Salmonella Surrogate Reduction Using Industrial Peanut Dry Roasting Parameters

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ABSTRACT

Studies were conducted to evaluate the effectiveness of industrial peanut dry roasting parameters in *Salmonella* reduction using a *Salmonella* surrogate, *Enterococcus faecium,* which is slightly more heat tolerant than *Salmonella*. Runner-type peanuts were inoculated with *E. faecium* and roasted in a laboratory scale roaster simulator in which temperature, airflow, airflow direction and bed depth were highly controlled, allowing for conditions that duplicate industrial dry roasting. Temperature data were collected at the top, middle and bottom of the roasting bed in addition to internal peanut temperature via thermocouples in the bed of peanuts and embedded in a peanut. Regardless of roast conditions, peanuts in the middle of the roasting bed received the least amount of heat and hence, represent the worst case scenario for microbial reduction. *E. faecium* reductions, reported as the logarithm of colony forming units/g (log CFU/g), followed a linear trend with increasing roasting time when peanuts were roasted at 149, 163, and 177 C, with > 5-log CFU/g reductions occurring at the middle of the peanut bed after 21, 15 and 11 min, respectively, at a bed depth of 75 mm and an air flow of 1.3 m/s. Increased air flow increased *E. faecium* reduction. At 16 min roast time and a 75 mm bed depth, reduction at the middle of the bed was ≤ 3-log CFU/g at 1 m/s and > 5-log CFU/g at 1.3 m/s. When all other roast parameters were held constant, decreasing bed depth also increased reduction of *E. faecium* in the middle of the bed. Comparing various samples roasted at 149, 163 and 177 C over a range of times, roast color (Hunter L-value) was positively correlated (R^2 = 0.73) with the log reduction of *E. faecium*. Most peanuts with an L-value darker than 53, a common threshold for light roast had ≥ 5-log CFU/g reductions; however, further study is required, including roasting peanuts from different origins and maturity, to fully understand the implications of roast color development and microbial reduction. This work provides valuable practical information for manufacturers of roasted peanuts when validating *Salmonella* reductions under a particular set of roasting parameters.

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Salmonella is a leading agent of foodborne illness, accounting for thousands of foodborne illness outbreaks reported each year. The Centers for Disease Control and Prevention (CDC) estimates that *Salmonella* causes approximately 1.0 million illnesses per year in the United States (Scallan *et al.*, 2011), amounting to a conservative annual average economic burden of approximately $4.4 billion (Scharff, 2012). Water activity (a_w), where a_w = P/P^0, and P = partial pressure of water over the sample at equilibrium and P^0 = equilibrium pressure of pure water at the same temperature, is a critical concept in microbial safety, as the minimum a_w for growth of most bacteria is approximately 0.87. Foods with an a_w below 0.85 are commonly classified as low-water activity, and these include roasted peanuts (Beuchat *et al.*, 2013). Although *Salmonella* contamination has traditionally been associated with high-water activity foods such as eggs and poultry, several recent outbreaks have involved lower-a_w foods such as almonds, peanut butter, powdered milk, cereal, chocolate, dry pet food, and various nuts (Beuchat *et al.*, 2013). *Salmonella* growth generally occurs at a_w between 0.94 and 0.99 (Bell and Kyriakides, 2009); however, it can survive at lower a_w, and may be difficult to inactivate (Farakos *et al.*, 2013). Survival of *Salmonella* is a concern in low-a_w foods since infection by *Salmonella* may occur with ingestion of even a single cell, depending on the health of the consumer (Food and Drug Administration, 2012).

Until recent years, nuts have been considered to be of low risk for *Salmonella* contamination due to low a_w. Although *Salmonella* does not generally grow on nuts, it can survive on nut surfaces for periods as long as a year, and develops increased resistance to thermal treatment over time (Danyluk *et al.,* 2007). One of the largest food recalls in U.S. history was due to an outbreak linked to *Salmonella* in peanut products causing 714 documented illnesses and 9 deaths, leading to 3,900 products being recalled by 200 companies (Wittenberger and Dohlman, 2010). In addition to peanut butter,

peanuts are used as an ingredient in a wide variety of products, including, snack foods and confections (Chang *et al.*, 2013). Many small companies buy peanuts from larger manufacturers who produce bulk quantities of peanuts to distribute to numerous clients (Wittenberger and Dohlman, 2010).

Salmonella contamination can occur at any point in the production of foods and is generally traced back to human or animal sources. Eliminating the risk of *Salmonella* contamination at the manufacturing level involves proper control and hygiene during all stages of processing, including raw materials handling, roasting, post-roast processing and packaging (Bell and Kyriakides, 2009). Prevalence of *Salmonella* on raw, grade samples of peanuts from all production areas in 2008 to 2010 was estimated at 2.33% and the concentration levels of *Salmonella* in positive samples, as determined by a most-probable-number assay (MPN), were <0.03 to 2.4 MPN/g (Calhoun *et al.*, 2013). In a separate study, *Salmonella* was found in 0.67% (68/10,162 samples) from raw, runner peanuts from 2009, 2010 and 2011 sampled at labs located in both GA and TX (Miksch et al. 2013). No difference in prevalence data was observed for the two growing regions and concentration levels of *Salmonella* in positive samples averaged 1.05 MPN per 350 g.

The FDA recommends that peanut processors use a process that is validated to reduce *Salmonella* on peanuts, e.g., 5 logarithm of colony forming units/g (5-log CFU/g) (Food and Drug Administration, 2009). Commercial testing laboratories that perform roaster validations currently use a *Salmonella* surrogate, *Enterococcus faecium* (personal communication, Deibel Laboratories, Inc.). This organism was used in almond processing validations (Almond Board of California 2007a, 2007b) and in recent studies on peanuts was found to be slightly more heat tolerant than *Salmonella* (Sanders and Calhoun, 2014). Roasting is used as the critical control point in most peanut processing operations. The two most common types of roasting are oil roasting and dry roasting. Studies have been performed to investigate *Salmonella* reduction in the thermal processing of various nuts, and in the later processing operations for several peanut-based products, such as peanut butter (Shachar and Yaron, 2006; Ma *et al.*, 2009 Sanders and Calhoun, 2014). Research on oil roasting of peanuts (Sanders and Calhoun, 2014) and almonds (Du *et al*, 2010) suggested that 5-log CFU/g or greater reductions were expected at normal oil roasting temperatures (150–160 C) because of the higher thermal conductivity of oil compared to air. Dry roasting is the most widely used roasting process in the peanut industry. Some information is available regarding reduction of *Salmonella* during dry roasting of almonds (Bari *et al.*, 2009), sesame (Torlak *et al*, 2013), pecans (Beuchat and Mann, 2011), and peanuts (Sanders and Calhoun, 2014). Sanders and Calhoun (2014) reported an examination of *E. faecium* and a cocktail of 7 different *Salmonella* cultures inoculated onto peanuts which were then subjected to a series of both dry and oil roasting temperatures for different times. They utilized 25 g samples and bed depth and air flow were not considerations in the studies. The data reported demonstrated that at every time and temperature, *E. faecium* was slightly more heat tolerant than *Salmonella*. These data demonstrated that *E. faecium* was an excellent surrogate for *Salmonella* as it was previous shown to be for almonds.

Given the lack of information available on reduction of *Salmonella* on peanuts in industrial dry-roasting processes which include temperature, time, bed depth, air flow, and air flow direction, the objectives of this study were; (i) to estimate the effectiveness of various industry-typical dry roasting conditions in reduction of *Salmonella*; (ii) to determine if *Salmonella* reduction depends on location in the bed of peanuts in the dry roaster; (iii) to determine if *Salmonella* reduction correlates to any physical roasted peanut properties.

