CPS CENTER for PRODUCE SAFETY

CPS 2010 RFP
FINAL PROJECT REPORT

Project Title
Pathogen transfer risks associated with specific tomato harvest and packing operations

Project Period
January 1, 2010 – December 31, 2012

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Objectives

1. Determine (i) transfer coefficients of *Salmonella* between inoculated clean and dirty clothes to tomatoes; (ii) transfer coefficients of *Salmonella* during subsequent touches of tomatoes to inoculated clean and dirty cloths; and (iii) fate of *Salmonella* on inoculated clean and dirty cloths over typical time periods at typical temperatures between cloth cleaning.

2. Determine (i) transfer coefficients between inoculated dirty, used tomato cartons and *Salmonella* stored for various times at temperatures; and (ii) the fate of *Salmonella* on used tomato cartons in the presence of dirt, debris, and tomatoes at various temperatures and relative humilities.

3. Develop a written comprehensive review covering food safety research and tomatoes.

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UCANR/USDA NIFA grant #2010-34608-20768 (SA7661) and the Florida Tomato Committee

FINAL REPORT

Abstract
The establishment standards related to removal of dirt and debris from tomato fruits during field pack operations and re-use of tomato cartons in re-pack operations within the Tomato Good Agricultural Practices and Best Management Practices document is essential for the responsible harvesting, handling and packing of fresh tomatoes. Little data which quantify cross-contamination risks specific to practices used during harvest and packing tomatoes exist. Laboratory based experiments have been completed to evaluate transfer coefficients (TC) between *Salmonella* inoculated clean and dirty cloths and tomatoes, the fate of *Salmonella* on clean and dirty cloths, transfer coefficients between dirty used tomato cartons and *Salmonella* and the fate of *Salmonella* on dirty used tomato cartons. *Salmonella* does not survive well on 100% cotton cloths, regardless of the presence of debris. The highest transfer rates from inoculated tomato to cloths occurred when the inoculum was wet, regardless of cloth condition. Contact time and degree of rubbing did not significantly affect transfer. Transfer from inoculated cloths to tomatoes was highest when the tomato was touched with the inoculated clean cloth, without rubbing (TC=0.48 ± 0.1). Transfer was greatly reduced when tomatoes were contacted on inoculated dirty dry (TC=0.002) or wet (TC=0.007) cloths. Detectable levels of *Salmonella* were not transferred from inoculated cloths to tomatoes 1 or 24 h post-inoculation, however upon enrichment; *Salmonella* could transfer up to 25 tomatoes from inoculated cloths dried for 0 and 1 h, regardless of cleanliness. *Salmonella* populations decreased following inoculation onto new, used, and dirty cartons by 2-3 log units during 24 h drying regardless of storage temperature; the presence of debris enhanced survival at 12°C. In general, the highest transfer rates occurred with wet inoculum, regardless of carton type or temperature storage. The highest TC was a wet, inoculated tomato stored 7 days at 25°C (TC=14.7). Increasing contact time decreased TCs for new cartons, but increased TCs for used and dirty cartons. A greater percentage of *Salmonella* transferred from tomatoes to cartons than from cartons to tomatoes, regardless of carton type or storage temperature. Comprehensive reviews have been published as EDIS documents from the University of Florida extension service. *Salmonella* transfer between tomatoes, tomato cloths and cartons is highly dependent on moisture, with increased levels of moisture increasing transfer, highlighting the importance of harvesting and packing dry tomatoes. Transfer also varies between new, used and dirty tomato cartons, indicating cross-contamination risks may increase under some conditions when cartons are dirty or reused.

Background
The large multi-state outbreaks that have been linked to tomatoes suggest that these products are either widely contaminated in the field prior to or during harvest, were subject to extensive cross contamination during or after harvesting, and/or underwent significant amplification of the pathogen levels during post-harvest processing and distribution (Lynch et al., 2009). Laboratory simulated and field trials have identified several factors that could impact the contamination of tomatoes during harvest such cross contamination via equipment, or handling by farm workers (Taormina et al., 2009)

When tomatoes are harvested, pickers place the fruits into plastic buckets that are carried to field trucks and emptied into pallet bins or gondolas. Tomato harvesters will frequently rub tomatoes on clothing or with cloths to aid in the removal of plant debris or dirt in the field. Tomatoes are then transported to the packinghouse and dumped into a chlorinated dump tank. After tomatoes exit the dump tank, they travel over a series of conveyor belts where they are sorted and eventually packed into corrugated boxes. These boxes can be stored in the packing house and sold directly. Tomatoes can also be purchased by repacking operations, where they are dumped into another chlorinated dump tank and re-sorted for size or color. In many repack operations, it is common to re-use the corrugated boxes from the primary packing houses to repack the tomatoes into. The reuse of packaging boxes can significantly complicate the traceability of tomatoes during outbreak investigations.

Within the Tomato Good Agricultural Practices (T-GAPs), specific guidance's exist for certain parts of harvesting and processing tomatoes. The T-GAPs document specifically states dirt and debris should be removed from tomatoes to the degree possible in the field. This has resulted in adoption of multiple approaches including wiping tomatoes on shirts or rags in the field. No specifics are given on how this should be done, and no current data exists to explore the food safety risks that may be associated with this process. While specific metrics are given to prevent the use of final packaging containers such as corrugated boxes during harvesting or packing in the field (T-GAPs Tomato Harvesting 1.b.ii), and to ensure any container used to hold tomatoes is checked for cleanliness prior to use (T-GAPs Tomato Harvesting 1.b.i), no such metrics exist for the use or reuse of corrugated boxes during final packing operations. The lack of specific metrics result in a reliance on individual company SOPs, specific for their procedures and location.

Failure of companies to adequately address the food safety risks related to debris removal in the field or re-use of boxes during packing my allow for fruit to cloth to fruit or box to fruit cross-contamination during harvesting and repacking remains a concern for the tomato industry. Such transfer potential may increase the risk associated with adherence of surviving pathogens to natural openings, harvest-induced microwounds, or pathogen internalization if conditions to promote this event are present.

The goal of this proposal is to identify and validate quantitative metrics in tomato field and repacking operations ensure the effectiveness of food safety controls during these operations. Specifically, to develop more specific metrics for: (i) use of cloths to wipe of dirt or remove debris from tomato fruits in field pack operations; (ii) re-use of tomato cartons in repack operations; and (iii) development of a written comprehensive review covering food safety research and tomatoes.

Research Methods and Results

Tomatoes: All tomatoes were purchased from local packinghouses or supermarkets, unwaxed, field tomatoes were used for cloth experiments, while washed and waxed tomatoes were used for carton experiments. Tomatoes were at stored at 4°C prior to use and left overnight at ambient temperature (18-23°C) prior to inoculation.

Pathogen: Five rifampicin resistant *Salmonella* strains were used including: *Salmonella* Michigan (MDD 251; Cantaloupe outbreak), *Salmonella* Montevideo (MDD 236; Almond survey), *Salmonella* Newport (MDD 314; Tomato outbreak), *Salmonella* Poona (MDD 237; Cantaloupe outbreak), and *Salmonella* Saintpaul (MDD 295; Orange juice outbreak). The modification of parent strains to rifampicin resistance is necessary to allow for easy identification of the inoculated strains in the presence of high natural levels of background microflora on tomatoes.

Inoculum preparation: Frozen stock cultures of each strain were streaked onto tryptic soy agar (TSA) with added rifampicin (TSAR) and isolated colonies from these plates were sub-cultured twice in tryptic soy broth (TSB) with added rifampicin (TSAR). Cultures were pelleted and washed twice in 0.1% peptone water. Equal volumes of the washed pelleted cultures were combined repelleted and then suspended in an equal volume of inoculum carrier (0.1% peptone).

Inoculation of tomatoes: Tomatoes were inoculated by distributing in 6-8 spots 10 µl of the prepared inoculum cocktail onto the sample. Controls were inoculated with 0.1% peptone. Inoculated samples were dried (dependent on variables) in a biosafety cabinet and will be subsequently stored at the test temperature and under the test conditions.

Pathogen recovery: Tomatoes or other surfaces were placed in a 19 by 14 cm Whirl-Pak filter bag (Nasco, Modesto, Calif.) with 20 ml of 0.1% peptone. Tomato samples were subjected to a "rub-shake-rub" method for 60 s, while intermediate surfaces were stomached at the high-speed setting for 1 min (Stomacher 400, Seward, Thetford, UK). Dilutions were plated on non-selective (tryptic soy agar) and selective (Bismuth Sulfite Agar) agar containing 0.1% pyruvate and rifampicin. To increase the limit of detection, 1 ml from the lowest dilution was spread over four plates (0.25 ml/plate). Plates were incubated at the appropriate time and temperature prior to enumeration. If population levels fall below the limit of detection, standard enrichment protocols (FDA-BAM) will be performed.

Transfer coefficients: Average transfer coefficients were calculated by the following equation: $TC = P_G/P_C$ where TC is the transfer coefficient, P_G is the pathogen population enumerated from the previously uncontaminated surface in CFU/surface and P_C is the pathogen population enumerated from the initial surface source of the pathogen in CFU/surface. Prior research has shown that the logarithm of TC is normally distributed (Chen at al., 2001).

Data Analysis and Interpretation: Appropriate statistical analysis (e.g., ANOVA) was performed using appropriate SAS to identify significant differences ($P < 0.05$) among treatments.

Objective 1.i: Transfer coefficients between cloths and tomatoes
Laboratory-based studies using unwashed mature green were set up to evaluate pathogen transfer coefficients from clean and dirty cloth (100% cotton) to the surface of tomatoes. Following experimentation evaluating soil, stem and leaf residuals, and water, a standard protocol to create a dirty cloth was established by rubbing a mature tomato leaf on the cloth for 20 s, and used either immediately (wet) or dried for 1 h under the laminar flow hood before conducting transfer studies. After inoculation, three different drying times (0, 1 and 24 h) were evaluated. Following experimentation of three contact times (5, 10 and 20 s) where the cloth or tomato were touched on to the inoculum for 5, 10 or 20 s, with mild rubbing, 20 s contact time was selected and was used to test different degrees of rubbing. Transfer was evaluated from inoculated cloth to tomatoes and inoculated tomatoes to cloths, with inoculums dried for 0 (wet), 1 or 24 h at ambient temperature. Contacted tomatoes/cloths were in contact for 20 s subjected to three different degrees of rubbing (none, mild and vigorous). Each experimental treatment will be replicated 10 times, and pathogens will be enumerated as previously described.

Results from inoculated green tomatoes to cloths and from inoculated cloths to green tomatoes, with various degrees of rubbing are displayed in figures 1 and 2 below. Regardless of transfer direction or degree of rubbing, the most significant factor influencing transfer is the degree of inoculum drying, with very little transfer occurring at or following 1 h of inoculum drying. The cleanliness of the cloth and the degree of rubbing did not influence the transfer of *Salmonella* from inoculated tomatoes to cloths (figure 1).

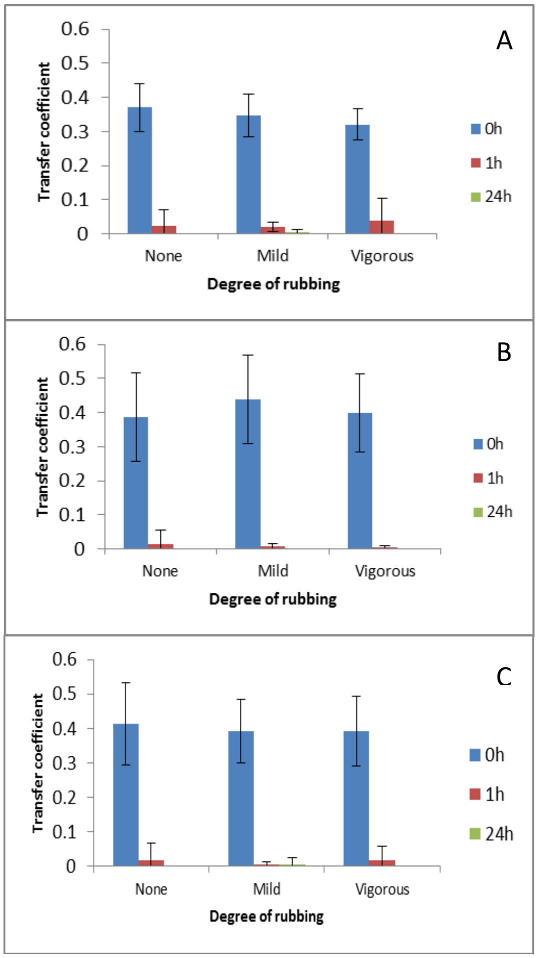


Figure 1. Transfer coefficients from inoculated tomatoes to (A) clean, (B) dirty wet, and (C) dirty dry cloth with three different degrees of rubbing (none, mild and vigorous), following inoculation drying for 0, 1, or 24 h (n=10).

