

## INSECT CONTROL AND WALNUT QUALITY FOLLOWING LARGE-SCALE INDUSTRIAL RADIO FREQUENCY TREATMENTS

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Prior to 2005, in-shell walnuts were routinely fumigated with methyl bromide for insect control prior to export for phytosanitary or quarantine purposes. Radio frequency (RF) energy has been developed through laboratory studies as a means to rapidly deliver thermal energy to walnuts for insect control based on thermal-death-time (TDT) curves determined for four important insects infesting walnuts at or after harvest: codling moth, Indianmeal moth, navel orangeworm, and red flour beetle. Nut quality was not significantly affected. Despite the success of these studies, it is important to transfer laboratory research results to industrial implementations.

In 2005, industrial-scale RF treatments producing a minimum kernel temperature of 52°C for 5 min were developed to control insect pests in in-shell walnuts. The efficacy tests were conducted in a 27.12 MHz industrial-scale, 25 kW RF system at the Diamond walnut processing plant in Stockton, CA. Walnuts were treated with RF either before washing or after washing and air-drying. During RF treatments, walnuts were held in plastic containers with perforated bottoms and side walls. Each container was evenly filled with 11 kg of in-shell walnuts and placed on the conveyor belt for treatment. Laboratory-reared fifth-instar navel orangeworm, which had previously been identified as the most heat tolerant species and stage, were brought to the processing plant on the morning of each test day. One larva was placed in each walnut through a 4 mm hole drilled in the shell. Each hole was closed with a polyethylene plug. After each treatment, samples of non-infested nuts were collected for quality determination by the Quality Assurance Laboratory at the Diamond plant. Quality evaluations were made immediately after treatment and after 10 and 20 days under accelerated storage conditions. The main quality parameters of concern were peroxide values (PV, meq/kg), fatty acids (FA, % oleic) and kernel color. Moisture contents of shell, kernel and whole walnut were also measured.

Insect mortality and final kernel and surface temperatures in unwashed and air-dried in-shell walnuts after RF treatments are shown in Table 1. Treating nuts before washing or after washing and drying both resulted in 100% mortality of fifth-instar navel orangeworm larvae. Initial kernel moisture content can affect heating rate within the RF unit. However, the treatment was effective over a relatively wide range of kernel moisture contents (3-7.5%).

The average moisture content in both treated and untreated nuts was highest in the

shells, followed by whole nuts and then the kernels (Table 2). The moisture content in RF treated walnuts was significantly less than that of untreated control walnuts ( $P < 0.05$ ). In particular, the moisture content in the shell was reduced by 1% (from 7.2% in control to 6.3% in treated samples). But moisture dropped only 0.2 to 0.6% in the kernel or whole nuts during RF treatments. The difference in final moisture content after RF treatment between the unwashed and air-dried nuts was less than 0.2%. The drying effect RF treatments have on walnuts may be beneficial, allowing the industry to reduce overall static air drying time and associated cost after washing.

Table 3 summarizes the results of quality evaluations of RF treated walnuts during accelerated storage. Only samples from treatments resulting in 100% kill were evaluated. Mean PVs increased with storage time for control and RF treated walnuts, but FA values did not show any clear trend. There was no statistically significant difference in PVs and FA values between control and RF treated samples except for the PVs of air-dried walnuts after 10 days of accelerated storage ( $P < 0.05$ ). For unwashed and air-dried nuts, the final PVs and FA values during accelerated storage for up to 20 days remained within the acceptable range ( $PV < 1.0$  meq/kg and  $FA < 0.6\%$ ) used by industry for good walnut quality. This confirms our earlier results in which RF heating to 53°C for 5 min, 55°C for 10 min, and 75°C for 5 min did not increase walnut rancidity after 10- and 20-day accelerated storage.

On the Hunter scale, L-values decrease as product color darkens. Kernel color was slightly darker after RF treatments and after storage (Table 3). However, there was no statistically significant difference between untreated controls and RF treated walnuts for different storage times ( $P > 0.05$ ). According to walnut industry standards, acceptable L-values for product color are  $>40$ . Consequently, the final color of treated walnuts, even after accelerated storage, would still be acceptable to the walnut industry.