Materials and Methods

Peanuts

A single lot of medium runner-type peanuts (Georgia O6G cultivar) obtained from a commercial processor was used for all studies. Georgia O6G (Branch, 2007) was selected as this is the most common cultivar of peanut grown in the Southeastern United States, accounting for approximately 77 percent of seed acres in 2012 (Brandon, 2013). All tests were conducted using whole, unblanched peanuts. Initial moisture of the peanuts was 6.1% on a wet weight basis (wwb).

Inoculation and Quantification

Inoculation of the peanuts was performed by Deibel Laboratories (3530 NW 97th Blvd, Gainesville, FL 32606) using a surrogate cocktail combination of *E. faecium* ATCC 8459 and *E. faecium* ATCC 35667 as utilized in studies conducted by the Almond Board of California (2007a, 2007b) and Sanders and Calhoun (2014). All inoculum cultures were grown in tryptic soy broth (BD Diagnostics, 7 Loveton Circle, Sparks, MD 21152). The nuts were inoculated and stabilized back to their original moisture levels using the protocol established by the Almond Board of California (2007b).
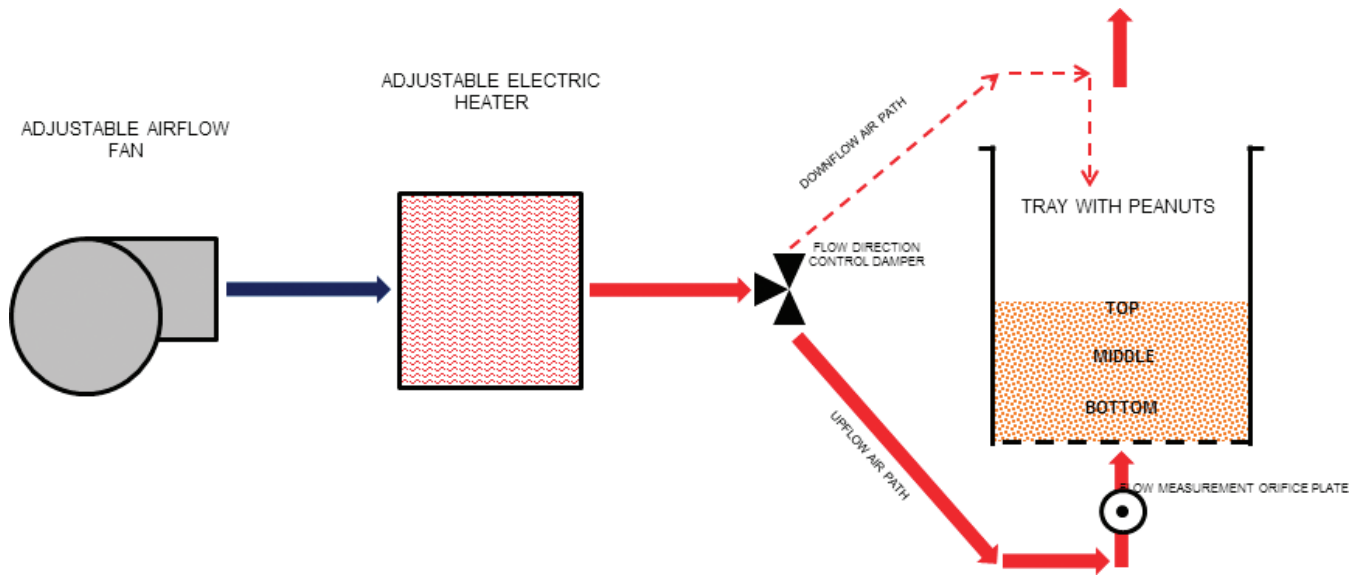
Fig. 1. Schematic of laboratory roaster.

The inoculation procedure involved diluting unroasted peanut samples at a 1:10 ratio with sterile Butterfield's Phosphate Buffer (BD Diagnostics, 7 Loveton Circle, Sparks, MD 21152) and mixing for 2 minutes employing a Stomacher Lab Blender (Fisher Scientific, 100 Technology Dr, Pittsburgh, PA 15219). The samples were then held for 3 to 5 min prior to further dilution. The samples were then vigorously shaken by hand a minimum of five times followed by serial dilution in 9 ml tubes of sterile peptone diluent. For each dilution, 0.1 ml aliquots of diluted sample were spread plated onto KF Streptococcus Agar plates (BD Diagnostics, 7 Loveton Circle, Sparks, MD 21152) tempered at ambient temperature for at least 4 hours. Plates were incubated in a Fisher Scientific
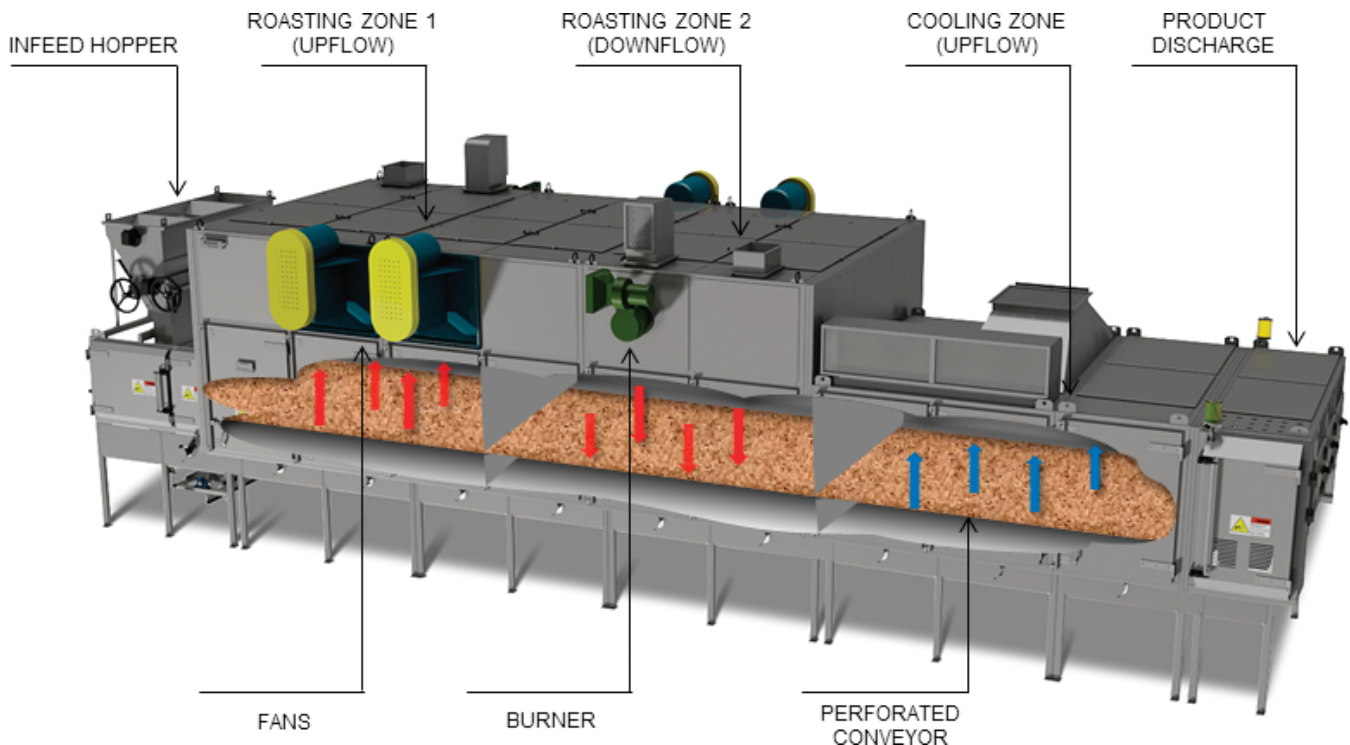

