Title: Quantitative Transfer of *Salmonella* Typhimurium LT2 during Mechanical Slicing
of Tomatoes as Impacted by Multiple Processing Variables

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ABSTRACT

Slicing of fresh produce can readily lead to pathogen cross-contamination with pre-sliced tomatoes having been linked to multistate outbreaks of salmonellosis in the United States. This study aimed to assess the impact of multiple processing variables on quantitative transfer of *Salmonella* during simulated commercial slicing of tomatoes. One red round tomato was inoculated with *Salmonella* Typhimurium LT2 at ~ 5 log CFU/g and sliced using a manual or electric slicer, followed by 20 uninoculated tomatoes. Thereafter, the distribution of *Salmonella* on inoculated and uninoculated tomato slices was evaluated along with the transfer of *Salmonella* from different parts of the slicer. The impact of multiple processing variables including post-contamination hold time (0 and 30 min), tomato wetness (dry and wet), processing room temperature (23, 10 and 4 °C), slice thickness (0.48, 0.64, and 0.95 cm), tomato variety (Torero, Rebelski, and Bigdena) and pre-wash treatment (no wash, tap water, and chlorine) was also investigated. The data were fitted to a two-parameter exponential decay model ($Y = A \cdot \exp(BX)$) with the percentage of *Salmonella* transferred to 20 uninoculated tomatoes then calculated. *Salmonella* populations on nine inoculated tomato slices ranged from 4.6 ± 0.2 to 5.5 ± 0.3 log CFU/g, with higher populations on slices from the blossom and stem scar ends. However, *Salmonella* transfer to the previously uninoculated slices was similar ($P > 0.05$), ranging from 2.1 ± 0.2 to 3.4 ± 0.2 log CFU/g. Significantly fewer salmonellae transferred from the blade (3.4 ± 0.4 log CFU, $P \leq 0.05$) than from the back and bottom plates (4.7 ± 0.3 log CFU) or the whole manual slicer (5.2 ± 0.2 log CFU) to the 20 uninoculated tomatoes. However, the blade was the primary contributor to *Salmonella* transfer for the electric slicer. Post-contamination hold time, processing temperature and

tomato slice thickness did not significantly impact ($P > 0.05$) the *Salmonella* transfer rate (parameter B) or the overall percentage cells transferred. A significantly lower ($P \leq 0.05$) transfer rate (-0.028 ± 0.002) was observed for wet as compared to dry tomatoes (-0.051 ± 0.002), with a significantly higher ($P \leq 0.05$) percentage ($12.2 \pm 2.4\%$) of *Salmonella* transferred to wet as opposed to dry tomatoes ($1.1 \pm 0.5\%$). Tomato variety also impacted *Salmonella* transfer with significantly lower ($P \leq 0.05$) transfer rates and *Salmonella* transfer percentages seen for Rebelski and Bigdena than Torero. These findings will provide practical guidelines for the fresh-cut tomato industry and will also be useful in developing science-based transfer models for risk assessments.

1. Introduction

Salmonella contamination has been an ongoing food safety concern for the tomato industry (Cummings et al., 2001; Flanders, 2008; Greene et al., 2008; Roberts, 2000) with 35 tomato-related outbreaks, including 5324 cases of illness, documented in the United States between 1990 and 2013 (Center for Science in the Public Interest, 2014). During the summer of 2004, one outbreak involving 429 cases of salmonellosis in nine states was traced to pre-sliced Roma tomatoes from a single processor with diced tomatoes also responsible for an outbreak of salmonellosis in 1999 (Weissinger et al., 2000). Despite improved food safety standards which have led to less frequent recalls, *Salmonella* contamination of tomatoes remains problematic as evidenced by the recall of 790 boxes of fresh tomatoes by one Florida tomato packer in 2014 (U.S. Food and Drug Administration, 2014). Such outbreaks and recalls along with multiple studies showing that *Salmonella* can survive and grow in sliced/diced tomatoes, especially at elevated temperatures (Maitland et al., 2011; Pan and Schaffner, 2010; Shi et al., 2007; Weissinger et al., 2000) point to tomatoes as a product of continuing concern.