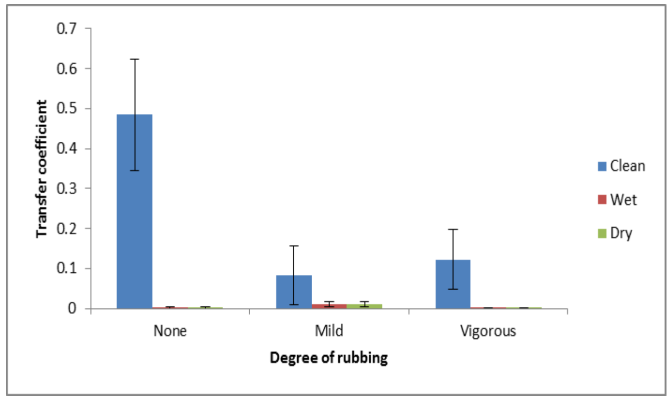


Figure 2. Comparison of transfer coefficients from inoculated cloth (clean (blue), dirty wet (red), and dirty dry (green)) to tomatoes at three degrees of rubbing (none, mild, and vigorous), after the inoculum was dried for 0 h.

When *Salmonella* transfer was evaluated from inoculated cloths that had been allowed to dry for 1 or 24 h, populations were not detectable by plate count, thus enrichments were performed. Between 10 and 30% of cloths were positive for Salmonella following 1 h of inoculum drying, while none of the clean, dirty wet, dirty dry cloths (0/30 for each, data not shown), were positive for *Salmonella*.

The transfer of *Salmonella* from inoculated cloths to tomatoes when wet (0 h inoculum drying) appears to be influenced by how much inoculum was absorbed into the clot. For clean cloths, much of the inoculum beaded up and was not immediately absorbed and able to transfer to the tomato; as rubbing occurred, more inoculum was absorbed, and transfer decreased (figure 2, blue bars). When dirty wet or dry cloths were inoculated, the inoculum was rapidly absorbed into the dirt matrix.

Objective 1.ii: Transfer coefficients of *Salmonella* during subsequent touches of tomatoes to inoculated clean and dirty cloths

Inoculated clean and dirty (wet and dry) cloths were subsequently touched with 25 tomatoes, one after another, after 0 h of inoculum drying, results are presented in table 1, below. As detectable levels of *Salmonella* were not present on all the samples, enrichment was performed on all 25 tomatoes, and is presented in Appendix A, below. After 1 of drying, there was no detectible *Salmonella* present on transferred tomatoes, enrichments were performed, results are presented in Appendix B below. Although in many cases, no populations were detectable by direct plating, for wet and dry dirty cloths, dried for 0 and 1 h, *Salmonella* was transfer detectable by enrichment through 25 tomatoes. No *Salmonella* was detected on any tomatoes touched with cloths where inoculums were dried for 24 h.

Table 1. Comparison of transfer coefficients from inoculated cloths (clean, dirty wet and dirty dry) to 25 tomatoes subsequently touched to an inoculated cloth where the inoculum was dried for 0 h (n=9).

Tomato no.	Clean Cloth TC	Dirty Wet Cloth TC	Dirty Dry Cloth TC
T1	0.09 ± 0.15	0.00 ± 0.00	0.04 ± 0.07
T2	0.03 ± 0.06	0.00 ± 0.00	0.03 ± 0.06
T3	0.00 ± 0.00	0.00 ± 0.00	0.03 ± 0.06
T4	0.03 ± 0.09	0.00 ± 0.00	0.00 ± 0.00
T5	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00
T6	0.00 ± 0.00	0.00 ± 0.01	0.01 ± 0.01
T7	0.00 ± 0.00	0.00 ± 0.02	0.00 ± 0.00
T8	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.01
T9	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00
T10	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00
T11	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.01
T12	0.00 ± 0.00	0.00 ± 0.01	0.01 ± 0.02
T13	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00
T14	0.00 ± 0.00	0.01 ± 0.02	0.00 ± 0.00
T15	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00
T16	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00
T17	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T18	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T19	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T20	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T21	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T22	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T23	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00
T24	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T25	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Objective 1.iii: Fate of *Salmonella* on inoculated clean and dirty cloths

Clean and dirty cloths (as described in objective 1.i) were inoculated with *Salmonella* (10^4) and stored 15, 25, and 35°C at 40-45% or 80% relative humidity for up to 7 days. Following the initial enumeration, populations were not detectable by plate count at any temperature. Enrichments were performed to evaluate *Salmonella* survival on cloths stored at 80% for 7 days and are presented below in Table 2. Survival of S*almonella* populations, regardless of debris presence, was enhanced at 15°C when compared to 25 or 35°C.

Table 2. Survival of *Salmonella* on inoculated cloth (clean and dirty) incubated 7 days at 10, 25, and 35°C and 80% RH; data represents the number of positive cloths (n=6) following Salmonella enrichment.

	Time	Temperature (°C)		
Cloth	(days)	15	25	35
Clean	0	6/6	6/6	6/6
	1	6/6	6/6	6/6
	3	6/6	6/6	4/6
	5	6/6	6/6	4/6
	7	6/6	1/6	0/6
Dirty	0	6/6	6/6	6/6
	1	6/6	6/6	6/6
	3	6/6	3/6	2/6
	5	6/6	6/6	1/6
	7	6/6	0/6	1/6

Objective 2.i: Transfer coefficients between dirty used tomato cartons and tomatoes

Laboratory-based studies using mature green and red waxed tomatoes were set up to evaluate pathogen transfer coefficients from dirty, used tomato cartons and tomatoes. Following experimentation evaluating soil, stem and leaf residuals, internal tomato debris and tomato wax, a standard protocol to create a dirty tomato cartons was established using 250 g of internal tomato debris from the locular cavity and 50 g of sandy soil, and mixing in a food processor for 1 min. Standard quantities of debris were painted onto used cartons and allowed to dry overnight. Transfer was evaluated from inoculated cartons to tomatoes and from inoculated tomatoes to cartons, with inoculums dried for 0 (wet), 1 or 24 h at ambient temperature. Contacted tomatoes/cartons were subjected to three contact times 0 (touch), 1 and 7 days and stored at either 12 or 25°C. Each experimental treatment will be replicated 10 times, and pathogens will be enumerated as previously described.

Results from inoculated cartons to green tomatoes at 12°C are displayed in figure 3 and 4, below. Further tables and figures of transfer from inoculated tomatoes to cartons at12°C (Appendix C and D), results at 25°C (Appendix E, F, G, and H) on red tomatoes (Appendix I and J), and comparing inoculum concentrations (Appendix K and L) are included in the appendices.

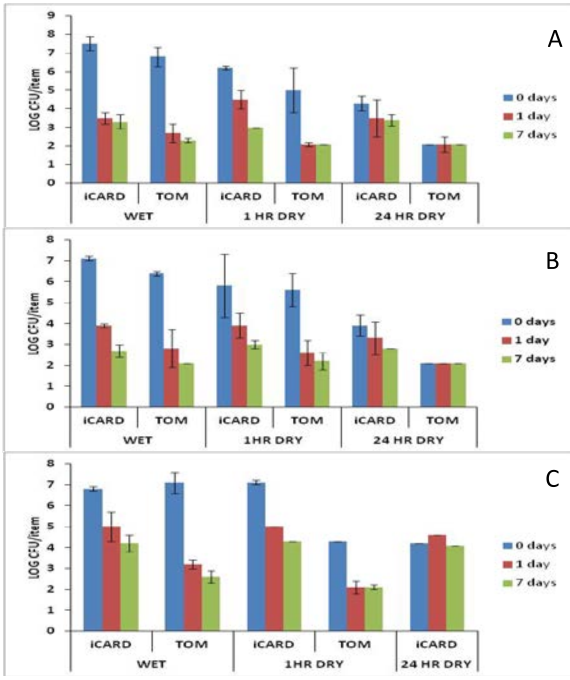


Figure 3. Transfer of *Salmonella* from inoculated new (A), used (B) and dirty (C) cartons to tomatoes at 12°C (n=10).

Under all conditions tested, the transfer of *Salmonella* to/from tomatoes from used or dirty cartons was greater than or equal to that from new cartons. The worst case for *Salmonella* transfer from new cartons is under wet conditions with short contact times. The worst case for *Salmonella* transfer for used cartons is under wet conditions with a long contact time (0 h dry, 7 d contact time, 25°C), where there was the equivalent of 1470% transfer, which is 16 times higher than from a new carton. The worst case for Salmonella transfer for dirty cartons is also under wet conditions (0 and 1 h dry).

The greatest variability in transfer is seen following a 1 h drying time in all conditions. This is likely because of the variable moisture remaining in the inoculum, and may be representative of variable moisture during tomato packing.

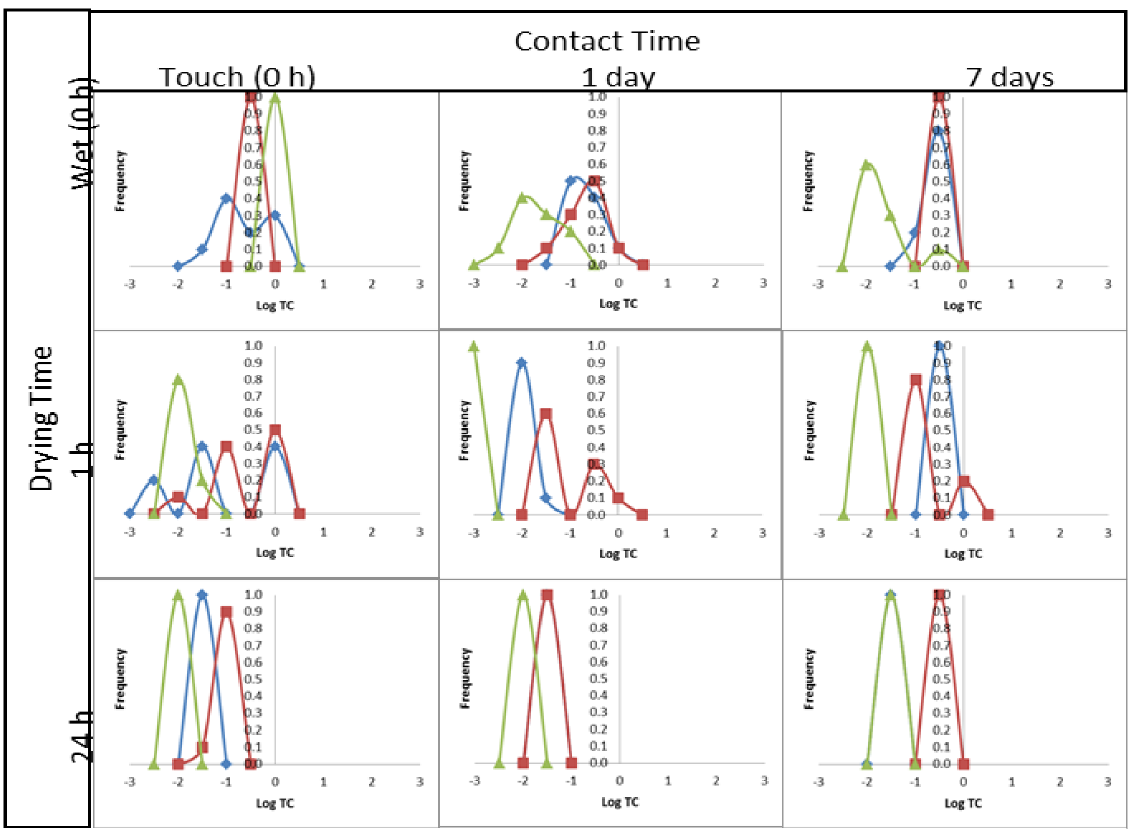


Figure 4. Distribution of transfer coefficients (log TC) of *Salmonella* from inoculated new (blue diamond), used (red square) and dirty (green triangle) cartons to tomatoes at 12°C (n=10).

Objective 2.ii: Fate of *Salmonella* on used tomato cartons

Used tomato cartons (clean, used and dirty as described in objective 2.i) were inoculated with *Salmonella* and stored at 12 and 25°C, for up to 7 days. Samples were enumerated as described above, and are included in figure 5.