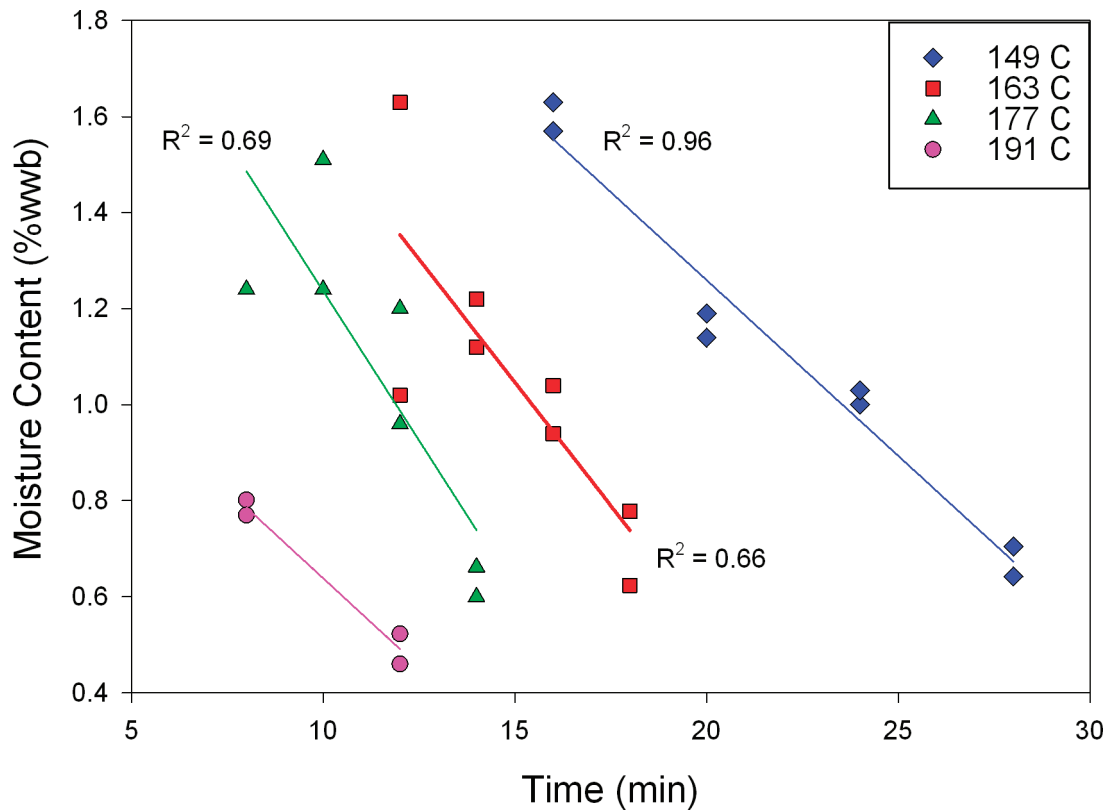**Fig. 2. Industrial dry roaster.**

Fig. 3. Final moisture content versus roasting time, by temperature, at 75 mm bed depth and 1.3 m/s air velocity.

Isotemp Lab Incubator (81 Wyman St., Waltham, MA 02454) at 35 C for 48 hours.

Inoculated samples were enumerated prior to shipment to confirm that the inoculation level was at least 6.5-log CFU/g. After samples for determination of inoculation levels had been removed, two 25 gram samples of the inoculated peanuts were scattered on aluminum mesh racks with the nuts separated and exposed to a heat treatment of 138 C for 15 minutes in a Fisher Scientific Isotemp 851F oven (81 Wyman St., Waltham, MA 02454). After heat treatment, the samples were plated as above. A reduction of less than 2.5-log CFU/g after the prescribed heating trial indicated the appropriate heat resistance of the surrogate cocktail (Almond Board of California 2007b).

Inoculated peanuts were held at 4 C after overnight shipment to the roasting location. Over the course of these studies, un-roasted, inoculated samples were tested to ensure that the initial level of inoculation was consistent for all trials and varied from 6.5 to 7.7-log CFU/g. Inoculation levels were verified prior to a given roast treatment and resulting log reduction levels were calculated accordingly.

During the roasting trials, 25 g samples of inoculated peanuts were equilibrated to ambient temperature in a cotton mesh steeping bag (com-monly used in home beer brewing), which was positioned in the desired location (top, middle or bottom) of the peanut bed. Sterile conditions were used immediately after roasting and cooling protocols, to refrigerate samples that were shipped overnight in insulated coolers with icepacks for enumeration of surviving *E. faecium*.

Treated samples were received at the Deibel Laboratory intact and under refrigeration. All treated samples and controls were enumerated twice on KF Streptococcus according to the protocol outlined above. After 48 hours at 35 C, plates were enumerated and the log CFU/g values of these counts were calculated. From these log values, minimum log reductions were calculated from the two enumeration results.

Roasting

Roasting was conducted in a laboratory scale roaster simulator (Figure 1) in which temperature, time, airflow speed, airflow direction and bed depth were regulated. The batch-type roaster consisted of a centrifugal fan for airflow, an electric heater and a rectangular tray which held 2 to 3 kg of peanuts depending on selected conditions. The square base of the tray (0.044 m^2) was uniformly perforated. Temperatures (149, 163, 177, and 191 C), bed depths (38, 75, and 113 mm) and air flows (1.0, and
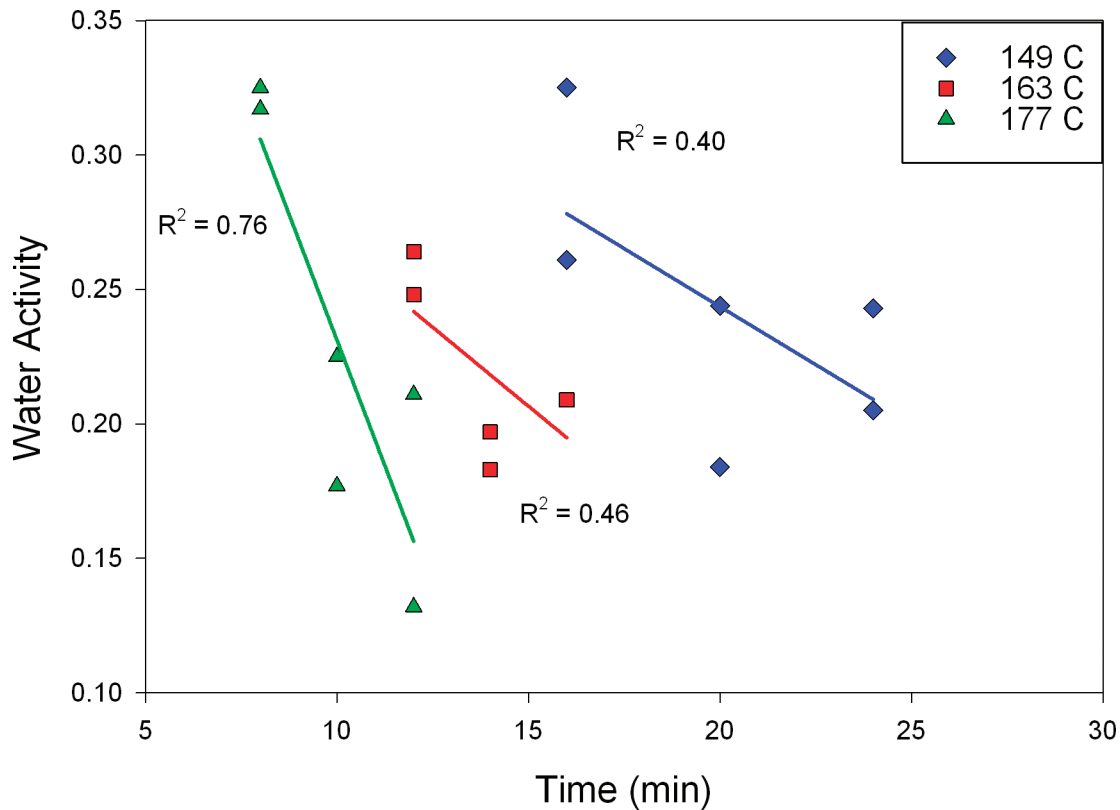
Fig. 4. Water activity versus roasting time, by temperature, at 75 mm bed depth and 1.3 m/s air velocity.