Different types of mechanical slicers – either manual or electric, are used by the industry to convert tomatoes into a value-added product. In restaurants, tomatoes are typically hand-sliced; however manual slicers are favored by most large-scale processors, supermarkets and foodservice establishments due to their low cost and ease of use which reduces the labor handling cost and improves operating efficiency (Edlund Company LLC, 2014; Maxwell Chase Technologies LLC, 2014). Manual slicers are made of metal and contain a pocket in which the tomato is placed and then manually pushed through a set of horizontal stainless steel blades to obtain uniform slices. Since the slicer is

typically not washed and sanitized during use, any microorganisms coming in contact with the product or slicer, including bacterial pathogens, can cross contaminate subsequent product.

Previous studies have focused on the transfer of various foodborne pathogens during slicing/mincing/grinding of meat products, such as deli meat (Chen et al., 2014; Pérez-Rodríguez et al., 2007; Sheen and Hwang, 2010, 2008; Sheen, 2011, 2008; Vorst et al., 2006a, 2006b), “gravad” salmon (Aarnisalo et al., 2007), beef fillet (Papadopoulou et al., 2012), and pork (Moller et al., 2012) and cutting/shredding during preparation of fresh-cut salads (Zilelidou et al., 2015). In most of these studies, various mathematical models (empirical or semi-empirical) were developed based on the experimental transfer data to describe the bacterial spread during processing. For example, Aarnisalo (Aarnisalo et al., 2007) and Sheen (Sheen and Hwang, 2010) observed an exponential decrease for *Listeria monocytogenes* and *Escherichia coli* O157:H7 during slicing of “gravad” salmon and RTE deli meat, respectively. Cross-contamination of delicatessen meats with *L. monocytogenes* during slicing remains a serious concern, particularly for higher fat products where bacterial transfer is prolonged (Vorst et al., 2006b).

Bacterial transfer is a complicated process, with many factors affecting the spread of microorganisms during slicing. For example, Vorst et al. (2006b) reported significantly greater ($P < 0.05$) transfer of *Listeria* to the table and back plate of a mechanical delicatessen slicer when 4.5 as opposed to 0 kg of force was applied against the product during slicing. In another study, inoculum level, temperature and attachment time significantly affected the total number of *L. monocytogenes* cells transferred during slicing of “gravad” salmon. However, Buchholz et al. (2012) failed to observe a

significant impact of either shred size or post-inoculation hold time on *E. coli* O157:H7 transfer during pilot-scale production of fresh-cut iceberg lettuce.

Published work on the spread of microbial contaminants during slicing of tomatoes is currently confined to a single study involving norovirus (Shieh et al., 2014) which did not assess the impact of any of slicing variables on virus transfer. Therefore, the objectives of this study were to 1) assess the spread of *Salmonella* from inoculated tomatoes to various surfaces of a manual and electric slicer as well as to subsequently uninoculated tomatoes during slicing and 2) quantify the impact of post-contamination hold time, tomato surface wetness, slicing room temperature, slice thickness, tomato variety, and pre-wash treatment on *Salmonella* transfer during manual slicing of tomatoes.

2. Materials and methods

2.1. Tomatoes

Red round, unwaxed tomatoes (*Solanum lycopersium*; Torero variety; ~260 g/tomato; ~6 cm height/tomato, pH ~4.6) were obtained from a local distributor (Mastronardi Produce Ltd., Livonia, MI), stored at 4°C, and used within 7 days of delivery. Two other tomato varieties, Rebelski and Bigdena, were also obtained from the same distributor to evaluate the impact of tomato variety on pathogen transfer.