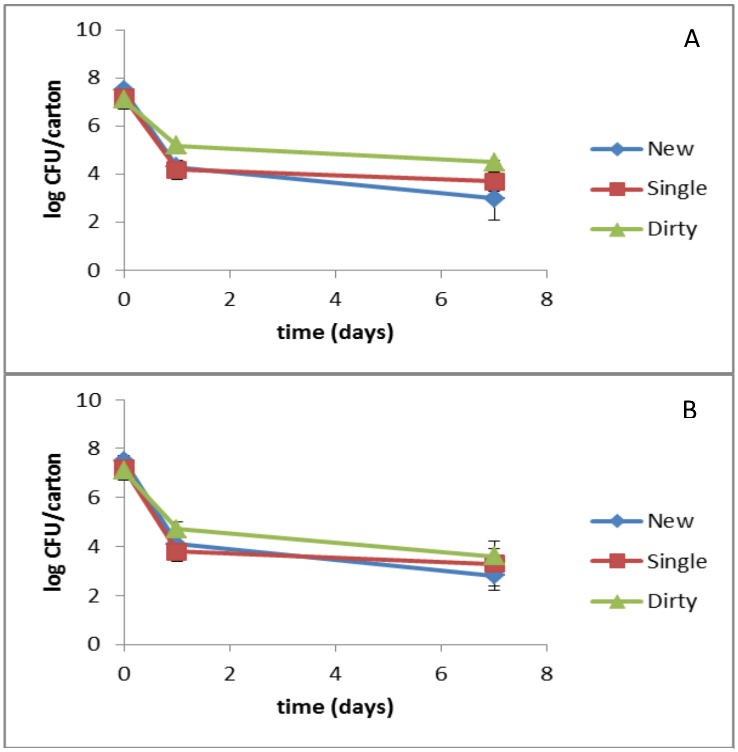


Figure 5. Fate of *Salmonella* populations on new (blue diamond), used (red square) and dirty (green triangle) cartons held at (A) 12 and (B) 25°C.

Salmonella populations significantly declined under all conditions on all cartons within 24 h. Following the initial decline, populations stabilized and no further decline was seen.

Within 24 h, population declines on the new and used cartons were significantly greater than those on dirty cartons at both 12 and 25°C.

Following 7 days of storage at 12°C, *Salmonella* populations on dirty cartons are significantly higher than those on clean or used cartons.

No significant differences in *Salmonella* populations are present following 7 days of storage at 25°C.

Objective 3. Tomato Food Safety Review.

Two comprehensive reviews, titled "Growth, reduction and survival of bacteria on tomatoes" and "Outbreaks of foodborne disease associated with tomatoes" have been published as EDIS documents from the University of Florida extension service, and are freely available online. This and additional information including preharvest factors is being synthesized into a review peer reviewed manuscript, targeted for publication in Critical Reviews in Food Science.

Outcomes and Accomplishments

The outcomes of this research have been previously described in the above methods and results section. All objectives have been met and data generated by the laboratory based experiments can be used to develop scientifically-based metrics on how debris from tomatoes can be removed without increasing the relative food safety risk, and how tomato cartons can be re-used safely in repacking operations.

Our original hypothesis in the proposal was that the use of contaminated clean or dirty cloths in the field during tomato harvest to eliminate debris effectively increased the risk of widespread contamination. In general, high levels of Salmonella do not survive well on clean or dirty cloths, with the highest survival seen at lower temperatures. *Salmonella* movement between cloths to tomatoes, is highly dependent on moisture levels, with relatively low levels of *Salmonella* movement under dry conditions regardless of debris present. Although transfer levels are low, *Salmonella*, from a wet or 1 h dry inoculm, is able to contaminate at least 25 tomatoes that are touched with a contaminated clean or dirty cloth, indicating the potential for widespread low levels of contamination.

We also hypothesized that *Salmonella* survival on used tomato cartons is increased in the presence of dirt and debris and under cool, moist conditions. While no growth of *Salmonella* on tomato cartons was observed, populations inoculated onto dirty cartons and stored at 12°C for 7 days were significantly higher than those on new or used cartons, and those at all conditions stored at 25°C. The presence of debris on tomato cartons coupled with storage at temperatures below ambient, increases the survival of *Salmonella* on tomato cartons.

Finally, we hypothesized, that the re-use of dirty, contaminated packing containers would increase the risk of wide-spread tomato contamination. Under no conditions was the transfer of *Salmonella* to/from tomatoes from new cartons greater than that from used or dirty cartons. However, under a number of different scenarios, transfer from dirty cartons was less than from clean or used cartons. Thus, while the presence of debris on tomato cartons may increase the survival of *Salmonella* on these surfaces, the re-use of dirty cartons would not significantly increase the risk of *Salmonella* transfer to tomatoes.

The publication of two online, freely available, UF/IFAS EDIS publications allows all interested industry members an easily available summary of available tomato safety resources.

Summary of Findings and Recommendations

The following summarized the findings of this study.

1. *Salmonella* transfer between tomatoes, tomato cloths and cartons is highly dependent on moisture, with increased levels of moisture increasing transfer. To decrease risks associated with *Salmonella* transfer during tomato harvesting and packing, the presence of moisture on tomatoes, cloths and cartons should be minimized or avoided.

2. Salmonella does not survive at high levels on cloths, regardless of the presence of debris. Survival is enhanced by storage at cooler temperatures where populations may persist for up to 7 days. Use of cloths, without cleaning between days, may be a source of contamination for the subsequently harvested tomatoes.

3. *Salmonella* can transfer, at low levels, from clean and dirty cloths to at least 25 tomatoes subsequently touched with the same cloth. A contaminated cloth may be the source of contamination to multiple tomatoes touched with the cloth. Presence of debris on cloths did not significantly increases the risk of *Salmonella* transfer.

4. The presence of debris on used tomato cartons, especially when stored at cooler temperatures, increases the survival of *Salmonella*; however, *Salmonella* can survive on tomato packing cartons for at least seven days even in the absence of debris. Reused tomato cartons may be a source of contamination for the subsequent tomatoes packed in these cartons.

5. Under no conditions was the transfer of *Salmonella* from new tomato cartons greater than that from used or dirty cartons. Under some conditions, dirty containers transferred less *Salmonella* than new and used cartons; the presence of debris on used cartons does not significantly increase the risk of *Salmonella* transfer between cartons and tomatoes.

APPENDICES

Literature Cited

Chen, Y., Jackson, K.M. Chea, F.P. and Schaffner, D.W. 2001. Quantification and variability analysis of bacterial cross-contamination rates in the kitchen. J.Food Prot. 64:72-80.

Lynch, M., J. Painter, R. Woodruff and C. Braden. 2006. Surveillance for Foodborne-Disease Outbreaks — United States, 1998–2002.MMWR - Surveillance Summaries 55(SS-10):1-42.

Taormina, P.J., Beuchat, L.R., Erickson, M.C., Ma, L., Zhang, G., Doyle, M.P. (2009) Transfer of *Escherichia coli* O157:H7 to iceberg lettuce via simulated field coring. J. Food Prot. 72, 465-472.

Publications and Presentations

Peer Reviewed Publications (PDF's Attached)

Valadez, A.M., K.R. Schneider, M.D. Danyluk. 2012. Growth, reduction and survival of bacteria on tomatoes. EDIS Publication FSHN 12-06 http://edis.ifas.ufl.edu/fs190 (PDF Attached)

Valadez, A.M., K.R. Schneider, M.D. Danyluk. 2012. Outbreaks of foodborne disease associated with tomatoes. EDIS Publication FSHN 12-08 http://edis.ifas.ufl.edu/fs192 (PDF's Attached)

Abstracts funded, in part, by this grant:

Danyluk, M.D. 2012. Pathogen transfer risks associated with specific tomato harvest and packing operations – Transfer from cloth during harvest. Center for Produce Safety, Produce Research Symposium, p. 23.

Friedrich, L, K. Schneider, and M. Danyluk. 2012. Transfer potential of *Salmonella* between cardboard cartons and tomatoes. International Association for Food Protection 2012 Annual Meeting Abstract P-34. (PDF Attached)

Sreedharan, A., M.D. Danyluk, and K.R. Schneider. 2013. Determine the transfer coefficient of *Salmonella* between green tomatoes and cotton cloth used for debris removal in a laboratory model system. International Association for Food Protection 2013 Annual Meeting - *Submitted*

Oral Presentations funded, in part, by this grant:

Pathogen transfer associated with tomato specific packing operations. Ohio Produce Growers and Marketers Association Congress, Sandusky, OH, 2013.

Pathogen transfer risks associated with specific tomato harvest and packing operations – Transfer from Tomato Cartons. Center for Produce Safety, Produce Research Symposium, Davis, CA, 2012.

Risk Potential for Postharvest Transfer. Advanced topics in Microbial food Safety of Fresh Produce Workshop. UC Davis Alumni Center, Davis, CA and Gulf Coast Research and Education Center, Wimauma, FL, 2011

Budget Summary

Florida Tomato Committee - $18,800

Budget Category	Proposed	Spent	Difference
Salary/Wages	6,300	6,857.18	-557.18
Fringe Benefits	554	569.08	-15.08
Equipment	-	-	
Materials and Supplies	6,314	7,370.96	1,056.96
Travel	-	-	
Computer Cost	-	-	
Student Assistance	5,632	3,846.33	1,1785
All other costs	-	-	
Total	18,800	18,643.55	156.45

The remaining $153.45 will be used in part to cover Danyluk's travel to the 2013 CPS annual symposium.

UCANR/USDA NIFA grant #2010-34608-20768 (SA7661) Danyluk - $47,773

Budget Category	Proposed	Spent	Difference
Salary/Wages	38,757	30,505.21	8,251.79
Fringe Benefits	-	6,204.52	-6,204.52
Equipment	-	-	
Materials and Supplies	5,149	5,113.60	35.40
Travel	4,500	1,442.52	3,057.48
Computer Cost	-	-	
Student Assistance	-	-	-
All other costs	-	-	
Total	47,773	43,265.85	4,507.15

The remaining $4,507.15 will be used to cover Danyluk and Schneider's travel to the 2013 CPS annual symposium.

UCANR/USDA NIFA grant #2010-34608-20768 (SA7661) Schneider - $50,872

Budget Category	Proposed	Spent	Difference
Salary/Wages	42,872	41,388.9	1,483.10
Fringe Benefits	-	1,530.03	-1,530.03
Equipment	-	-	
Materials and Supplies	6,500	6,500	-
Travel	1,500	1,217.66	282.34
Computer Cost	-	-	
Student Assistance	-	-	
All other costs	-	-	
Total	50,872	50,636.59	235.41

The remaining $235.41 will be used to cover part of Schneider's travel to the 2013 CPS annual symposium.

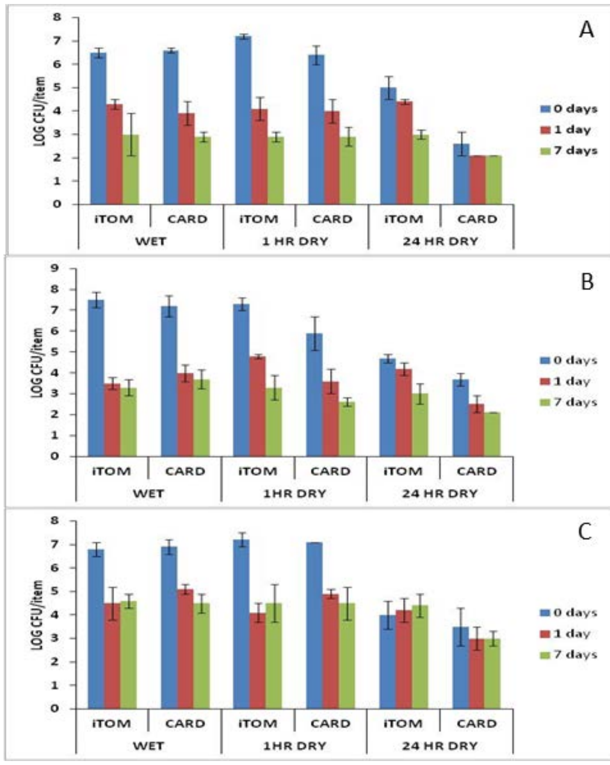
Tables and Figures (optional)

Appendix A. Presence of detectable levels of *Salmonella* on 25 tomatoes touched subsequently touched to inoculated cloths (clean, dirty wet and dirty dry) dried for 0 h for 20 s (n=9).