1.3 m/s) were variously combined to simulate industrial roaster conditions. Air temperature was measured and recorded manually with type J thermocouples from Omega Engineering (One Omega Drive, P.O. Box 4047, Stamford, CT 06907-0047) positioned above and below the tray containing peanuts. Airflow through the tray containing peanuts was measured using an orifice plate in the tray. Dampers in the roaster were used to switch the airflow through the tray between up-flowing air and down-flowing air. Airflow always began as up-flow and was changed to down-flow halfway through the roasting time, which is the most common configuration for continuous dry roasters in the industry. After roasting, the peanuts were cooled to ambient temperature (~25 C) using ambient up-flowing airflow through the tray of roasted peanuts to simulate the convection cooling commonly incorporated into an industrial dry roaster.

Bed and Peanut Temperature

Multiple type K thermocouples and a data logger from Omega Engineering (One Omega Drive, P.O. Box 4047, Stamford, CT 06907-0047) were used to measure and collect temperature data every 5 seconds during each test. Three thermocouples were located in the center of the tray, one at the bottom, one in the middle and one at the top of the bed of peanuts. In addition, a thermocouple was inserted approximately 3 mm into a peanut, which was placed near the middle bed temperature probe. Calibration of the data logger was done by an independent laboratory and checked using boiling water.

Measurement of Moisture, Water Activity and Color

Representative samples of each roast treatment were collected for additional measurements. Peanut moisture content was determined by drying the peanuts in a convection oven at 80 C until no further loss in weight occurred. Moisture content was calculated from wet and dry weights. Water activity was determined using an AquaLab water activity meter from Decagon Devices, Inc. (2365 NE Hopkins Court, Pullman, WA 99163). Roast peanut color was measured using a HunterLab DP-900 Colorimeter from Hunter Associates Lab (11491 Sunset Hills Rd, Reston, VA 20190). Hunter L values (McDaniel et al, 2012) of coarsely ground, blanched (skins removed) peanuts are reported.

Statistical Analysis

All roast treatments (a specified combination of roast temperature, roast time, air flow rate and bed depth) were evaluated in duplicate. Analysis of
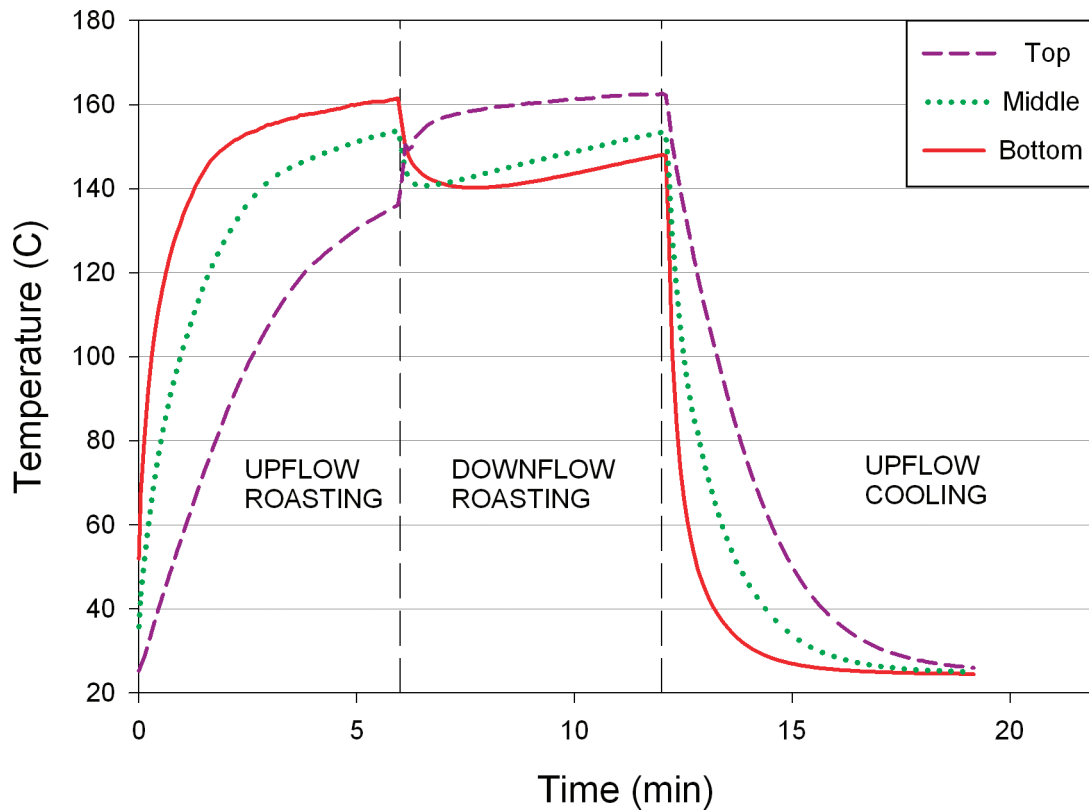
Fig. 5. Air temperature at top, middle, and bottom of the bed over time.

variance was performed using JMP® Ver. 9.0 (SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513). Means were separated using a Student's t test when a significant F-value was obtained.

Results and Discussion

Most continuous, industrial dry roasters (Figure 2) consist of a perforated steel belt that conveys the peanuts through the nut roaster. Peanuts are typically stacked on the conveyor to depths between 50–125 mm (75 mm is a commonly used bed depth). As the conveyor moves the peanuts through the dry roaster, the bed of product is subjected to forced convection airflow at elevated temperatures, typically between 140 and 190 C. Airflow through the bed of product is between 0.7–1.3 m³/s per m² of bed (expressed as m/s in this study). The dry roaster is divided into independent roaster zones and the direction of the airflow through the bed of peanuts typically alternates between upflow and downflow from one zone to the next. The parameters used in this study (bed depth, process air temperature, airflow, airflow direction) were specifically chosen to simulate the industrial dry roaster conditions described above.