2.2. Salmonella strain

Salmonella enterica subsp. *enterica* serovar Typhimurium LT2 (an avirulent strain) was obtained from Dr. Michelle Danyluk (University of Florida, Gainesville, FL) and stored at -80°C in trypticase soy broth containing 0.6% (w/v) yeast extract (TSBYE, BD,

Sparks, MD) and 10% (v/v) glycerol. The working culture was prepared by streaking the stock culture onto trypticase soy agar containing 0.6% (w/v) yeast extract (TSAYE, BD). Following 24 h of incubation at 37°C, a single colony was subjected to two successive transfers (24 h/37°C) in 9 ml of TSBYE after which 10 µl was transferred to 1000 ml of TSBYE and incubated at 37°C for 18 to 20 h. The same avirulent *Salmonella* strain as used in our previous study was selected for this study. However, based on preliminary tests, no significant difference ($P < 0.05$) in growth rate or attachment was observed between this strain and three virulent outbreak-related *Salmonella* strains.

2.3. Inoculation of tomatoes

Red round tomatoes were immersed in the *Salmonella* suspension ($\sim 10^8$ CFU/ml) for 2 min with gentle agitation to ensure uniform inoculation, followed by 2 h of air drying in a biosafety cabinet at $\sim 23^\circ\text{C}$. Two tomatoes were randomly collected before processing to determine the initial inoculation level.

2.4. Tomato slicer

Two different slicers were evaluated - a manual slicer widely used by the industry (Model 943, Prince Castle Inc., Carol Stream, IL) and a less common electric slicer (Model 350, Edlund Company, Inc., Burlington, VT). Using Glo-GermTM powder as previously described by Vorst et al. (2004), the major tomato contact areas of the manual slicer included the blade, back plate, and bottom plate (Figure 1A), whereas the blade, pusher, and side plate were identified for the electric slicer (Figure 1B).

2.5. *Salmonella* transfer to individual tomato slices

Salmonella distribution on individual tomato slices was assessed by slicing one inoculated tomato. Each of the nine slices obtained was collected in a separate Whirl-

Pak[®] bag (Nasco, Fort Atkinson, WI) containing 20 ml of sterile phosphate buffer, weighed, homogenized by stomaching (Stomacher 400 Circulator, Seward, Worthington, UK) for 1 min at 260 rpm, and then quantitatively analyzed for *Salmonella*. Thereafter, one uninoculated tomato was sliced using the same slicer with all nine slices similarly examined. Based on these results, only the top, middle, and bottom slices were collected and analyzed in subsequent experiments with the resulting *Salmonella* populations for the three slices then averaged to estimate the *Salmonella* concentration (log CFU/g) for the whole tomato.

2.6. *Salmonella* transfer to the slicer

Transfer of *Salmonella* to the previously identified product contact areas of the manual and electric slicer was assessed after slicing inoculated as well as uninoculated tomatoes. Briefly, after slicing one inoculated tomato, the blade, back plate, and bottom plate of the manual slicer as well as the blade, pusher and side plate of the electric slicer were individually sampled using one-ply composite tissues moistened with 1 ml of sterile phosphate buffer (Vorst et al., 2004). Similarly, after slicing one inoculated followed by 20 uninoculated tomatoes, the same product contact areas from the two slicers were sampled to quantify *Salmonella*.

2.7. *Salmonella* transfer from individual slicer components to tomatoes

The contribution of individual slicer components to *Salmonella* transfer was also evaluated. In order to assess *Salmonella* transfer from the contaminated back and bottom plates of the manual slicer, one inoculated tomato was sliced after which the blade of the slicer was removed, sanitized and replaced, with 20 uninoculated tomatoes sliced thereafter. Similarly, the number of salmonellae transferred from the blade was

determined by slicing one inoculated tomato, sanitizing the back and bottom plates and then slicing 20 uninoculated tomatoes. For the electric slicer, the same protocol was followed to assess *Salmonella* transfer from the blade and the pusher and side plates. In all cases, the top, middle and bottom slices were collected from each tomato and analyzed for numbers of salmonellae. Considering that the limits of detection (LOD) differed due to varying tomato weights, the final LOD for *Salmonella* was calculated as the lowest LOD value (2.1 log CFU/tomato) from all three replicates. For subsequent statistical analyses, samples (tomato slices) that were positive for *Salmonella* by enrichment were assigned a count of 1 CFU for all three tomato slices collected, with the total *Salmonella* population for the corresponding whole tomato calculated based on tomato weight. For purposes of mathematical modeling, enrichment-negative tomatoes were assigned a *Salmonella* population of 1 CFU per tomato equal to the lower limit of detection. The detailed enrichment protocol follows in section 2.9.