By completely controlling navel orangeworm within in-shell walnuts without adversely affecting product quality, our study successfully demonstrated the efficacy of RF treatments as an option to methyl bromide fumigation for postharvest insect control in in-shell walnuts. We have previously demonstrated that fifth-instar navel orangeworm larvae are the most heat tolerant species and life stage of the important postharvest walnut pests in California, therefore the RF treatment developed in this study would also control codling moth, Indianmeal moth and red flour beetle. In addition to providing insect control for incoming, unwashed walnuts, RF treatments may be useful in reducing drying time and energy costs for air dried walnuts.

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Table 1. Mortality (Mean  $\pm$  SD, %) of fifth-instar navel orangeworm, final kernel (n=10) and surface (n=45,056) temperatures in control and RF treated walnuts<sup>1</sup>

| Rep                         | Runs                             | Containers | Kernel<br>temps (°C) | Surface<br>temps (°C) | Mortality<br>(%) |     |
|-----------------------------|----------------------------------|------------|----------------------|-----------------------|------------------|-----|
| Unwashed walnuts (option 1) |                                  |            |                      |                       |                  |     |
| Rep 1                       | 1                                | Control    | 26.0±0.7             | 27.8±1.7              | 0                |     |
|                             |                                  | #9         | 60.0±5.2             | 63.4±2.8              | 100              |     |
|                             |                                  | #12        | 58.3±3.4             | 63.5±3.3              | 100              |     |
|                             | 2                                | #9         | 57.4±2.0             | 64.3±2.8              | 100              |     |
|                             |                                  | #12        | 58.5±4.7             | 64.0±2.6              | 100              |     |
|                             |                                  | Control    | 23.7±0.3             | 22.7±0.3              | 1.1              |     |
| Rep 2                       | 1                                | #9         | 57.5±1.9             | 62.3±2.9              | 100              |     |
|                             |                                  | #12        | 58.2±1.9             | 62.4±3.1              | 100              |     |
|                             |                                  | #9         | 57.4±2.2             | 61.8±3.1              | 100              |     |
|                             | 2                                | #12        | 58.5±1.6             | 63.8±3.5              | 100              |     |
|                             |                                  | Control    | 24.3±0.4             | 23.9*                 | 0                |     |
|                             |                                  | #9         | 54.8±2.1             | 58.6                  | 100              |     |
| Rep 3                       | 1                                | #12        | 56.7±2.3             | 59.6                  | 100              |     |
|                             |                                  | #9         | 57.0±2.8             | 58.6                  | 100              |     |
|                             |                                  | #12        | 55.3±2.3             | 60.1                  | 100              |     |
|                             | Hot air-dried walnuts (option 2) |            |                      |                       |                  |     |
|                             | Rep 1                            | 1          | Control              | 28.6±0.8              | 27.5±0.8         | 1   |
|                             |                                  |            | #9                   | 59.0±2.3              | 67.2±5.0         | 100 |
| #12                         |                                  |            | 61.4±5.9             | 68.4±6.2              | 100              |     |
| 2                           |                                  | #9         | 59.2±3.0             | 64.5±3.3              | 100              |     |
|                             |                                  | #12        | 59.0±2.4             | 66.0±4.0              | 100              |     |
|                             |                                  | Control    | 27.8±0.7             | 28.3*                 | 0                |     |
| Rep 2                       | 1                                | #9         | 58.9±1.7             | 60.8                  | 100              |     |
|                             |                                  | #12        | 59.8±5.8             | 61.9                  | 100              |     |
|                             |                                  | #9         | 55.2±1.8             | 58.8                  | 100              |     |
|                             | 2                                | #12        | 56.6±1.8             | 60.0                  | 100              |     |

<sup>1</sup>Each treatment consisted of 17 containers of walnuts. Containers #9 and #12 including 75 infested walnuts, and temperature measurements were taken from these containers. Replicates consisted of two separate treatment runs done on the same day.