Moisture content of the peanuts prior to roasting was 6.1% wwb. After roasting at different time/

temperature combinations (constant bed depth of 75 mm and air flow of 1.3 m/s) the highest moisture content observed was 1.7% wwb (Figure 3). At equivalent roast times, moisture content was reduced more at higher roast temperatures. For example, after 12 min roasting, samples prepared at 163 C and 177 C had greater ($P<0.05$) moisture contents than samples prepared at 191 C, whereas at 16 min roasting, samples prepared at 149 C had greater ($P<0.05$) moisture content than samples roasted at 163 C. Across these test conditions, linear ($R^2 \geq 0.66$) trends were observed in moisture loss with increasing roast time at a given roast temperature. Many food processors control the final moisture of their product to ensure that the product is below a target water activity (a_w), where $a_w = P/P^0$, and P = partial pressure of water over the food sample at equilibrium and P^0 = equilibrium pressure of pure water at the same temperature. Water activity is a critical concept in microbial safety, as the minimum a_w for growth of most bacteria is approximately 0.87. Foods with an a_w below 0.85 are commonly classified as low-water activity, and these include roasted peanuts (Beuchat *et al.*, 2013). Importantly, many low-water activity foods have been implicated over recent years in microbial illness outbreaks, and it is now understood that some bacteria, including *Salmonella,* can survive for some limited time on
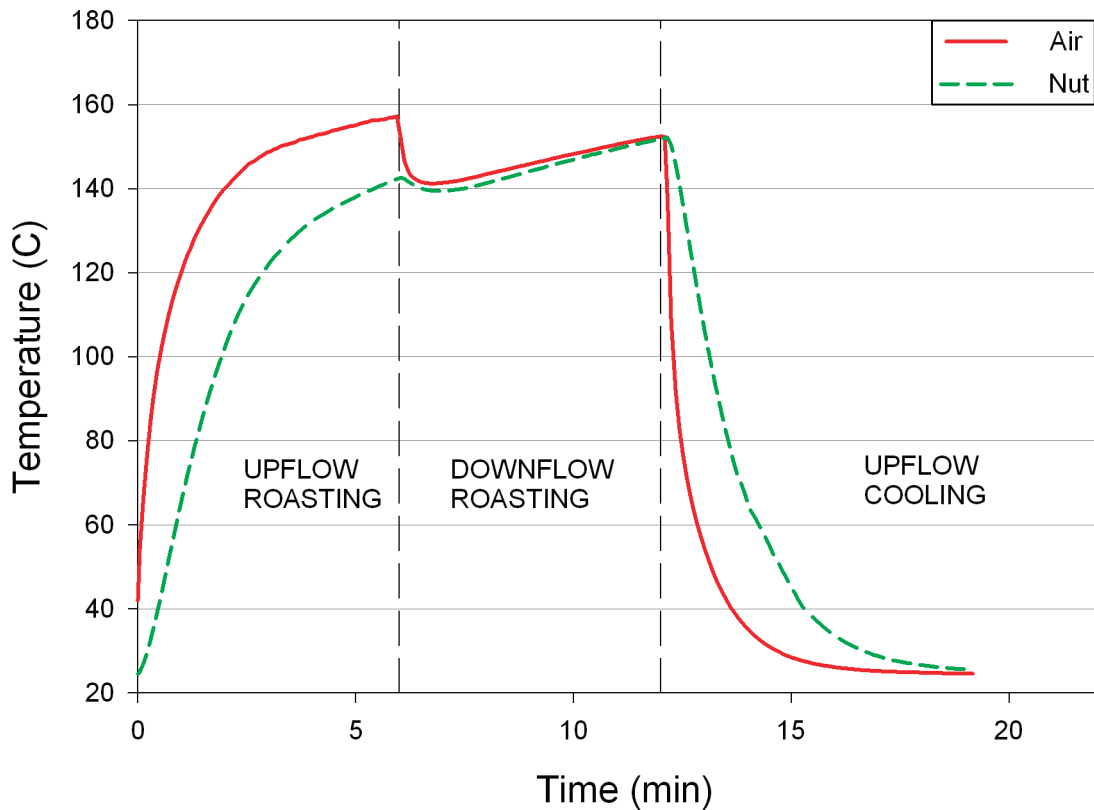
Fig. 6. Air temperature compared with internal nut temperature over time.

low-water activity foods if contaminated (Beuchat *et al.*, 2013). Water activity is also critical in governing various reactions important to final product quality, including lipid oxidation, hydrolytic reactions, non-enzymatic browning and enzyme activity (Fennema, 1996). Water activity for peanuts prior to roasting was approximately 0.73 and after roasting this value ranged from 0.33 to 0.13 (Figure 4). Water activity for roasted peanut samples decreased with increasing roast time at a given roast temperature (Figure 4), although linear trends were not as good as those observed for corresponding moisture content data (Figure 3). This is attributable to water activity data being inherently less accurate/precise for low moisture, high lipid products such as roasted peanuts. Regardless, at equivalent roast times, a_w was lower at higher roast temperatures (Figure 4). For all roasted peanut samples, a_w was less than 0.35, meaning no roasted peanut would be at risk for microbiological growth if properly packaged with a suitable moisture barrier; however, documenting survival after various roast conditions is critical.

During all roasting trials, the air flow direction was up through the peanut bed for the first half of the roasting time and down through the bed for the second half. This protocol simulates industrial roasting procedures in which air flow is alternated as the peanuts progress through the roaster zones. This alternating air flow prevents over roasting of either the bottom, or top, of the bed that would result from unidirectional airflow. Real time temperature data was collected for all roasted samples, and Figure 5 shows a typical temperature plot as measured via thermocouples placed at the top, middle and bottom of the peanut bed. As air flowed up for the first half of each roasting trial, the hot air first contacts the peanuts at the bottom of the bed and the air subsequently loses temperature as it flows upward through the bed, as evident in Figure 5. For this reason, peanuts at the top of the bed are initially subjected to lower temperatures than those at the bottom of the bed. However, half way through the prescribed roasting time, the airflow direction is reversed and the heated air contacts peanuts at the top of the bed first. As evident in Figure 5, the heated air loses energy as it passes down through the product bed and initially cools the peanuts at the bottom of the bed (Figure 5). After roasting, the nuts were cooled using up-flowing air (the industry standard), meaning nuts at the bottom of the bed cooled most rapidly.
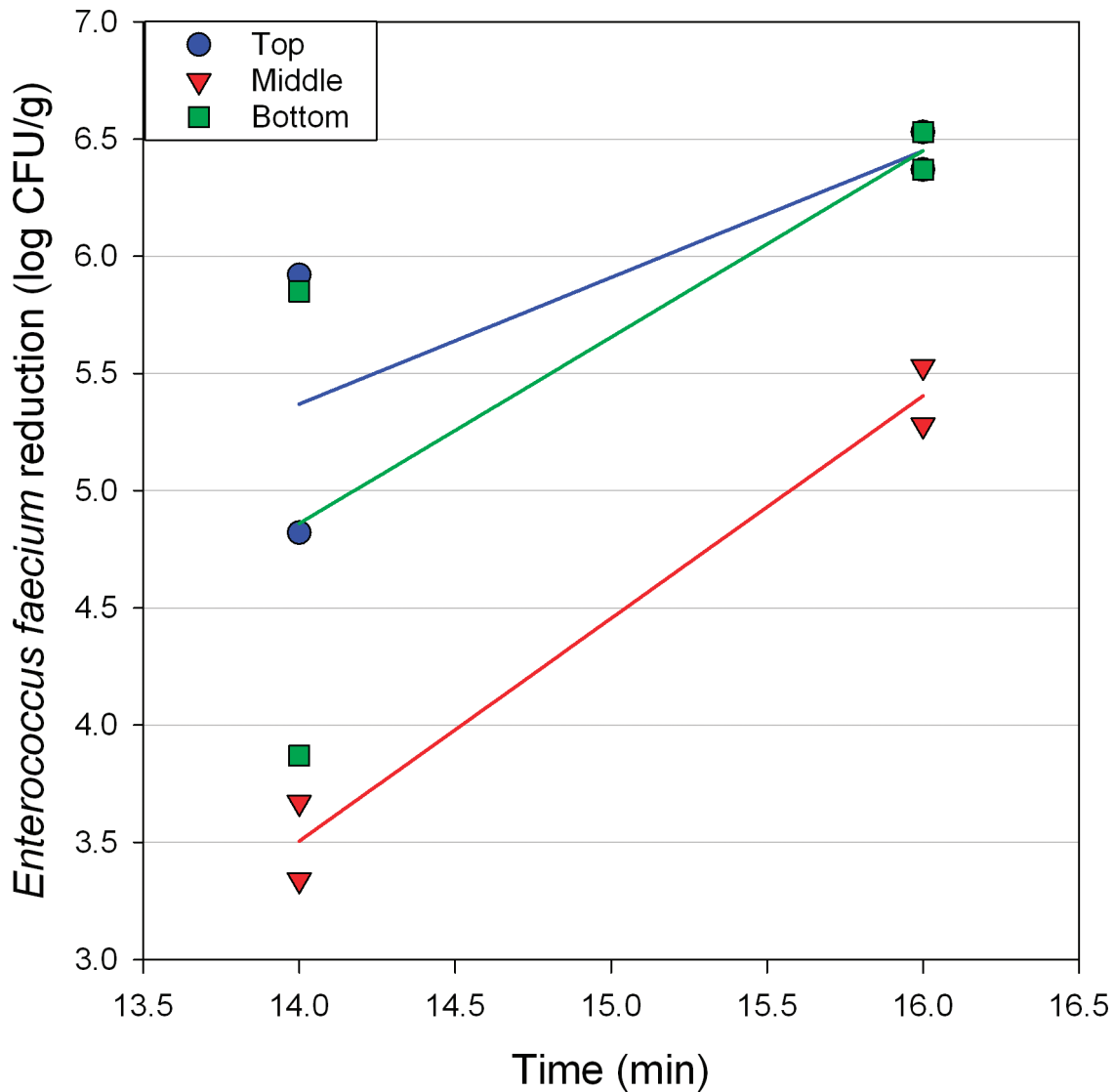
Fig. 7. *Enterococcus faecium* log reduction vs. roasting time at 163 C, 75 mm bed depth, and 1.3 m/s air velocity. Lines are added to better visualize paired data points.