2.8. Impact of different processing variables on *Salmonella* transfer.

Based on observations from a preliminary study, six processing variables as shown in Table 1 were evaluated for their impact on *Salmonella* transfer by slicing one inoculated followed by 20 uninoculated tomatoes under the following conditions: 1) Post-contamination hold time - after slicing one inoculated tomato, 0 or 30 min elapsed before the slicer was again used to slice 20 uninoculated tomatoes, 2) Tomato wetness - dip-inoculated tomatoes were sliced immediately or after 2 h of drying followed by 20 uninoculated tomatoes that were either dipped in sterile water or dry, 3) Processing room temperature - slicing was conducted in a walk-in cold room at 4 or 10°C or at room temperature (23°C) with all tomatoes tempered to the temperature of the room before

slicing, 4) Slice thickness - three different sets of blades were used to generate tomato slices that were 3/16" (0.48 cm), 1/4" (0.64 cm) or 3/8" (0.95 cm) thick, 5) Tomato variety - Rebelski and Bigdena in addition to Torero (control) were evaluated, and 6) Pre-wash - both inoculated and uninoculated tomatoes were washed for 2 min in tap water or 100 ppm of chlorine (XY12, Ecolab, St. Paul, MN) adjusted to pH 6.0 with citric acid before slicing with unwashed tomatoes serving as the control.

2.9. Microbiological analyses

Tomato samples collected in Whirl-pak[®] bags containing 20 ml of phosphate buffer solution or 50 ml of lactose broth were weighed, homogenized by stomaching (Stomacher 400 Circulator, Seward, Worthington, UK) for 1 min at 300 rpm, and then surface-plated on trypticase soy agar (BD) containing 0.6% yeast extract (BD), 0.05% ferric ammonium citrate (Sigma) and 0.03% sodium thiosulfate (Fisher Science Education, Hanover, IL) (TSAYE-FS) with or without 0.45 µm membrane filtration (Milipore Corporation, Billerica, MA) to quantify *Salmonella* (limit of detection: 20 and 50 CFU/sample for one and three tomato slices, respectively). Equipment surface swab samples were homogenized by stomaching in 30 ml of phosphate buffer for 1 min at 300 rpm and then similarly examined for salmonellae (limit of detection: 3 CFU/slicer part). Plates were incubated at 37°C for 24 h after which all black colonies were counted as *S. Typhimurium* LT2. Along with the plates, tomato samples in Whirl-pak[®] bags containing lactose broth were incubated at 37°C for 24 h to enrich for *Salmonella*. When *Salmonella* was not detected by plating or filtration, xylose lysine tergitol-4 (XLT-4; Neogen Corporation, Lansing, MI) plates streaked from the previous lactose broth-enriched sample were examined for the presence or absence of *Salmonella* after 24 h of incubation

at 37°C. Selected colonies were confirmed as *Salmonella* using the Neogen Reveal[®] 2.0 kit (Neogen Corporation, Lansing, MI).