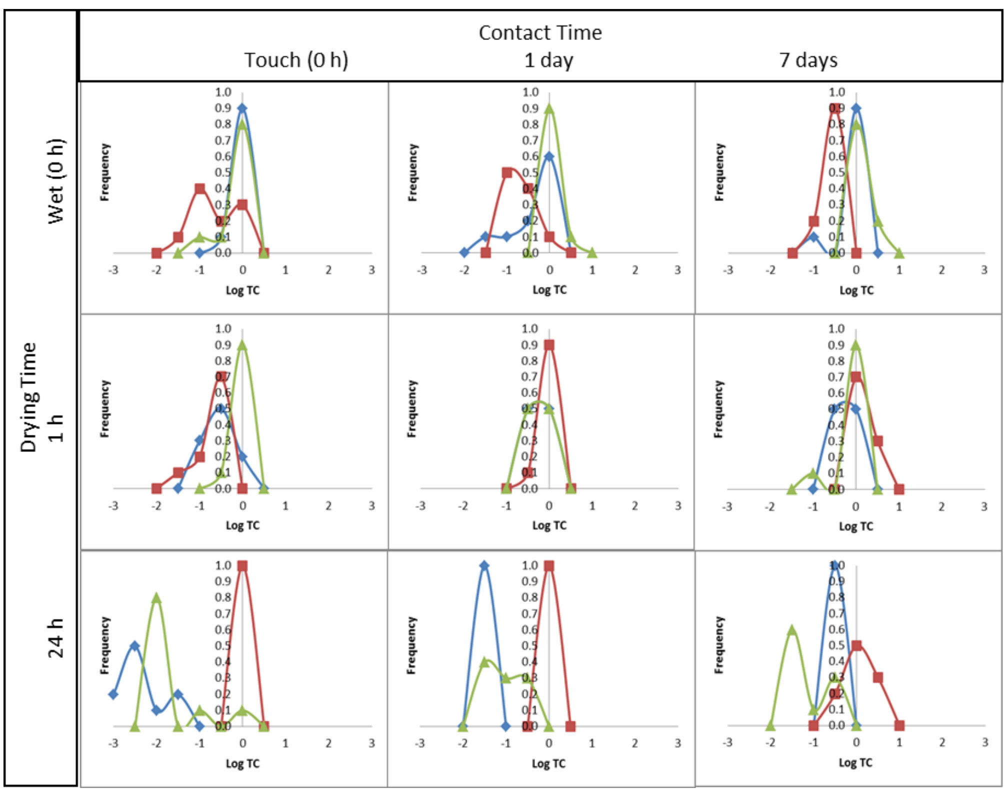
Tomato no.	Clean Cloth	Dirty Wet Cloth	Dirty Dry Cloth
T1	9/9	8/9	9/9
T2	8/9	9/9	7/9
T3	8/9	9/9	7/9
T4	7/9	9/9	7/9
T5	7/9	9/9	7/9
T6	5/9	8/9	8/9
T7	6/9	7/9	6/9
T8	3/9	6/9	7/9
T9	6/9	9/9	7/9
T10	7/9	8/9	8/9
T11	3/9	8/9	7/9
T12	6/9	9/9	7/9
T13	3/9	5/9	6/9
T14	4/9	5/9	9/9
T15	3/9	6/9	6/9
T16	4/9	5/9	8/9
T17	1/9	6/9	8/9
T18	3/9	5/9	7/9
T19	2/9	5/9	7/9
T20	2/9	6/9	5/9
T21	2/9	3/9	6/9
T22	3/9	4/9	8/9
T23	5/9	4/9	7/9
T24	2/9	6/9	6/9
T25	4/9	3/9	6/9

Appendix B. Presence of detectable levels of *Salmonella* on 25 tomatoes touched subsequently touched to inoculated cloths (clean, dirty wet and dirty dry) dried for 1 h for 20 s (n=9).

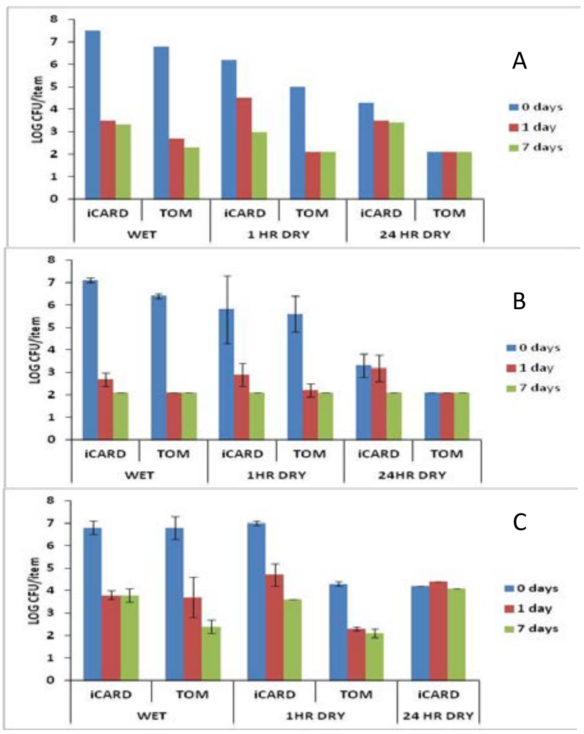
Tomato no.	Clean Cloth	Dirty Wet Cloth	Dirty Dry Cloth
T1	2/9	4/9	3/9
T2	5/9	4/9	7/9
T3	0/9	3/9	4/9
T4	3/9	4/9	3/9
T5	0/9	3/9	3/9
T6	2/9	3/9	4/9
T7	0/9	3/9	3/9
T8	1/9	2/9	4/9
T9	2/9	3/9	2/9
T10	1/9	3/9	2/9
T11	2/9	3/9	2/9
T12	3/9	1/9	4/9
T13	1/9	5/9	4/9
T14	2/9	1/9	4/9
T15	4/9	0/9	3/9
T16	0/9	2/9	3/9
T17	2/9	2/9	3/9
T18	2/9	2/9	1/9
T19	1/9	2/9	3/9
T20	0/9	5/9	1/9
T21	1/9	1/9	2/9
T22	1/9	3/9	1/9
T23	1/9	2/9	2/9
T24	0/9	1/9	3/9
T25	0/9	4/9	2/9



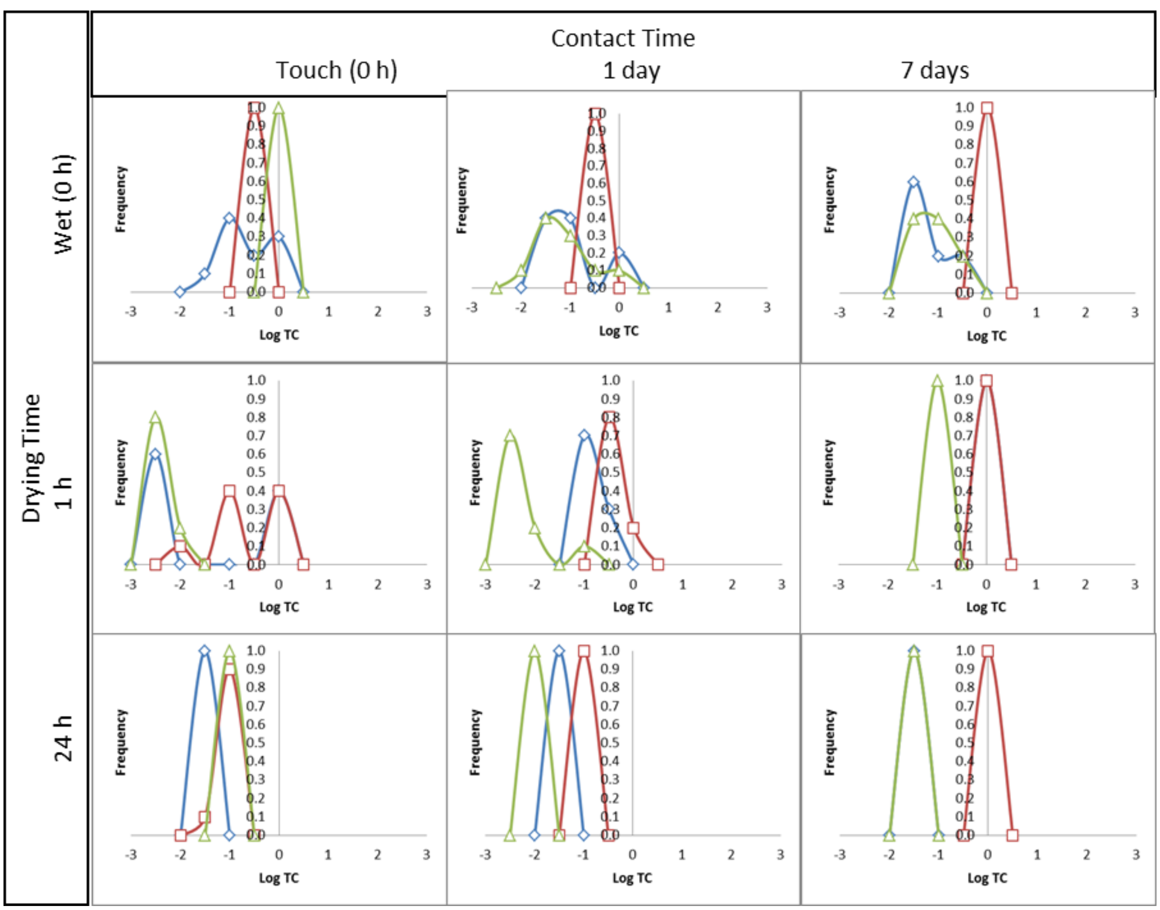
Appendix C. Transfer of *Salmonella* from inoculated tomatoes to new (A), used (B) and dirty (C) cartons to tomatoes at 12°C (n=10).



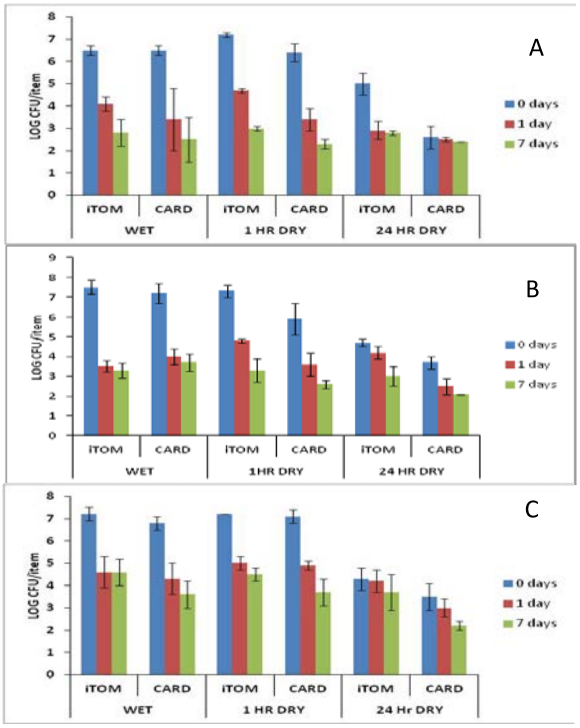
Appendix D. Distribution of transfer coefficients (log TC) of *Salmonella* from inoculated tomatoes to new (blue diamond), used (red square) and dirty (green triangle) cartons at 12°C (n=10).



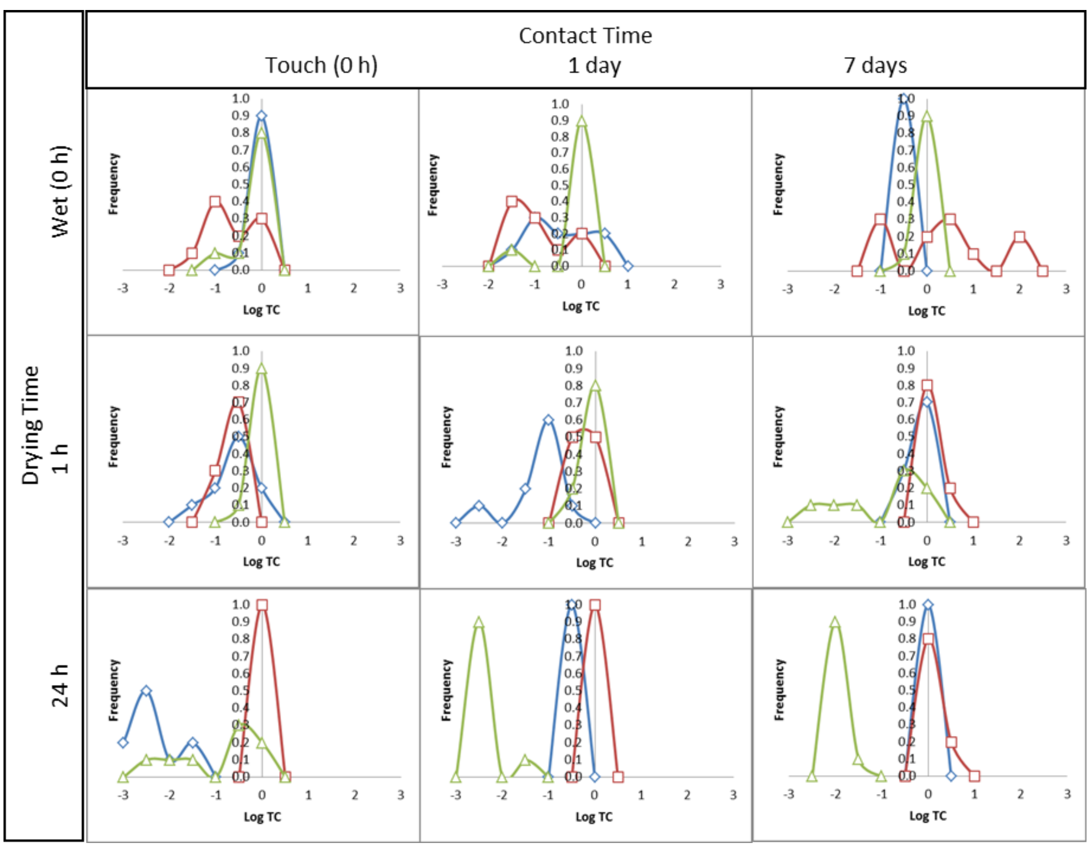
Appendix E. Transfer of *Salmonella* from inoculated new (A), used (B) and dirty (C) cartons to tomatoes at 25°C (n=10).