The thermocouple measurements in Figure 5 show measurements of the local conditions in the interstices between peanuts and are most representative of the surface temperature of the peanuts. Since *Salmonella* will likely exist on the surface of peanuts, these measurements most closely represent the conditions to which *Salmonella* cells are exposed during the roasting process. Based on these temperature measurements, it was evident that thermal inactivation of *Salmonella* during dry roasting would vary throughout the depth of the product bed. A thermocouple was also embedded inside a peanut for each roast trial to better understand internal peanut temperature during roasting. Figure 6 shows an example of the relationship between the internal temperature of the peanut and the temperature in the interstices around the peanut. The internal temperature lags

behind the surface temperature because of the conductive heat transfer through the peanut; however, the internal temperature of the peanut reaches the process air temperature.

Salmonella surrogate log reduction was measured at the top, middle and bottom of the peanut bed (75 mm depth) after 14 and 16 min of roasting at 163 C with a constant air velocity of 1.3 m/s (Figure 7). Log reductions were significantly ($P<.05$) lower at the middle of the bed, compared to the top or bottom, across these conditions (Figure 7). Furthermore, log reduction was greater ($P<.05$) after 16 min of roasting compared to 14 min, regardless of measurement location (Figure 7). When samples were roasted at 163 C with a bed depth of 75 mm for 16 min, increasing the air flow from 1.0 to 1.3 m/s significantly ($P<.05$) increased log reduction in the middle and top of the bed, with
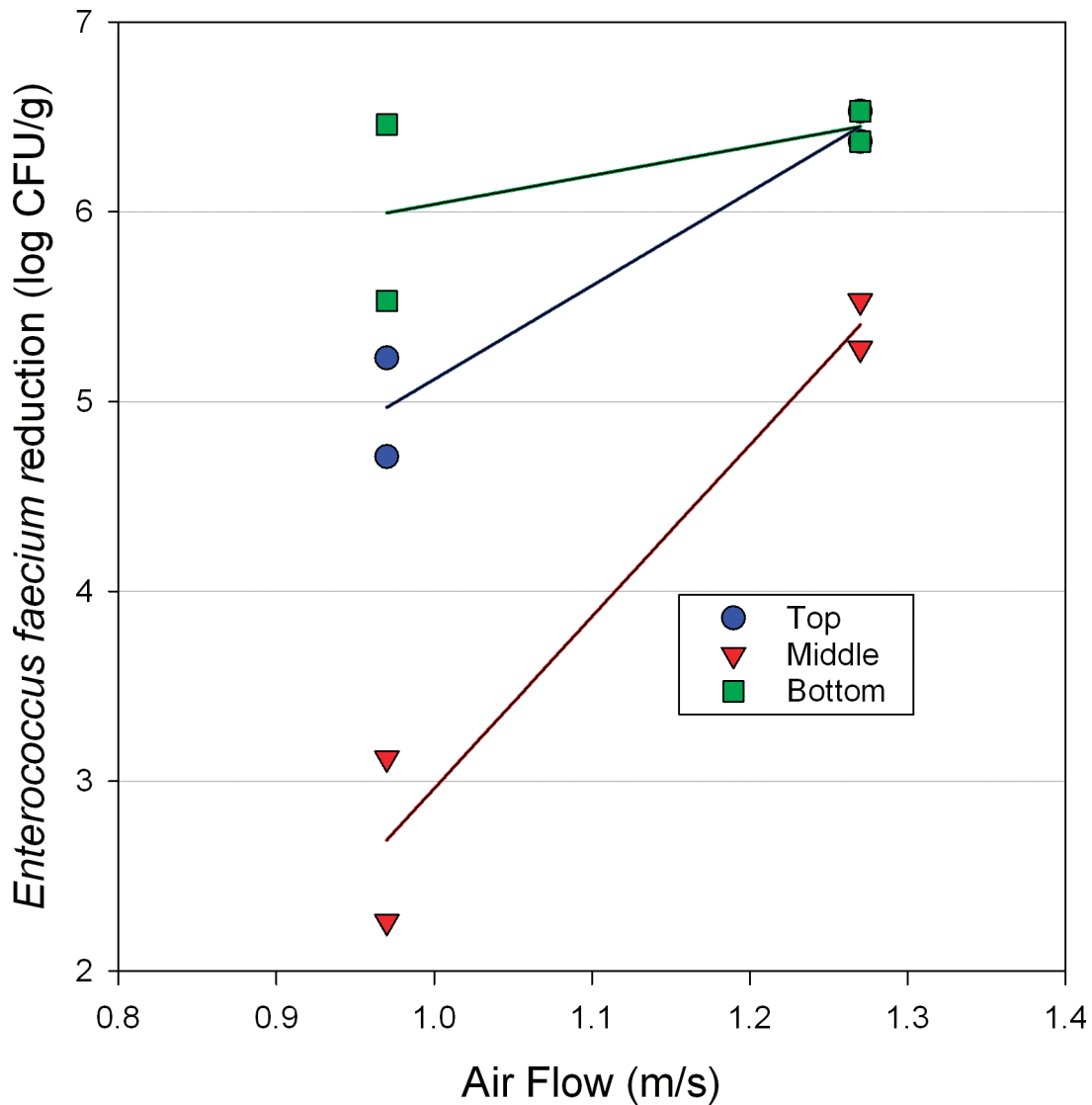
Fig. 8. *Enterococcus faecium* **log reduction vs. air velocity at 163 C and 75 mm bed depth with 8 minutes of upflow and 8 minutes of downflow. Lines are added to better visualize paired data points.**