2.10. Statistical analysis

All experiments were performed in triplicate. Average *Salmonella* populations were calculated from three replicates and then converted to log CFU per gram, per slicer part, or per tomato for the *Salmonella* distribution, surface transfer, and tomato transfer studies, respectively. For the *Salmonella* distribution and surface transfer studies, analysis of variance and the Tukey-Kramer HSD test were performed using JMP 11.0 (SAS Institute Inc., Cary, NC). Statistical significance was set at $P \leq 0.05$. Two-parameter exponential decay curves were fitted to the *Salmonella* transfer (log CFU/tomato) data for tomatoes using Eq. (1):

$$Y = A \cdot \exp(BX) \quad (1)$$

Where Y (dependent variable) is the log CFU/tomato transferred and X (independent variable) is the number for the specific uninoculated tomato that was sliced. A and B are transfer model parameters. The parameter $\pm$ standard error for each replicate and the root mean square error (RMSE) of the model were obtained using JMP 11.0. In addition, the percentage of the *Salmonella* population transferred from one inoculated to 20 uninoculated tomatoes was calculated as in Eq. (2)

$$\%T = \frac{\text{Salmonella population transferred to 20 uninoculated tomatoes}}{\text{Salmonella population on the original inoculated tomato}} \times 100 \quad (2)$$

Analysis of variance and the Tukey-Kramer HSD test were performed using JMP to compare percent transfer and the decay parameter for the different processing variables.

3. Results and discussion

3.1. *Salmonella* transfer to individual tomato slices

After slicing tomatoes inoculated to contain an average *Salmonella* population of 4.9 ± 0.1 log CFU/g, populations on the nine tomato slices ranged from 4.6 ± 0.2 to 5.5 ± 0.3 log CFU/g, with significantly fewer ($P \leq 0.05$) salmonellae transferred to interior slices 4 through 7 compared to those closer to or including the blossom and stem ends (Figure 2). However, when one inoculated tomato was sliced followed by one uninoculated tomato, *Salmonella* populations on the previously uninoculated tomato ranged from 2.1 ± 0.2 to 3.4 ± 0.2 log CFU/g and were not significantly different ($P > 0.05$) from each other. For the nine slices, the inoculated and uninoculated tomatoes yielded average populations of 4.9 and 2.9 log CFU/g, respectively, which were statistically similar to the average *Salmonella* populations from slices 1 (blossom end), 5 (center) and 9 (stem end) for both inoculated (5.2 log CFU/g) and uninoculated (2.9 log CFU/g) tomatoes. Therefore, in all subsequent work, slices 1, 5 and 9 were collected and analyzed for *Salmonella* populations (log CFU/g) with the average count then multiplied by the total weight of the corresponding tomato to most accurately estimate the number of salmonellae transferred to the whole tomato. In a hand contamination study, Shieh et al. (2014) similarly examined tomato slices 3, 5, and 7 for norovirus. However, the distribution of natural surface contaminants on tomatoes is most likely non-uniform.

3.2. *Salmonella* transfer to the slicer

After slicing one inoculated tomato (5.0 ± 0.02 log CFU/g) on the manual slicer, the blade, back plate, and bottom plate yielded statistically similar *Salmonella* populations ($P > 0.05$) of 3.9 ± 0.3 , 3.3 ± 0.6 , and 4.6 ± 0.4 log CFU/part, respectively (Figure 3A). When 20 uninoculated tomatoes were subsequently sliced, numbers of salmonellae

decreased to 1.9 ± 0.8 , 2.2 ± 0.1 , and 2.3 ± 0.8 log CFU/part with statistically similar populations again seen ($P > 0.05$) for the three components of the manual slicer. Similarly, for the electric slicer, no significantly different *Salmonella* populations ($P > 0.05$) were observed on the blade, pusher, and side plate either before or after slicing 20 uninoculated tomatoes (Figure 3B).

The components from different types of slicers have been previously assessed for their role in bacterial transfer. When delicatessen meats were sliced using a commercial slicer, Vorst et al. (2006b) found that after slicing *L. monocytogenes*-inoculated turkey breast ($\sim 10^5$ CFU/cm²) with an application force of 4.5 kg, ~ 2.5 log CFU of *L. monocytogenes* transferred to the various slicer components including the table, back plate, guard, blade, and collection area. However, in the absence of an application force, significantly lower numbers of *Listeria* transferred to the table and back plate.