Appendix F. Distribution of transfer coefficients (log TC) of *Salmonella* from inoculated new (blue diamond), used (red square) and dirty (green triangle) cartons to tomatoes at 25°C (n=10).



Appendix G. Transfer of *Salmonella* from inoculated tomatoes to new (A), used (B) and dirty (C) cartons to tomatoes at 25°C (n=10).



Appendix H. Distribution of transfer coefficients (log TC) of *Salmonella* from inoculated tomatoes to new (blue diamond), used (red square) and dirty (green triangle) cartons at 12°C (n=10).

Appendix I. Transfer Coefficients between single use cartons and red tomatoes, stored at either 25 or 12 °C for up to 7 days (n=10).

	Inoculated carton → tomato						Inoculated tomato → carton					
	12°C			25°C			12°C			25°C		
Inoculum Drying	0 d	1 d	7 d	0 d	1 d	7 d	0 d	1 d	7 d	0 d	1 d	7 d
Wet	0.2	0.1	0.3	0.2	0.2	0.1	1.8	2.0	4.5	1.8	2.9	0.2
1 h	0.2	0.1	0.1	0.2	0.1	1.0	0.2	0.3	0.2	0.2	0.05	0.6
24 h	0.1	0.0	0.2	0.1	0.1	1.0	0.1	0.01	0.10	0.1	0	0.1

Appendix J. Transfer Coefficients between dirty cartons and red tomatoes, stored at either 25 or 12 °C for up to 7 days (n=10).

	Inoculated carton → tomato						Inoculated tomato → carton					
	12°C			25°C			12°C			25°C		
Inoculum Drying	0 d	1 d	7 d	0 d	1 d	7 d	0 d	1 d	7 d	0 d	1 d	7 d
Wet	0.5	0.1	0	0.5	0.2	0	0.7	1.0	2.0	0.7	0.6	1.0
1 h	0	0	0	0	0	0	0.6	0.4	1.1	0.6	0.5	0.4
24 h	0	0	0	0	0	0	0.2	0	0	0.2	0	0

Appendix K – Comparison of transfer between inoculated cartons and mature green tomatoes at 12°C at different inoculum concentrations and drying times (n=6)

	Single use cartons			Dirty cartons		
Inoculum	0 d	1 d	7 d	0 d	1 d	7 d
8 Log	0.3± 0.1	0.0± 0.0	4.5± 8.8	0.3 ± 0.1	1.0 ± 0.5	4.8 ± 4.6
5 Log	0.5± 0.2	25.1± 43	1.0 ± 0.0	0.3 ± 0.0	175 ± 112	0.3 ± 0.6

Appendix L – Comparison of transfer between inoculated cartons and tomatoes at 25°C at different inoculum concentrations (n=6)

	Single use cartons			Dirty cartons		
Inoculum	0 d	1 d	7 d	0 d	1 d	7 d
8 Log	3.2 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	3.3 ± 0.7	0.0 ± 0.4	0.1 ± 0.0
5 Log	0.2 ± 0.1	0.6 ± 0.5	0.8 ± 0.7	2.2 ± 0.2	3.3 ± 3.0	0.0 ± 0.0

Suggestions to CPS (optional)
None.

Growth, Reduction, and Survival of Bacteria on Tomatoes[1]

Angela M. Valadez, Keith R. Schneider, and Michelle D. Danyluk[2]

Fresh-market tomatoes are a popular commodity in homes and food service around the world. In the United States, fresh-market tomatoes are produced in every state, with commercial-scale production in about 20 states (USDA-ERS, 2009). In terms of consumption, the tomato is the nation's fourth most popular fresh-market vegetable behind potatoes, lettuce, and onions (USAD-ERS, 2009). In total, approximately 5 billion pounds of fresh tomatoes are eaten annually in the United States (CDC, 2007). In 2010, Florida produced 45% of the total U.S. value of fresh-market tomatoes behind California, Georgia, Virginia, and Tennessee (FDACS, 2012; USDA-ERS, 2008).

UF/IFAS Photo / Thomas Wright

Tomato producers are committed to taking proactive steps to ensure and enhance the safety of the food they produce, in addition to providing consistency in product quality and wholesomeness. Still, the inherent risks of contamination by foodborne pathogens present a challenge to the produce industry and regulators. Since fresh-market tomatoes are intended to be consumed fresh, there is no "kill-step" in the processing that would eliminate pathogens in the event of contamination (Maitland et al., 2011). As such, the concern for tomato safety in the United States will continue to grow as tomato consumption increases. Even with the advancements in food processing and food safety controls employed by tomato growers and packers, the risk for foodborne pathogens, including *Salmonella enterica*, to be linked to outbreaks of illness associated with tomato consumption still exists.

Fresh-produce handlers and processors have developed hazard analysis and critical control point (HACCP) plans where the critical control points (CCPs) are set in place

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to help reduce contamination and aid in the prevention of cross-contamination (Hedberg et al., 1999). Currently, however, there exists no technology proven to eliminate bacterial hazards in any fresh-market fruit or vegetable once contamination occurs (Maitland et al., 2011). Many processing methods have been studied, a number of which warrant further examination of their efficacy as the search continues for fail-safe intervention strategies to ensure the safety of fresh-market tomatoes.

This document, therefore, is intended to highlight current tomato safety related studies on the growth, reduction, and survival of bacteria on fresh-market tomatoes. Enclosed are evaluated bacterial studies on natural antimicrobials including carvacrol (oregano), eugenol, β-resorcylic acid, *trans*-cinnamaldehyde (cinnamon), allyisothiocynail (mustard and horseradish), thymol, and thyme oil; detergents including chlorine dioxide (C_lO_2), chlorine, carbon dioxide (CO_2), hydrogen peroxide (H_2O_2), sodium hypochlorite, ozone, sodium lauryl sulfate (SDS), tween80, acidified sodium chlorite (ASC), peroxyacetic acid (PAA), and calcinated calcium; and food processing studies including high pressure processing, irradiation, X-ray, and modified atmosphere packaging (MAP). Cross-contamination and shelf-life studies were also evaluated.

The table focuses primarily on three categories:

1. By tomato shape or variety, including Round, Roma, plum, cherry, grape, vine, unknown red, green mature, mixed green to red, and diced

2. By tomato composition, including the tomato stem, pulp, seeds, cotyledons, hypocotyls, and leaves

3. By bacteria, including acid-adapted and non-acid adapted *Salmonella* spp., *Shigella* spp., *E. coli* O157:H7, *Listeria monocytogenes, Erwinia carotovora*, and *Staphylococcus aureus*

The intended audience for this document includes tomato processors, researchers, and government officials interested in tomato safety:

- During evaluation of their current processing and sanitation facilities, tomato processors can use the table as a reference as they seek alternative or adaptable technologies.

- Researchers can use this table as a guide to innovate future experiments from current literature.

- Government officials can reference this table as current policies and regulations are evaluated and updated.

Limited studies in tomato sanitation, primarily focusing on salsa preparation and natural antimicrobial usage, are also featured here for home consumers. Overall, this tomato safety review serves as a reference for everyone concerned in the safety of fresh-market tomatoes.

Table 1

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Round red	Unknown	S. Typhimurium S. Newport S. Javiana S. Braenderup (CDC) Dip inoculated for 30 s at ~25°C and then dried overnight	Unspecified time collection points	Compared their lab-model (chicken replica), Pathogen Modeling Program, and ComBase	10 12.5 15 17.5 20 22.5 25 27.5 30 35	10^6 CFU/ml pre-inoculation 10^3 to 10^4 CFU/ whole tomatoes 10^2 CFU/g of cut tomato post-inoculation	Their lab model (chicken replica) was more favorable compared to the other models.	pH 4.0–4.5	Researchers developed a mathematical model to predict the growth rate of *Salmonella* (10^2 CFU/g to 10^8 CFU/g) on cut tomatoes as a function of incubation temp.	Pan and Schaffner, 2010
Roma Untreated (no washing or oiling)	No	S. Enteritidis ATCC 13076 S. Newport ATCC 6962 S. Typhimurium ATCC 14028 300 µl spot inoculated	(s) 2 4 6 10	ClO_2 + sterile tap water (ppm) (High) 20 10 5 (Low) 0 1 3 5 10	23	7 log CFU/ml *S. enterica*	**Reduction:** A full minute of contact with ClO_2 at 20 and 10 ppm was required to achieve a 5 log reduction of *S. enterica* on freshly spot-inoculated tomatoes. Immersing wet-inoculated tomatoes in water (0 ppm ClO_2) for 1 min alone reduced *S. enterica* by ~ 1.2 log CFU/cm^2. On inoculated fruit surfaces, populations decreased >3 log CFU/cm^2 during desiccation at 24°C for 24 h. Populations of air-dried *Salmonella* were not significantly reduced by ClO_2 at ≤20 ppm after 1 min.	For each treatment, nine inoculated tomatoes were immersed in 2 liters of ClO_2 or water for 20 to 60 s. Relative humidity 40–50%	The study investigated the sanitizing effects of a ClO_2 solution on *S.* enterica in water, on tomato surfaces, and between tomato loads.	Pao et al., 2007
Roma Untreated (unwashed or oiled)	No	S. Enteritidis ATCC 13076 S. Newport ATCC 6962 S. Typhimurium ATCC 14028 30 ml of inoculum was distributed evenly over two synthetic polyethylene roller brushes rotating at 85 revolutions per minute.	(s) 10 20 40 60	ClO_2 flow rate 5.0 ml/s	NA	Calculated brush contami- nation of 6.9 log CFU/cm^3	**Reduction:** Washing with ClO_2 at 5 ppm for 10 to 60 s reduced the transfer of *Salmonella* from revolving brushes to fruit surfaces by 4.5 to 5.0 log cycles. The presence of ClO_2 lowered the *Salmonella* transfer to runoff by 5.2 to 6.4 log cycles in comparison to using water alone.		The study tested the ability of ClO_2 at 5 ppm during spray washing of tomatoes to prevent *Salmonella* transfer from inoculated revolving brushes to fruit and wash runoff. Cross-contamination study.	Pao et al., 2009