the greatest increase occurring at the middle of the bed (Figure 8). Data in Figs. 7 and 8 indicated that the middle of the bed always exhibited the lowest (P<.05) level of *Salmonella* surrogate reduction. The California Almond Board procedures for validation of almond dry roasters recommends "embedding" the inoculated sample in the bed of almonds on the roaster conveyor (Almond Board of California, 2007b), and these results support that approach. Data in Figs. 7 and 8 also show that any change in processing parameters that allow the hot air to more effectively heat the nuts at the middle of the bed will increase *Salmonella* reduction and decrease variation in *Salmonella* reduction when comparing reductions at the top, middle and bottom of the bed. Figure 7 shows that longer roasting time increases *Salmonella* surrogate reductions and ultimately results in more consistent inactivation across

the bed depth. Figure 8 shows that higher air flow rates through the bed also increases *Salmonella* surrogate reduction and results in more consistent inactivation throughout the bed of peanuts. Higher air flow heats peanuts in the middle of the bed more rapidly since the air loses less energy as it travels through the peanut bed. Based on these results, all subsequent *Salmonella* surrogate inactivation data was collected at the middle of the bed, as this location represents the worst case in terms of inactivation.

Another processing parameter that impacts heating at the middle of the bed is the bed depth. Peanuts were roasted at 163 C for 16 min using 3 bed depths, 38, 75 and 113 mm and log reductions were measured at the middle of the bed (Figure 9). Log reduction was negatively linearly correlated ($R^2 = 0.67$) with increasing bed depth. A deeper bed reduced the capacity of the process air to heat
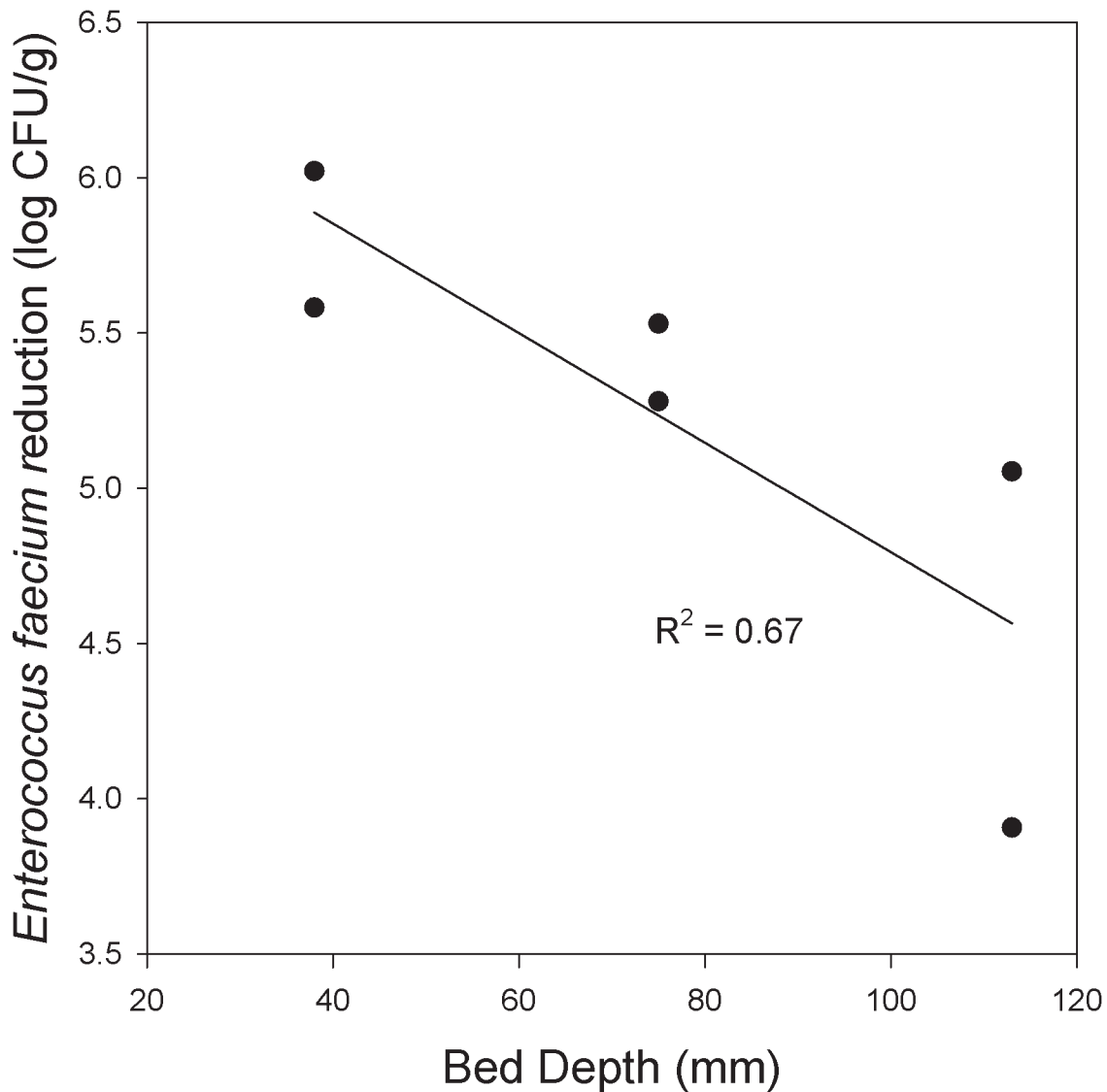
Fig. 9. *Enterococcus faecium* log reduction vs. bed depth at 163 C with 8 minutes of upflow and 8 minutes of downflow.

the peanuts in the middle of the bed. Over this limited data set, bed depth impact on log reduction was significant at the P=0.16 level.

Figure 10 shows the impact of time and temperature of roasting on *Salmonella* surrogate log reduction at the middle of the bed (75 mm) with a constant air velocity of 1.3 m/s. Higher temperatures and longer roast times increased inactivation across these conditions, with log reductions generally increasing linearly with roast time at a given roast temperature. The 5-log reduction in CFU/g line is highlighted on this graph since this is a common target in the peanut roasting industry (Food and Drug Administration, 2009). A 5-log CFU/g reduction was achieved during dry roasting at the middle of the product bed under these conditions at 11, 15 and 21 min when roasting at 177, 163 and 149 C, respectively.