3.3. *Salmonella* transfer from the slicer to tomatoes during sequential slicing

After slicing one *Salmonella*-inoculated tomato (4.9 ± 0.1 log CFU/g) followed by 20 previously uninoculated tomatoes in three separate trials, 58 of 60 (96.7%) tomatoes yielded *Salmonella* – 47 by direct plating and 11 by enrichment (Figure 4). *Salmonella* populations decreased 3.1, 2.8, and 2.4 log CFU/tomato in trials 1, 2, and 3 after slicing 20 uninoculated tomatoes. When these results were fitted to a previously published two-parameter exponential decay model (Sheen and Hwang, 2010), similar transfer rates of -0.047, -0.052, and -0.054, were observed for trials 1, 2, and 3, respectively, with the root mean square error (RMSE) of 0.42 indicating a relatively good fit (Zilelidou et al., 2015).

Various exponential, logarithmic, semi-logarithmic and Weibull models have been used to describe *L. monocytogenes* transfer during slicing of salmon (Aarnisalo et al.,

2007), *E. coli* O157:H7 and *Staphylococcus aureus* transfer during slicing of cooked meat (Pérez-Rodríguez et al., 2007) and norovirus transfer during slicing of tomatoes (Shieh et al., 2014). The R^2 value has been most often used to describe the goodness of fit for the model. However, in this study, root mean square error (RMSE) was used with the values for all variables being less than 0.5 (Table 2). The *Salmonella* populations on 20 previously uncontaminated tomatoes similarly decreased in all three trials as confirmed by the similar transfer rates (parameter B).

3.4. *Salmonella* transfer from different slicer components

In order to assess the contribution of individual slicer components to cross-contamination, the numbers of *Salmonella* transferred from specific parts of the slicer to uninoculated tomatoes during slicing were quantified. When the blade alone on the manual slicer was contaminated, *Salmonella* transferred to 12 of 20 uninoculated tomatoes (0.036% of the original inoculums), with these low numbers likely due to the smaller contact area between the blade and tomato along with the washing effect from the blade and juices produced during slicing (Figure 5A). However, *Salmonella* spread to all 20 uninoculated tomatoes when the entire slicer or the back and bottom plates were contaminated before slicing. The total number of salmonellae transferred from the contaminated blade to 20 uninoculated tomatoes (3.4 ± 0.4 log CFU), was significantly lower ($P \leq 0.05$) than for the contaminated back and bottom plates (4.7 ± 0.3 log CFU) and the whole slicer (5.2 ± 0.2 log CFU). The back and bottom plates were the primary contributors to *Salmonella* transfer during manual slicing.

Opposite results were obtained for the electric slicer with more consistent transfer to 20 uninoculated tomatoes seen from the blade (3.6 ± 0.4 log CFU) compared to the

pusher and side plate (1.8 ± 0.4 log CFU) (Figure 5B). The pusher (equivalent to the back plate of the manual slicer) of the electrical slicer is made of high density polyethylene compared to the back plate of the manual slicer which is stainless steel. The side plate (equivalent to the bottom plate of the manual slicer) of the electric slicer, which is designed to keep the tomato inside the “cutting pocket” during slicing, also serves to minimize tomato contact during slicing. In addition to the equipment material, the cutting action of the electric slicer, which includes motorized blade movement and manual pushing, is different from the manual slicer which solely relies on manually pushing the tomato through the blades.

3.5. *Salmonella* transfer impacted by different processing variables

For each of the six processing variables assessed, *Salmonella* populations obtained during the slicing of 20 uninoculated tomatoes were fitted to the previously described two-parameter exponential decay model. Model parameter averages for the three trials and the root mean square error (RMSE) are shown in Table 2, along with the percent transfer for *Salmonella*. Post-contamination hold time, processing temperature and tomato slice thickness did not significantly ($P > 0.05$) impact the transfer rate (parameter B) or the overall percentage of salmonellae transferred. When the tomato surface was wet, a significantly lower ($P \leq 0.05$) transfer rate (-0.028 ± 0.002) was observed compared to dry tomatoes (-0.051 ± 0.002) with a significantly higher ($P \leq 0.05$) percentage of *Salmonella* transferred to wet ($12.2 \pm 2.4\%$) as opposed to dry tomatoes ($1.1 \pm 0.5\%$). When different tomato varieties were assessed, significantly lower ($P \leq 0.05$) transfer rates and *Salmonella* transfer percentages were observed for Rebelski and Bigdena as compared to Torero. When the tomatoes were washed for 2 min in tap water