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Roma Untreated (unwashed or oiled)	No	*S.* Enteritidis ATCC 13076 *S.* Newport ATCC 6962 *S.* Typhimurium ATCC 14028 Spot inoculated	Up to 60 sec	ClO_2 or water spray washing for up to 60 s at either low or high flow rate (5.0 or 9.3 ml/s per fruit, respectively). For wet-inoculum trials, six fruits marked with circles were brushed on inoculated revolving brushes without spraying to obtain cross-contamination for 60 s to simulate newly introduced contaminants.	NA	5.7 log CFU/cm² on fruit surfaces	**Reduction:** Washing with ClO_2 at a low flow rate for 10 to 60 s generated a 4.4 to 5.2 log CFU/cm² reduction of air-dried *Salmonella* on fruit surfaces.		The study tested the ability of ClO_2 at 5 ppm during spray washing of tomatoes to prevent *Salmonella* transfer from fruit surface to uninoculated revolving brushes.	Pao et al., 2009
Roma (*Lycopersicon esculentum*)	No	*S.* Montevideo *S.* Javiana *S.* Baildon (Purdue University Bacteria Collection) 100 µl spot inoculated Air dry, 1 h	(s) 0 10 30 60 120 180	ClO_2 gas (mg/liter) 0 2 5 8 10	25	1.0 x 10^8 CFU/ml	**Reduction:** Range of 1.16 to 5.53 log cfu/cm². The greatest reduction at 10 mg/l of ClO_2 and 180 s gave a post population 4.87 log cfu/cm².	Relative humidity 90–95%	ClO_2 parameters were then taken from this study that gave the optimal 3, 4, and 5 log reduction to select for optimal treatment conditions. The data 10 mg/l for 180 s gave a >5 log reduction.	Trinetta et al., 2010
Ripe Roma (*Lycopersicon esculentum* cv Roma)	Unknown	*S.* Anatum F4317 *S.* Stanley H0558 *S.* Enteritidis PT30 Submerged for 1 min	(h) 0 24 48 72	(kGy) 0.25 0.50 0.75 1.0 1.5	4	8.0 log CFU/ml	**Reductions** ranged from 3.3 to 4.2 log CFU/g (1.5 kGy). The irradiation sensitivity of *Salmonella* did not differ significantly with increasing refrigerated storage time. A 5-log reduction in dose would be approximately 1.9 to 2.4 kGy.	Cesium-137 at a dose rate of 4.89 kGy/h	The study evaluated the influence of refrigerated storage time on the efficacy of irradiation for removing *Salmonella* from sliced Roma tomatoes.	Niemira 2011

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Roma (*Lycopersicon esculentum*)	Unknown	A 3-serotype mixture of: S. Javiana S. Montevideo S. Typhimurium (ATCC or personal collection) Spot inoculated	NA	X-ray (# kGy/16 min) 0.1 0.5 0.75 1.0 1.5	22	Three or two strains of each bacterium were mixed with an equal volume to give approximately 10^{7-9} CFU/ml.	**Reduction:** ~3.7 log CFU/tomato reduction S. enterica was achieved by treatment with 0.75 kGy X-ray, respectively. More than a 5 log CFU/tomato reduction was achieved at 1.0 or 1.5 kGy X-ray for all tested pathogens.	Relative humidity 55–60%	Inactivation of inoculated *Salmonella* enterica on whole Roma tomato surfaces.	Mahmoud, 2010
Roma (*Lycopersicon esculentum*)	Unknown	A 2-strain mixture of S. flexneri ATCC 9199 and ATCC 12022 Spot inoculated	NA	X-ray (#kGy/16 min) 0.1 0.5 0.75 1.0 1.5	22	Three or two strains of each bacterium were mixed with an equal volume to give approximately 10^{7-9} CFU/ml.	**Reduction:** ~3.6 log CFU/tomato reduction of S. flexneri was achieved by treatment with 0.75 kGy X-ray, respectively. More than a 5 log CFU/tomato reduction was achieved at 1.0 or 1.5 kGy X-ray for all tested pathogens.	Relative humidity 55–60%	Inactivation of inoculated *Shigella flexneri* on whole Roma tomato surfaces.	Mahmoud, 2010
Plum	Wax was washed off with 70% ethanol followed by DI wash	S. Montevideo S. Poona S. Newport v. Baildon S. Braenderup S. Saintpaul (University of Georgia – L. Beuchat) 100 µl spot inoculated, held to dry for 1 h at 23°C	15 s 1 min 3 min	DI (control) Chlorine (100 ppm) Carvacrol (0.25 and 0.75 %) Trans-cinnamaldehyde (0.5 and 0.75%) Eugenol (0.25 and 0.75%) b-resorcylic acid (0.75 and 1.0 %)	25°C in water bath shaker	10^8 CFU/ml before inoculation and 10^7 CFU/ml post inoculation	**Reduction:** ~2 log CFU/ml for DI ~4 log CFU/ml for Cl ~7 log CFU/ml for Carvacrol (0.25 and 0.75%) ~6 log CFU/ml for Trans-cinnamaldehyde (0.5 and 0.75%) 2.5 log CFU/ml for Eugenol (0.25%) >6 log CFU/ml (0.75%) 6 log CFU/ml for b-resorcylic acid (0.75 and 1.0 %)			Mattson et al., 2010
Cherry (fresh and uncoated)	Unknown	S. Enteritidis PT4 E10 (Uludag University) 50 µl spot inoculated for 1 h at 22°C 50 µl was injected into the stem scar with a sterile syringe 50 µl was pipetted onto the stem scar	Day at 7°C: 10 Day at 22°C: 20	Air storage	7 22	Before inoculation: 8.3 and 4.3 log CFU/ml Post inoculation: (high) 7.0 log CFU/tomato; (low) 3.0 log CFU/tomato	**Reduction:** Spot inoculated: (High) ~4–5 log CFU/tomato reduction at 7°C and 22°C; (low) ~3 log CFU/tomato reduction Stem-scar syringe/pipetted: ~1 log CFU/tomato growth at 7 and 22°C			Das et al., 2006

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Cherry (fresh and uncoated)	Unknown	S. Enteritidis PT4 E10 (Uludag University) 50 µl spot inoculated for 1 h at 22°C 50 µl was injected into the stem scar with a sterile syringe 50 µl was pipetted onto the stem scar	Day at 7°C: 10 Day at 22°C: 20	Modified atmosphere packaging (LDPE film)	7 22	Before inoculation: 8.3 and 4.3 log CFU/ml Post inoculation: (high) 7.0 log CFU/tomato;(low) 3.0 log CFU/tomato	**Reduction:** Spot inoculated: (High) ~5 log CFU/tomato reduction at 7°C and 22°C; (low) ~3 log CFU/tomato reduction Stem-scar syringe/pipetted: ~1 log CFU tomato **growth** at 7 and 22°C	20% O_2 80% CO_2		Das et al., 2006
Cherry (fresh and uncoated)	Unknown	S. Enteritidis PT4 E10 (Uludag University) 50 µl spot inoculated for 1 h at 22°C 50 µl was injected into the stem scar with a sterile syringe 50 µl was pipetted onto the stem scar	Day at 7°C: 10 Day at 22°C: 20	5% CO_2	7 22	Before inoculation: 8.3 and 4.3 log CFU/ml Post inoculation: (high) 7.0 log CFU/tomato; (low) 3.0 log CFU/tomato	**Reduction:** Spot inoculated: (High) ~5 log CFU/tomato reduction at 7°C and 22°C; (low) ~3 log CFU/tomato reduction Stem-scar syringe/pipetted: ~1 log CFU/tomato **growth** at 7 and 22°C			Das et al., 2006
Cherry (fresh and uncoated)	Unknown	S. Enteritidis PT4 E10 (Uludag University) 50 µl spot inoculated for 1 h at 22°C	20 min	10 mg/l ozone	NA	Before inoculation: 8.3 and 4.3 log CFU/ml Post inoculation: (high) 7.0 log CFU/tomato (low) 3.0 log CFU/tomato	**Detection:** High/4 h - the cells died completely High/1 h - the complete death time was 15 min Low/1 h and 4 h - the complete death time was 5 min	1 h or 4 h attachment time of the cells on tomatoes after inoculation		Das et al., 2006
Cherry (fresh and uncoated)	Unknown	S. Enteritidis PT4 E10 (Uludag University) 50 µl spot inoculated for 1 h at 22°C	20 min	5 and 20 mg/l ozone	NA	Before inoculation: 8.3 log CFU/tomato Post inoculation: 7.0 log CFU/tomato	**Reduction:** High/5 mg/1 h - there was a ~4 log CFU/tomato reduction High/5 mg/4 h - there was a ~2.5 log CFU/tomato reduction High/20 mg/4h - death at 15 min High/20 mg/1h - death at 10 min	1 h or 4 h attachment time of the cells on tomatoes after inoculation		Das et al., 2006
Cherry	Unknown	S. Typhimurium (ATCC 14028, KCTC 2421, KCTC 2057) 1 ml spot inoculated	10 day storage	10 mg/L chlorine dioxide (5 min) 5 kJ m^{-2} UV-C (254 nm) irradiation Chlorine dioxide + UV-C irradiation	4	5.90 log CFU/g	**Reduction:** Chlorine dioxide + UV-C irradiation achieved the most effective among the three treatments, which eliminated detection. Chlorine dioxide achieved a 2.53 log CFU/g; UV-C irradiation achieved a 2.58 log CFU/g.			Song et al., 2011

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Cherry	Unknown	*E. coli* O157:H7 (NCTC 12079) 1 ml spot inoculated	10 day storage	10 mg/L chlorine dioxide (5 min) 5 kJ m^{-2} UV-C (254 nm) irradiation Chlorine dioxide + UV-C irradiation	4	6.21 log CFU/g	**Reduction:** Chlorine dioxide + UV-C irradiation achieved the most effective among the three treatments, which eliminated detection. Chlorine dioxide achieved a 2.26 log CFU/g; UV-C irradiation achieved a 2.65 log CFU/g.			Song et al., 2011
Grape	Unknown	*S.* Typhimurium *S.* Kentucky *S.* Senftenberg *S.* Enteritidis (University of Delaware Culture Collection) Inocula (25 ml) were deposited on intact surfaces to form a drop and allowed to air dry at 25°C for about 2 h.	5 min 10 min	Chlorine (200 ppm) thymol (0.2 and 0.4 mg/ml) thyme oil (2.0 mg/ml) carvacrol (0.4 mg/ml) washing solutions	NA	10^{7-8} CFU/ml	**Reduction:** Thymol was the most effective among the three natural antimicrobial agents, which achieved >4.1 log CFU/ml reductions of *S. enterica* serovars Typhimurium, Kentucky, Senftenberg, and Enteritidis on grape tomatoes after a 5-min washing and >4.3 log CFU/ml reductions after a 10-min washing. A >4.6 log CFU/ml reduction in the *S. enterica* populations in comparison to control was observed with the use of thymol solutions.		Evaluated the antibacterial activities of thymol, carvacrol, and thyme oil compared to chlorine against *Salmonella* spp. on grape tomatoes during the washing procedure.	Lu and Wu, 2010
Grape (*Lycopersicon esculentum* Mill.)	Unknown	*S.* Poona (Cantaloupe) *S.* Stanley H 1256 (Alfalfa sprouts) *S.* Baildon (Tomato) *S.* Typhimurium DT 104 (Resistant to multiple antibiotics) *S.* Montevideo (Tomato) (University of Georgia – M. Harrison) Spot inoculated 100 µl	At 4°C and 10°C (d) 0 4 7 10 At 25°C (h) 0 4 7 10	Allyl isothiocyanate (AIT, from mustard and horseradish) Carvacrol (from oregano) Cinnamaldehyde (from cinnamon) 5, 10, and 15 µl (equivalent to 41.5, 83.3, and 125 µl/liter of air, respectively) of ≥97% pure carvacrol or ≥98% pure cinnamaldehyde or 1, 2, and 4 µl (equivalent to 8.3, 16.6, and 33.3 µl/liter of air, respectively) of ≥98% pure AIT	4 10 25	Whole grape tomatoes 100 µl 9.0 log CFU/ml placed on 10 separate spots	**Reduction:** AIT exhibited the highest antimicrobial activity followed by cinnamaldehyde. This level of AIT inactivated *Salmonella* on whole tomatoes to the detection limit of <2 log CFU/tomato at 4 and 10°C in 10 d and by 1.3 log CFU/tomato at 25°C in 10 h. Overall, greater inactivation occurred at 10 than at 4°C and on the tomato surface than between tomato slice study.		The study elucidated the effect of these antimicrobial activity on pathogen inactivation on tomato skin (using whole tomatoes) and on tomato pulp (using sliced tomatoes).	Obaidat and Frank, 2009