Standard industry practice is to roast peanuts to a target color, as color measurements are rapid, inexpensive, nondestructive and correlate well with final product quality, including flavor, texture, and nutritional composition (McDaniel *et al*, 2012). Specific L-values from the Hunter Lab scale are commonly targeted in the peanut industry as the L-value corresponds to the relative lightness or darkness of the sample, with 100 and 0 equaling perfectly white and dark, respectively. Figure 11 shows the same log reduction data from Figure 10 plotted versus Hunter-L values of the roasted, ground peanuts. L-values of 53 and 48.5 are industry commonly accepted L values for light and medium colored peanuts, respectively (McDaniel *et al*, 2012). This graph indicates most peanuts roasted to an L-value of 53 and darker had more than a 5-log CFU/g reduction. Further study is
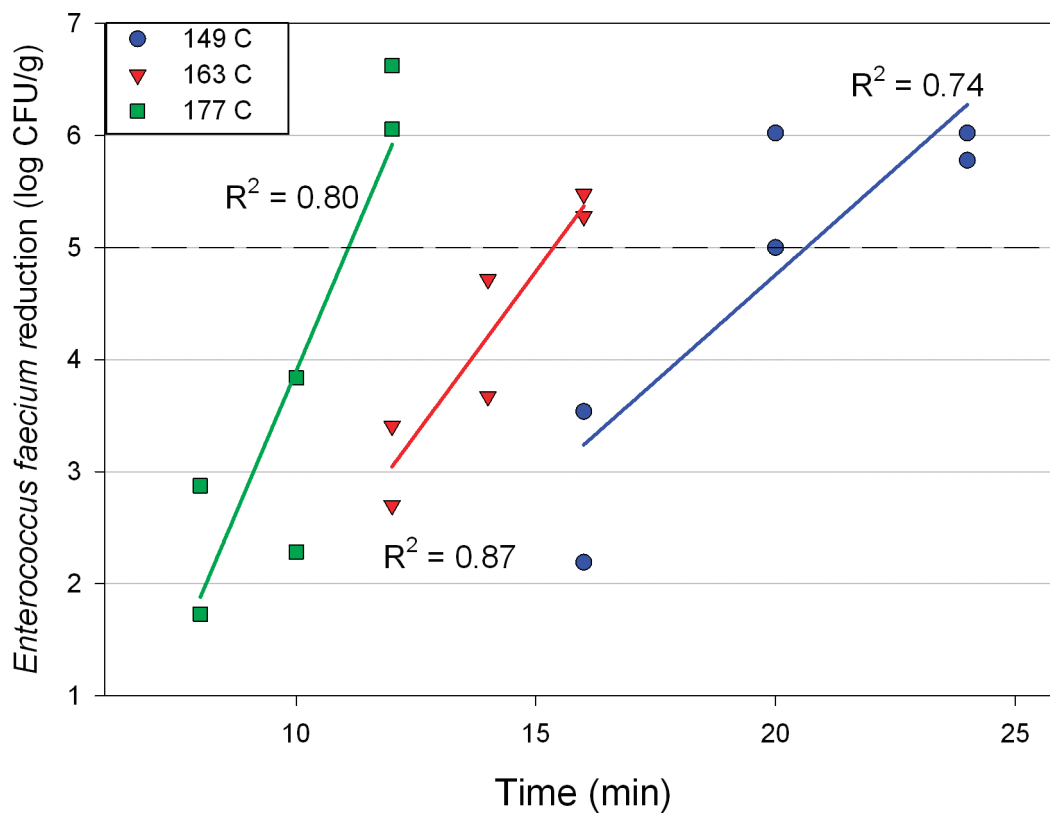
Fig. 10. *Enterococcus faecium* log reduction vs. roasting time, by temperature, at 75 mm bed depth and 1.3 m/s air velocity.
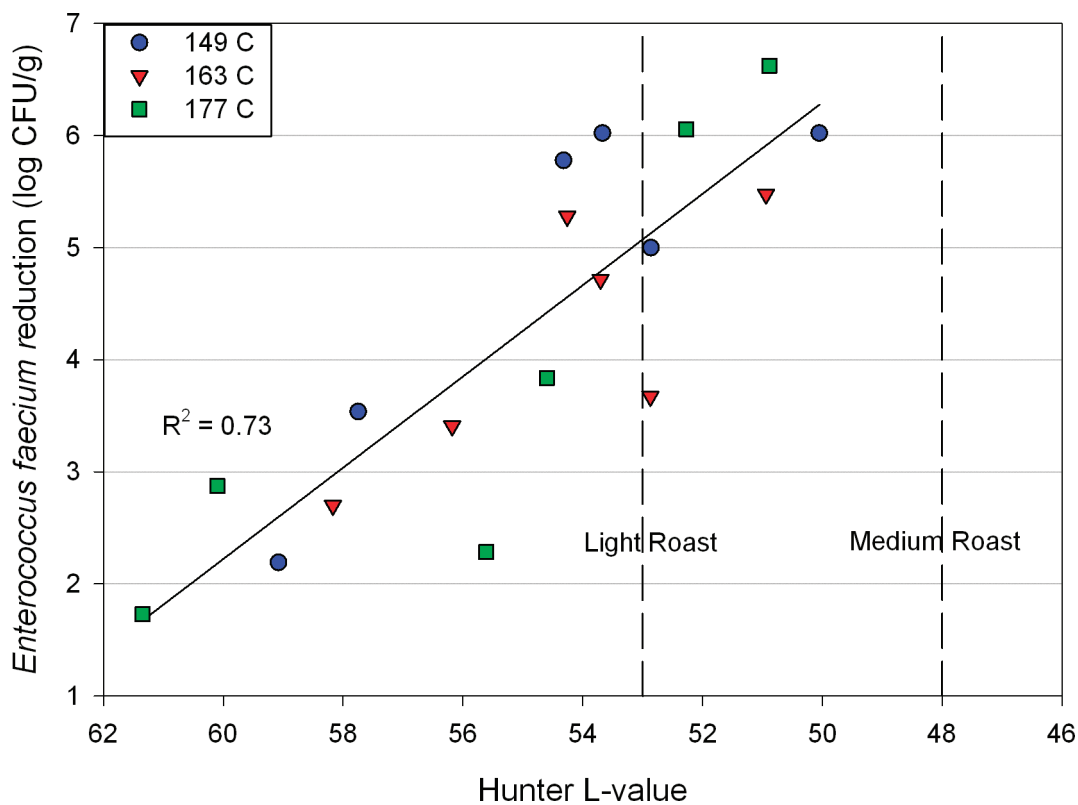

Fig. 11. *Enterococcus faecium* log reduction vs. Hunter L-value, by temperature, at 75 mm bed depth and 1.3 m/s air velocity.

needed to understand and bolster this finding, but this data suggests a good correlation between *E. faecium* reduction (and thus *Salmonella* reduction) and Hunter-L color, regardless of roast conditions. As color darkens with both increasing time of roast and increasing temperature of roast, roast color is a good indicator of total heat exposure, which could explain the good correlation observed in Figure 11. However, since roast color is well established to be a function of seed maturity and production location, among other factors, further data is required to understand this correlation and processors should not use roast color as an indication of microbial reduction.

Summary and Conclusions

Because of the close correlation of *E. faecium* and *Salmonella* in relative heat stability, this study indicated that *Salmonella* reductions of 5-log CFU/g and higher may be obtained with typical industrial dry roasting parameters for peanuts. The peanuts located in the middle of the roasting bed were shown to have the lowest microbial reduction. Processing parameter changes that allowed the heated air used for roasting to more effectively heat the middle of the bed (longer time, increased airflow or shallower bed depth) improved reductions and reduced variation in reduction among the top, middle and bottom of the bed. Data from the study also suggested that *Salmonella* reductions correlate to the Hunter L-value of ground, roasted peanuts. This information provides processors practical guidance to better understand and utilize data from microbial validations performed on specific process parameters in their facilities and, as needed, in selection and modification of those parameters to achieve desired *Salmonella* reductions during industrial roasting of peanuts.

Acknowledgements

Disclaimer

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