before slicing, no significant differences in the transfer rate or transfer percentage were observed compared to the control. However, all 20 uninoculated tomatoes were negative for *Salmonella* when a 100 ppm chlorine wash treatment was applied for 2 min before slicing. The RMSE for all processing variables ranged from 0.17 to 0.56, which supported the exponential decay model.

Pathogen transfer during slicing of foods is a complex process. In this study, six variables were evaluated individually for their impact on *Salmonella* transfer during mechanical slicing of tomatoes. Except for surface wetness and tomato variety, no significant difference ($P > 0.05$) in the transfer rate (parameter B) or overall percent transfer was observed for the other four processing variables. These observations partially agree with those of Aarnisalo et al. (2007) who evaluated the impact of inoculum level, processing temperature and attachment time on *L. monocytogenes* transfer during slicing of salmon fillets (Aarnisalo et al., 2007). In these two studies, the wet and dry surfaces of inoculated tomatoes corresponded to the shorter (10 min) and longer (2.5 h) attachment times, respectively, in the salmon slicing study. In both of these studies, greater transfer was seen from wet as opposed to dry surfaces. However, in contrast to salmon slicing, changing the processing room temperature did not impact the extent of *Salmonella* transfer during tomato slicing. In both studies, the pathogen of interest decreased exponentially during slicing, leading to the development of corresponding transfer models for each scenario. However, *Listeria* transfer from an inoculated blade to salmon was far lower (0.00011 to 0.17%) than that seen for *Salmonella* in our tomato study (0.07 to 12.21%). These results were also likely influenced by the method of blade inoculation which differed between the two studies (direct inoculation with bacteria vs indirect

inoculation through tomato slicing), in addition to other product properties such as pH, fat, and protein levels.

The tomato variety significantly impacted *Salmonella* transfer during slicing. Further analysis of the three tomato varieties (Torero, Rebelski and Bigdena) indicated that Torero tomatoes which yielded greater transfer had a tougher texture and lower water content compared to the other two varieties (data not shown). The free liquid released potentially “washed off” the *Salmonella* cells transferred to the slicer blade from the first inoculated tomato, thus decreasing the extent of transfer. These observations are also supported by the earlier work of Vorst et al. (2006b) who reported less transfer of *L. monocytogenes* during mechanical slicing of delicatessen turkey breast compared to salami with similar findings also reported for delicatessen hams containing different levels of water (unpublished data).

In summary, the order in which different varieties of tomatoes are sliced, along with the degree of ripeness, are important considerations when attempting to minimize potential cross-contamination during slicing. When possible, the tomato surface should also be dry before slicing. Given ongoing concerns regarding the safety of sliced tomatoes, the slicer should be intermittently (between breaks and shift changes) disassembled, cleaned and sanitized to avoid the potential spread of bacterial pathogens during extended use. Such practical guidelines should be of interest to the fresh-cut produce industry with these findings also useful in the development of future science-based transfer models for risk assessments.

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519 Table 1. Six variables evaluated for their impact on *Salmonella* transfer.

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Variable	Control	Condition 1	Condition 2
Post-contamination hold time (min)	0	30	--
Tomato surface wetness	Dry	Wet	--
Processing temperature (°C)	23	10	4
Tomato slice thickness (")	1/4	3/16	3/8
Tomato variety	Torero	Rebelski	Bigdena
Wash treatment	No wash	Tap water	Chlorine

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Table 2. Transfer model parameters and percent transfer of *Salmonella* for six processing variables.

