess Technology* **2013**, *6*(8), 2165–2176.
10. Wang, Y.; Zhang, L.; Gao, M.R.P.J.; Tang, J.; Wang, S. Developing hot air-assisted radio frequency drying for in-shell Macadamia nuts. *Food and Bioprocess Technology* **2014**, *7*(1), 278–288.
11. Gao, M.; Tang, J.; Villa-Rojas, R.; Wang, Y.; Wang, S. Pasteurization process development for controlling Salmonella in in-shell almonds using radio frequency energy. *Journal of Food Engineering* **2011**, *104*(2), 299–306.
12. Marra, F.; Lyng, J.; Romano, V.; McKenna, B. Radio-frequency heating of foodstuff: Solution and validation of a mathematical model. *Journal of Food Engineering* **2007**, *79*, 998–1006.
13. Ikediala, J.N.; Hansen, J.D.; Tang, J.; Drake, S.R.; Wang, S. Development of a saline water immersion technique with RF energy as a postharvest treatment against codling moth in cherries. *Postharvest Biology and Technology* **2002**, *24*(1), 25–37.
14. Birla, S.L.; Wang, S.; Tang, J.; Hallman, G. Improving heating uniformity of fresh fruit in radio frequency treatments for pest control. *Postharvest Biology and Technology* **2004**, *33*(2), 205–217.
15. Wang, S.; Yue, J.; Chen, B.; Tang, J. Treatment design of radio frequency heating based on insect control and product quality. *Postharvest Biology and Technology* **2008**, *49*(3), 417–423.
16. Wang, S.; Tiwari, G.; Jiao, S.; Johnson, J.A.; Tang, J. Developing postharvest disinfestation treatments for legumes using radio frequency energy. *Biosystems Engineering* **2010**, *105*(3), 341–349.
17. Liu, Y.; Wang, S.; Mao, Z.; Tang, J.; Tiwari, G. Heating patterns of white bread loaf in combined radio frequency and hot air treatment. *Journal of Food Engineering* **2013**, *116*(2), 472–477.
18. Wang, Y.; Zhang, L.; Gao, M.; Tang, J.; Wang, S. Evaluating radio frequency heating uniformity using polyurethane foams. *Jounal of Food Engineering* **2014**, *136*, 28–33.
19. Jiao, S.; Tang, J.; Johnson, J.A.; Tiwari, G.; Wang, S. Determining radio frequency heating uniformity of mixed beans for disinfestation treatments. *Transactions of the ASABE* **2011**, *54*(5), 1847–1855.
20. Wang, S.; Yue, J.; Tang, J.; Chen, B. Mathematical modeling of heating uniformity of in-shell walnuts in radio frequency units with intermittent stirrings. *Postharvest Biology and Technology* **2005**, *35*, 94–104.
21. Wang, S.; Tang, J.; Sun, T.; Mitcham, E.J.; Koral, T.; Birla, S.L. Considerations in design of commercial radio frequency treatments for postharvest pest control in inshell walnuts. *Jounal of Food Engineering* **2006**, *23*, 304–312.
22. Wang, S.; Monzon, A.; Johnson, J.A.; Mitcham, E.J.; Tang, J. Industrial-scale radio frequency treatments for insect control in walnuts I: Heating uniformity and energy efficiency. *Postharvest Biology and Technology* **2007**, *45*(2), 240–246.
23. Wang, S.; Luechapattanaporn, K.; Tang, J. Experimental methods for evaluating heating uniformity in radio frequency systems. *Biosystems Engineering* **2008**, *100*, 58–65.
24. Gao, M.; Tang, J.; Wang, Y.; Powers, J.; Wang, S. Almond quality as influenced by radio frequency heat treatments for disinfestations. *Postharvest Biology and Technology* **2010**, *58*, 225–231.
25. Zhang, M.; Tang, J.; Mujumdar, A.S.; Wang, S. Trends in microwave-related drying of fruits and vegetables. *Trends in Food Science and Technology* **2006**, *17*, 527–534.