\*Only mean surface temperatures were obtained.

Table 2. Moisture contents (Mean  $\pm$  SD, % w.b.) of the kernel, shell and whole walnuts in unwashed (n=3) and air dried (n=2) samples before and after RF treatments

| Walnut sample type | Unwashed        |                | Air-dried      |                |
|--------------------|-----------------|----------------|----------------|----------------|
|                    | Control         | RF treated     | Control        | RF treated     |
| Kernal             | 3.2 $\pm$ 0.1a* | 3.0 $\pm$ 0.1b | 3.3 $\pm$ 0.2a | 3.0 $\pm$ 0.1b |
| Shell              | 7.2 $\pm$ 0.4a  | 6.3 $\pm$ 0.3b | 7.4 $\pm$ 0.3a | 6.4 $\pm$ 0.3b |
| Whole nut          | 4.7 $\pm$ 0.4a  | 4.3 $\pm$ 0.3b | 4.9 $\pm$ 0.2a | 4.3 $\pm$ 0.3b |

\*Different letters for each walnut fraction indicate that means are significantly different (P<0.05) between the control and RF treated walnuts.

Table 3. Storage quality characteristics (Mean  $\pm$  SD) of unwashed (n=3) and air dried (n=2) in-shell walnuts before and after RF treatments

| Storage time at 35°C (days) <sup>z</sup> | Peroxide value <sup>y</sup> (meq/kg) |                  | Fatty acid <sup>y</sup> (%) |                 | Kernel color (L value) <sup>x</sup> |                 |
|------------------------------------------|--------------------------------------|------------------|-----------------------------|-----------------|-------------------------------------|-----------------|
|                                          | Control                              | RF treated       | Control                     | RF treated      | Control                             | RF treated      |
| Unwashed walnuts                         |                                      |                  |                             |                 |                                     |                 |
| 0                                        | 0.04 $\pm$ 0.03a <sup>w</sup>        | 0.18 $\pm$ 0.29a | 0.15 $\pm$ 0.07             | 0.19 $\pm$ 0.06 | --                                  | --              |
| 10                                       | 0.32 $\pm$ 0.21a                     | 0.21 $\pm$ 0.03a | 0.23 $\pm$ 0.07             | 0.24 $\pm$ 0.04 | 47.5 $\pm$ 1.04                     | 46.5 $\pm$ 1.29 |
| 20                                       | 0.71 $\pm$ 0.41a                     | 0.86 $\pm$ 0.26a | 0.20 $\pm$ 0.02             | 0.20 $\pm$ 0.05 | 46.8 $\pm$ 0.97                     | 45.8 $\pm$ 1.00 |
| Hot air-dried walnuts                    |                                      |                  |                             |                 |                                     |                 |
| 0                                        | 0.15 $\pm$ 0.11a                     | 0.09 $\pm$ 0.11a | 0.42 $\pm$ 0.36             | 0.17 $\pm$ 0.12 | --                                  | --              |
| 10                                       | 0.41 $\pm$ 0.13a                     | 0.75 $\pm$ 0.08b | 0.17 $\pm$ 0.07             | 0.26 $\pm$ 0.07 | 46.3 $\pm$ 3.14                     | 46.8 $\pm$ 2.77 |
| 20                                       | 0.74 $\pm$ 0.30a                     | 0.82 $\pm$ 0.28a | 0.23 $\pm$ 0.02             | 0.22 $\pm$ 0.08 | 45.0 $\pm$ 2.46                     | 44.9 $\pm$ 2.42 |

<sup>z</sup>10 and 20 days at 35°C simulate 1 and 2 years storage at 4°C

<sup>y</sup>Accepted peroxide value and fatty acid values for good quality are less than 1.0 meq/kg and 0.6%, respectively

<sup>x</sup>L value (lightness): 0 = black and 100 = white; good quality  $\geq$ 40

<sup>w</sup>Different letters for peroxide values indicate that means are significantly different (P<0.05) between the control and RF treated walnuts.