Processing variables		A ± SE	B ± SE	RMSE ¹	% Transfer ± SE
Post-contamination hold time (min)	0	4.74 ± 0.17	-0.051 ± 0.002A ²	0.42	1.1 ± 0.5a ³
	30	4.84 ± 0.14	-0.044 ± 0.007A	0.38	1.0 ± 0.5a
Tomato surface wetness	Dry	4.74 ± 0.17	-0.051 ± 0.002B	0.42	1.1 ± 0.5b
	Wet	6.78 ± 0.03	-0.028 ± 0.002A	0.17	12.2 ± 2.4a
Processing temperature (°C)	23	4.74 ± 0.17	-0.051 ± 0.002A	0.42	1.1 ± 0.5a
	10	3.32 ± 0.55	-0.060 ± 0.051A	0.33	0.1 ± 0.1a
	4	4.33 ± 0.76	-0.076 ± 0.038A	0.35	0.6 ± 0.3a
Tomato slice thickness (")	1/4	4.74 ± 0.17	-0.051 ± 0.002A	0.42	1.1 ± 0.5a
	3/16	4.77 ± 0.05	-0.036 ± 0.003A	0.25	0.7 ± 0.2a
	3/8	3.59 ± 0.34	-0.024 ± 0.012A	0.56	0.2 ± 0.1a
Tomato variety	Torero	4.74 ± 0.17	-0.051 ± 0.002B	0.42	1.1 ± 0.5a
	Rebelski	3.32 ± 0.12	-0.011 ± 0.006A	0.45	0.3 ± 0.0b
	Bigdena	3.28 ± 0.46	-0.015 ± 0.015A	0.46	0.1 ± 0.1b
Wash treatment	No wash	4.74 ± 0.17	-0.051 ± 0.002A	0.42	1.1 ± 0.5a
	Tap water	4.56 ± 0.21	-0.068 ± 0.012A	0.37	2.7 ± 1.5a
	Chlorine	--	--	--	0.0 ± 0.0

¹ RMSE: root mean square error for the exponential decrease model.

² Means with different capital letters for the same processing variable are significantly different ($P \leq 0.05$).

³ Means with different letters for the same processing variable are significantly different ($P \leq 0.05$).

549 *Figure 1. Components of the manual slicer 1A: (a) blade; (b) back plate, (c) bottom plate*
 550 *and electric slicer 1B: (a) blade, (b) pusher, and (c) side plate.*

551 *Figure 2. Salmonella distribution (mean $\pm$ SE) on nine tomato slices from inoculated and*
 552 *uninoculated tomatoes (1: top slice is the blossom end; 9: bottom slice is the stem end).*
 553 *Means with different capital letters for inoculated tomato slices are significantly different*
 554 *($P \leq 0.05$). Means with different letters for uninoculated tomato slices are significantly*
 555 *different ($P \leq 0.05$).*

556 *Figure 3. Salmonella distribution (mean $\pm$ SE) on different components of the slicer*
 557 *(manual (3A) and electric slicer (3B)) before and after slicing 20 uninoculated tomatoes.*
 558 *Means with different capital letters for surface population before slicing 20 uninoculated*
 559 *tomatoes are significantly different ($P \leq 0.05$). Means with different letters for surface*
 560 *population after slicing 20 uninoculated tomatoes are significantly different ($P \leq 0.05$).*

561 *Figure 4. Salmonella transfer from one inoculated tomato to twenty uninoculated*
 562 *tomatoes via the slicer (control). The discrete data points represent the observed data for*
 563 *three trials, respectively. The corresponding line represent the predictive line based on*
 564 *the model. “+” and “-” represent “Salmonella positive” and “Salmonella negative” for*
 565 *corresponding tomatoes respectively. “LOD” represents “limit of detection”.*

566 *Figure 5. Salmonella transfer (mean $\pm$ SE) through different parts of manual (A) and*
 567 *electric slicer (B) during slicing.*

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Figure 1

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Figure 2

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Figure 3

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3A

3B

Figure 4

Figure 5

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