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Vine-ripened (*Lycopersicon esculentum* Mill., cv Rutgers)	No wax or oil	*S.* Agona (Alfalfa sprouts) *S.* Baildon (Tomato) *S.* Gaminara (Orange juice) *S.* Michigan (Cantaloupe) *S.* Montevideo (Tomato) 50 µl spot inoculated Dip inoculated in 5 liters for 1 min 50 µl spray inoculated for 2 s with thin-layer chromatography reagent sprayer at 22°C for 1 or 24 h	Agitated at 150 rpm for 5 min	Chlorine (200 mg/ml) solution	NA	Spot and spray inocula to each tomato were 7.22 log CFU/tomato. Dip count could not be determined.	**Reduction:** Spot decreased by 0.80 and 2.20 log CFU/ml, respectively, within 1 and 24 h of drying. Spray-inoculated tomatoes decreased by 1.37 and 4.00 log CFU/ml within the same respective drying times 24 and 1 h.		Populations of *Salmonella* declined substantially between 1 and 24 h of drying; reductions were high on spray-inoculated tomatoes compared with spot-inoculated tomatoes.	Lang et al., 2004
Vine-ripened	Unknown	*Shigella exneri* (ATCC 12023) *Shigella sonnei* (ATCC 25931) *Shigella boydii* (ATCC 9207)	2 min	Sodium lauryl sulfate (SLS) 0.1 % Tween 80 (polysorbate 80) 0.1%	22 40	6 log CFU/ml	**Reductions** of 1.5 to 4 log CFU/ml were achieved.		The study evaluated the efficacies of these detergents in removing *Shigella* from the surfaces of vine tomatoes at different treatment temps.	Raiden et al., 2003
Vine-ripened	Unknown	A five-strain *Salmonella* cocktail: *S.* Typhimurium (ATCC 14028) *S.* Agona (Alfalfa sprouts) *S.* Baildon (Lettuce/tomato) *S.* Michigan (Cantaloupe) *S.* Montevideo (Tomato) (University of Georgia – L. Beuchat)	2 min	0.1 % sodium lauryl sulfate (SLS) 0.1% Tween 80 (polysorbate 80)	22 40	6 log CFU/ml	**Reductions** of 1.5 to 4 log CFU/ml were achieved.		The study evaluated the efficacies of these detergents in removing *Salmonella* from the surfaces of vine tomatoes at different treatment temps.	Raiden et al., 2003

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Firm tomatoes at the light-red stage of ripeness, free of external defects	Unknown	*S.* Montevideo G4639 (Tomato) *S.* Baildon 61-99 (Tomato) (University of Georgia – L. Beuchat) Dip inoculated	2 min	200 ppm Cl_2 5% H_2O_2	60	10.13 log CFU/ml	**Reduction:** 1.34 log CFU/g (Cl_2) 1.45 log CFU/g (H_2O_2)		Efficacy of wash treatments in reducing population of *Salmonella* on dip-inoculated tomatoes.	Sapers and Jones, 2006
Fully ripened (variety not known)	Yes	*S.* Montevideo G4639 (CDC) 1 ml inoculated on diced	2 min. treatment; At 5°C (h) 22 46 96 142 216 At 20°C (h) 6 22 46 70 96 142 At 30°C (h) 6 22 46 70	Sodium hypochlorite (0.5%)	5 20 30	~4.5 log CFU/g	*S.* Montevideo remained essentially constant in tomatoes stored at 5°C for 216 h. **Growth** 3 log CFU/g at 30°C and 2 log CFU/g at 20°C		Fate of *S.* Montevideo in chopped ripe tomatoes.	Zhuang et al., 1995
Red, ripened	Unknown	*S.* Braenderup (Tomato) (CDC) Whole tomatoes at room temp. (22°C) were spot inoculated (at stem scar) with 0.1 ml of inoculum.	120 s	High pressure processing (MPa) 350 450 550	20	Whole skin: 6.33 log CFU/g Whole pulp: 5.44 CFU/g	**Reduction:** Whole Skin 4.15 log CFU/g reduction Whole pulp 3.44 log CFU/g reduction		To determine the effect of pressure to reduce or eliminate the more pressure-resistant *S. enterica* tomato outbreak serovar from whole red Round tomatoes.	Maitland et al., 2011

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Red, ripened (*Lycopersicon esculentum*)	Unknown	*S.* Montevideo (Tomato) (University of Georgia), resistant to rifampicin 100 µl spot inoculated for 90 min at 22°C under 97% RH	(d) 0 0.4 1 4 7 10	NA	22 30	5 log CFU/ fruit before attachment; after attachment, 3.8 log CFU/ fruit	**Growth:** After 10 days of storage at 30°C, the *S.* Montevideo population increased to 0.7, 1.0, 1.2, and 2.2 log CFU/ tomato. A similar trend was observed at 22°C, although populations were lower than at 30°C.	Relative humidity (%): 60, 75, 85, 97		Iturriaga et al., 2007
Mature, red, ripe, organic tomato (*Lycopersicon esculentum*)	Unknown	*S.* Montevideo (Tomato) (University of Georgia), resistant to rifampicin 100 µl drops on the tomato surface near the blossom; stored 22°C for 90 min	(min) 0 90	NA	22	5 and 8 log CFU/100 µl	Number is proportional to storage time. The highest percentage of attachment (6.6%) after 90 min occurred on tomatoes inoculated with the lowest population (4.95 log CFU/tomato).	100% RH	Effect of inoculum population on attachment of *Salmonella* on tomatoes.	Iturriaga et al., 2003
Red, ripe	No	*Salmonella* Enteritidis IFO-3313, SE-1, SE-3, SE-4 (Chicken feces); SE-2 (Bovine feces) (Japan) 100 µl spot inoculated	30 min	Calcinated calcium 0.5% (wt/vol) 200 ppm chlorine water Sterile distilled water	22	7.36–7.46 log CFU/tomato for *Salmonella*	**Reduction:** Treatment with 200 ppm chlorine and calcinated calcium resulted in 2.07 and 7.36 log CFU/tomato .	Antimicrobials were sprayed on.		Bari et al., 2002
Lycopersicon esculentum	No	*S.* Agona (Alfalfa sprouts) *S.* Baildon (Tomato) *S.* Montevideo (Tomato) *S.* Gaminara (Orange juice) *S.* Michigan (Cantaloupe) 100 µl spot inoculated and air dried 20–22 h at 22°C	(min) 0 6 12 25	ClO_2 gas (mg/liter) 1.4 2.7 4.1	22	8 log CFU/tomato	**Reduction** (log CFU/tomato): 1.11 2.04 4.33	Relative humidity: 34-62%		Sy et al., 2005

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Hydroponic (*Lycopersicon esculentum*)	Unknown	*S.* Javiana (Tomato) *S.* Baildon (Tomato) *S.* Montevideo (Tomato) 100 µl spot inoculated and air dried 2 h at 22°C	(min) 0 12	ClO_2 Gas (mg/liter) 0.1 0.3 0.5	22	8–9 log CFU/ tomato before drying and 7–8 log CFU/cm^2 after drying	**Reduction** (log CFU/cm^2): ~2.5–3.0 ~3.0 >5	Relative humidity: 85–90%		Bhagat et al., 2010
Hydroponic (*Lycopersicon esculentum*)	Unknown	*Listeria monocytogenes* LCDC 81-861 (Coleslaw/cabbage) and F4244 (Ice cream) 100 µl spot inoculated and air dried 2 h at 22°C	(min) 0 12	ClO_2 Gas (mg/liter) 0 0.1 0.3 0.5	22	8–9 log CFU/ tomato before drying and 7–8 log CFU/cm^2 after drying	**Reduction:** *L. monocytogenes* ~3.5, ~4.5, >5 log CFU/cm^2	Relative humidity: 85–90%		Bhagat et al., 2010
Round, unripe, green 'Florida 47'	No	Cocktail of: *S.* Agona *S.* Gaminara *S.* Michigan *S.* Montevideo *S.* Poona (University of California –Davis – L. Harris) Rifampicin resistant Puncture: 10 µl aliquot inoculum Shaved, stem scars, and intact surfaces: 100 µl aliquot inoculum	(s) 30 60 120	150 ppm free chlorine, pH 6.5	25 35	At 25°C: 6.52 to 6.77 log CFU/ml At 30°C: 5.77 to 6.49 log CFU/ml	**Reductions** at 120 s: At 25°C, Stem 1.86 log CFU/ml, Scrape 1.42 log CFU/ml, Puncture 0.73 log CFU/ml, Intact 6.36 log CFU/ml At 30°C, Stem 1.0 log CFU/ml, Scrape 0.56 log CFU/l, Puncture 0.71 log CFU/ml, Intact 4.85 log CFU/ml		*Salmonella* recovery was tested on four surface types: intact, punctures, shaves, and stem scars.	Felkey et al., 2006
Round, unripe, green 'Florida 47'	No	*S.* Agona *S.* Gaminara *S.* Michigan *S.* Poona *S.* Montevideo Ten-10 µl aliquot, spot inoculated around blossom scar	(d) 0 1 3 7 11 14 21 28		20 30	4.6–5.1 log CFU/ml	**Reduction** by day 28: At 20°C/60% RH, 3.1 log CFU/ml At 20°C/90% RH, 3.2 log CFU/ml At 30°C/80% RH, 5 log CFU/ml	Relative humidity (%): 60, 80, 90		Allen et al., 2005

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Lightly waxed, mature green	Unknown	*S.* Montevideo (Tomato) *S.* Michigan (Cantaloupe) v. Poona (Cantaloupe) *S.* Hartford Orange juice *S.* Enteritidis (Eggs) (CDC) Ampicillin resistant, inoculated 50 µl near the blossom end of the tomato	Tomatoes were analyzed after storage for (d) 0 1 2 4 7 10 14	NA	20	7.72 log CFU/ tomato	**Reduction** of ~4 log CFU/tomato by day 14	70% RH	Determine the survival characteristics of *Salmonella* inoculated on tomato surfaces following storage at 20°C.	Guo et al., 2002 JFP
Lightly waxed, mature green	Unknown	*S.* Montevideo (Tomato) *S.* Michigan (Cantaloupe) *S.* Poona (Cantaloupe) *S.* Hartford Orange juice *S.* Enteritidis (Eggs) (CDC) Ampicillin resistant, inoculated 50 µl near the blossom end of the tomato	Tomatoes were analyzed after storage for (d) 0 1 2 4 7 10 14	NA	20	7.77–8.15 CFU/g	**Growth** of 2.5 log CFU/tomato at 4–10 days		Study attachment and infiltration of *Salmonella* into tomatoes placed on the surface of water-saturated soil inoculated with the pathogen.	Guo et al., 2002 JFP
Mature green (*Lycopersicon esculentum* cv Agriset, and *Lycopersicon esculentum* cv Solimar), stored at RT until ripe	Unknown	*S.* Montevideo G4639 (CDC) Rifampicin resistant 25 µl spot inoculated	NA	NA	Room temp.	Four groups of 5 tomatoes each were inoculated on the stem scars with a bacterial population of 4.4×10^3, 5.4×10^4, 6.6×10^5, or 5.0×10^6 CFU in 25 µl	**Detection:** 1st set, 33–95% detectable on 10^3–10^6 CFU 2nd set, 10–45% on 10^5–10^6 CFU 3rd set, no detection		Bacterial transfer by using a cutting knife from inoculated to uninoculated tomatoes. Bacteria were transferred by using a cutting knife from inoculated to uninoculated tomatoes at high CFU.	Lin and Wei, 1997

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Mature green (*Lycopersicon esculentum* cv Agriset, and *Lycopersicon esculentum* cv Solimar), stored at RT until ripe	Unknown	*S.* Montevideo G4639 (CDC) Rifampicin resistant 25 µl spot inoculated	NA	NA	Room temp.	25 µl 2.8×10^2, 2.8×10^3, 2.8×10^4 or 2.8×10^5 CFU/ml in butterfield phosphate buffer or tryptic soy broth was placed on the stem scars of 10 tomatoes to yield a final population of 7, 70, 700, or 7,000 CFU.	**Detection:** 3.8–36% detectable by direct plating for 70–7,000 CFU, no detection for 7 CFU, 4.2–94% detectable after 6 h enrichment for 7–7,000 CFU		Determination of the rate of bacterial detection following cutting of inoculated tomatoes: introduction and/or transfer of bacterial contaminants by using a cutting knife could occur at a bacterial population as low as <10 CFU at the stem scar.	Lin and Wei, 1997
Mature green (*Lycopersicon esculentum* cv Agriset, and *Lycopersicon esculentum* cv Solimar), stored at RT until ripe	Unknown	*S.* Montevideo G4639 (CDC) Rifampicin resistant 25 µl spot inoculated	NA	NA	Room temp.	Four tomatoes were each inoculated with 6.25×10^3, 6.25×10^4, or 9.5×10^5 CFU in 25 µl at stem scar.	**Detection:** At the lower inoculum dose of 6.25×10^3 CFU, *S.* Montevideo colonies were found to cluster at the stem scar region on TSA-RIF plates. However, as the inoculum levels were increased, the colonies were found to spread from the stem scar region to the center and bottom of cut tomatoes along the cutting direction of the knife.		Bacterial distribution on the cut surface of tomato halves.	Lin and Wei, 1997
Green ('Florida 47' cultivar)	No	*S.* Agona *S.* Gaminara *S.* Michigan *S.* Montevideo *S.* Poona (University of California - Davis – L. Harris) Rifampicin resistant, spot inoculated	(s) 60 20 treatment and 5 d study	200 ppm chlorine (pH 6.5)	35	30–100 µL of inoculums of 10^8 to 10^9 CFU/mL *Salmonella* cocktail	**Reduction** of 96.19 – >99.99 % at 120 sec on day 5		Effectiveness of 200 ppm chlorine (pH 6.5) treatment on smooth surface, stem scar tissue, and puncture wound of tomatoes.	Yuk et al., 2005

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Green ('Florida 47' cultivar)	No	*S.* Agona *S.* Gaminara *S.* Michigan *S.* Montevideo *S.* Poona (University of California - Davis – L. Harris) Rifampicin resistant Spot inoculated	(s) 60 20 treatment and 5 d study	1,200 ppm acidified sodium chlorite (ASC; pH 2.5)	35	30-100 µL of inoculums of 10^8 to 10^9 CFU/mL *Salmonella* cocktail	**Reduction** of 98.05 – >99.99 % at 120 sec on day 5		Effectiveness of 1200 ppm acidified sodium chlorite wash on smooth surface, stem scar tissue, and puncture wound of tomatoes.	Yuk et al., 2005
Green ('Florida 47' cultivar)	No	*S.* Agona *S.* Gaminara *S.* Michigan *S.* Montevideo *S.* Poona (University of California - Davis – L. Harris) Rifampicin resistant Spot inoculated	(s) 60 20 treatment and 5 d study	87 ppm peroxyacetic acid (PAA)	35	30–100 µL of inoculums of 10^8 to 10^9 CFU/mL *Salmonella* cocktail	**Reduction** of 94.79 – >99.99 % at 120 sec on day 5		Effectiveness of 87 ppm peroxyacetic acid treatment on smooth surface, stem scar tissue, and puncture wound of tomatoes.	Yuk et al., 2005
Green ('Florida 47' cultivar)	No	*S.* Agona *S.* Gaminara *S.* Michigan *S.* Montevideo *S.* Poona (University of California - Davis – L. Harris) Rifampicin resistant Spot inoculated	1 h treatment and 5 d study	100 mg chlorine dioxide (ClO_2) gas treatment	35	30–100 µL of inoculums of 10^8 to 10^9 CFU/mL *Salmonella* cocktail	**Reduction** of 99.35 – >99.99 % at 120 sec on day 5		Effectiveness of chlorine dioxide (ClO_2) gas treatment on smooth surface, stem scar tissue, and puncture wound of tomatoes.	Yuk et al., 2005

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Green ('Florida 47' cultivar)	No	*S.* Agona *S.* Gaminara *S.* Michigan *S.* Montevideo *S.* Poona (University of California - Davis – L. Harris) Rifampicin resistant Spot inoculated	NA	200 ppm chlorine (pH 6.5), a 1200 ppm acidified sodium chlorite (ASC; pH 2.5) a chlorine dioxide (ClO_2), gas treatment	35	30–100 µL of inoculums of 10^8 to 10^9 CFU/mL *Salmonella* cocktail	**Reduction** of 99.245 – >99.99 % at 120 sec on day 5	2 min in the chlorine bath (200 ppm, 35°C, pH 6.5) as the initial treatment, followed by a 30 s washing in acidified sodium chlorite (1200 ppm, 35°C, pH 2.5), and then tomatoes were treated with chlorine dioxide gas for 1 hour at room temp. (23°C ± 2°C) in a 22-quart vessel	Effectiveness of combination treatment on smooth surface, stem scar tissue, and puncture wound of tomatoes.	Yuk et al., 2005
Mature green (Sunny cultivar)	No	*S.* Montevideo G4639 (CDC) Batches of tomatoes (18 to 20) were submerged and constantly agitated in the bacterial suspension for 2 min and were then air dried in a laminar flow hood at 22°C for 4 h.	Storage (d) 1 2 4 7 9 15 18	NA	10 20 30	~1.5 log CFU/cm^2	**Growth:** Pathogen did not change significantly on tomatoes stored at 10°C throughout the 18-day storage period. Significant increases in the population of *S.* Montevideo occurred within 7 days and within 1 day when tomatoes were stored at 20 and 30°C, respectively. A 3 log CFU/cm^2 growth at 30°C	Relative humidity 45–60%	Fate of *S.* Montevideo on tomato surfaces.	Zhuang et al., 1995

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Mature green (Sunny cultivar)	No	*S.* Montevideo G4639 (CDC) 10 tomatoes were submerged and constantly agitated for 2 min, dried, placed in plastic bags, and stored at 10 or 20°C.	Storage (d) at 10°C 1 3 5 8 At 20°C (d) 1 3 5 8 18	NA	10 20	~4.5 log CFU/g	**Growth:** A significantly higher number of *S.* Montevideo cells were taken up by core tissue when tomatoes at 25°C were dipped in suspension at 10°C compared with the number of cells taken up by tomatoes dipped in suspensions at 25 or 37°C. Tomatoes remained essentially constant throughout subsequent storage for 18 days at 10°C. Storage of tomatoes at 20°C resulted in significant increases in the population of *S.* Montevideo in core tissues within 3, 5, and 18 days of storage of tomatoes that had been dipped in suspension at 10, 25, and 37°C.		Uptake of *S.* Montevideo by core tissue. Effect of temp. differential between tomatoes (25°C) and dip suspension (10, 25, or 37°C) on uptake of *S.* Montevideo by core tissue, and effect of subsequent storage temp. (10 or 20°C) on survival.	Zhuang et al., 1995
Mature green (Sunny cultivar)	No	*S.* Montevideo G4639 (CDC) Batches (18 to 22) of tomatoes were submerged in the suspension, constantly agitated for 2 min, air dried for 5 h, and stored at 25°C for 18 h.	2-min treatment	Free Cl_2 (ppm) 60 110 210 320	NA	~4.95 log CFU/cm^2 on surface and unknown in core	**Reduction:** Dipping in a solution containing 320 ppm chlorine for 2 min resulted in approximately 1.5 log reduction in the number of viable *S.* Montevideo on the surfaces of tomatoes. Concentrations of 110 to 320 ppm significantly reduce the number of viable cells.		Efficacy of chlorine for inactivating *S.* Montevideo.	Zhuang et al., 1995

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Freshly-harvested Unripened (green), and ripened	Unknown	Separately: *S.* Javiana 5913 (Chicken feces) *S.* Javiana 6027 (Bovine feces) *S.* Montevideo (Tomato) *S.* Newport (Alfalfa sprouts) v. Enteritidis (Egg) *S.* Hadar (Poultry house) *S.* Typhimurium (Pork slaughter line) *S.* Dublin (Raw milk) *S.* Senftenberg (Alfalfa sprouts) *S.* Infantis (Clinical isolate) (University of Guelph Culture Collection)	(d) 7 14	NA	15 25	10^6 CFU/ml	**Growth** (internal and exter- nal) was promoted at the high incubation temp. (25°C) and high relative humidity (95%), although this was serovar dependent. The growth and persistence of *Salmonella* introduced on and into ripened (red) tomatoes was serovar dependent. *Salmonella* serovars Enteritidis, Typhimurium, and Dublin were less adapted to grow in or on intact red tomatoes than were serovars Hadar, Montevideo, or Newport.	Vacuum chamber (operating at 10^3 Pa), 75 or 95% RH	Inoculation of tomato fruit on surface and internally.	Shi et al., 2007
Mature, red, ripe tomato; green tomato; ripened tomatillo (*Physalis ixocarpa*)	Unknown	*S.* Montevideo (Tomato) (University of Georgia) Rifampicin resistant 100 µl spot inoculated	90 min	NA	12 22 30	7 log CFU/fruit	Population ranged from 4.0 to 5.4 log CFU/fruit). Temp. and RH alone did not affect the number of cells attached to the tomato or tomatillo surface. Both the type of product and interaction of temp. and RH showed a significant effect on the attachment of *Salmonella* Montevideo to the surface of tomatoes and tomatillos.	Relative humidity (%): 75, 85, 97	Influence of relative humidity, temp., and stage of ripening on attachment of *Salmonella* to tomatoes and tomatillos.	Iturriaga et al., 2003

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Mature green through fully red tomatoes of the Sunny variety	Unknown	*S.* Montevideo G4639 (CDC) Rifampicin resistant 25-µl aliquots on the stem scar of each tomato	30 s 1 min 2 min	Free chlorine (ppm) 100	Room temp.	8.09 log CFU/ tomato skin circle in DI 3.25 log CFU/ tomato skin circle in TSB Low 3.98 log CFU/stem scar in DI High 8.09 log CFU/stem scar in DI	**Reduction:** After 2 min, 1.09 (DI) to 5.95 (TSB) log CFU/tomato skin circle and Low 1.27 log CFU/stem scar After 1 min, High 1.66 log CFU/ stem scar		Efficacy of aqueous chlorine solutions against populations of *S.* Montevideo located on the surface, wounded areas, or stem scars of tomatoes.	Wei et al., 1995
Mature green through fully red tomatoes of the Sunny variety	Unknown	*S.* Montevideo G4639 (CDC) 0.5 ml aliquot added	30 s 1 min 2 min	Free chlorine (ppm) 50 75 100	Room temp.	Tryptic soy broth: 3.72, 5.99, 9.07 log CFU/ml Butterfield buffer: 9.34 log CFU/ml DI: 9.36 log CFU/ml	**Reduction:** After 2 min for TSB, 2.60 (75 ppm), 3.61 (75 ppm), 7.18 (100 ppm) log CFU/ml Buffer, 8.49 log CFU/ml (100 ppm) DI, 8.36 log CFU/ml (100 ppm)		Efficacy of aqueous chlorine against *S.* Montevideo populations suspended in distilled water, in growth medium, or on the dried surface of glass beads (a model for cellular attachment or embedding in particulates).	Wei et al., 1995
Mature green through fully red tomatoes of the Sunny variety	Unknown	*S.* Montevideo G4639 (CDC) 25 µl aliquot added	Growth (h) 18 24 48 Survival (d) 1 2 3 7	NA	Growth 25°C Survival 20°C 25°C	Growth: 9.06 log CFU/ml to 9.48 CFU/ml Survival: 25 µl of low 4.76, medium 5.76, or high 8.76 log CFU/ml, which dried up to be 3.16, 4.16, and 7.16 log CFU/ml	**Growth:** Low ~1.75 log CFU/wounded area growth Medium ~0.4 log CFU/wounded area High no growth. Ripeness had no apparent effect on bacterial growth.	Survival, relative humidity: 83 and 72%	Determine the ability of *S.* Montevideo to grow and/or survive on tomato surfaces, including the unbroken skin, wounded areas, growth cracks, or stem scars.	Wei et al., 1995

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Roma (*Lycopersicon esculentum*)	Unknown	A 3-strain mixture of *E. coli* O157:H7 (C7927, EDL933, and 204P) Spot inoculated	NA	X-ray (#kGy/16 min) 0.1 0.5 0.75 1.0 1.5	22	Three or two strains of each bacterium were mixed with an equal volume to give approximately 10^{7-9} CFU/ml.	**Reduction:** ~ 4.2 log CFU/tomato reduction of E. coli O157:H7 were achieved by treatment with 0.75 kGy X-ray. More than a 5 log CFU/tomato reduction was achieved at 1.0 or 1.5 kGy X-ray for all tested pathogens.	Relative humidity: 55–60%	Inactivation of inoculated *Escherichia coli* O157:H7 on whole Roma tomato surfaces.	Mahmoud, 2010
Vine-ripened (*Lycopersicon Esculentum* Mill. cv Rutgers)	No	*E. coli* O157:H7 strains LJH557 (Apple cider), SEA-13B88 (Apple cider), CDC-658 (Cantaloupe), H1730 (Lettuce), and F4546 (Alfalfa sprouts) 50 µl spot inoculated or dip inoculated in 5 liters for 1 min or 50 µl spray inoculated for 2 sec with thin- layer chromatography reagent sprayer at 22°C for 1 or 24 h	Agitated at 150 rpm for 5 min	Chlorine (200 mg/ml) solution	NA	Spot and spray inocula to each tomato were 7.21, log CFU/ml. Dip could not be determined.	**Reduction:** Spot inoculation was reduced by 1.07 and 3.17 log CFU/ml after drying times of 1 and 24 h. Spray-inoculated tomatoes were 1.03 and 4.34 log CFU/ml at 1 and 24 h, no recovery from chlorine.		Evaluate methods for applying inoculum and to examine the effect of inoculum drying time on survival and recovery of foodborne pathogens inoculated onto the surface of raw, ripe tomatoes.	Lang et al., 2004
Firm tomato at the light-red stage of ripeness, free of external defects	Unknown	*E. coli* NRRL B-766 (ATCC 9637), a nonpathogenic surrogate for *Salmonella* (USDA-ARS-NCAUR - L.K. Nakamura)	(min) 2 3 5	5% H_2O_2	60	9.71 log CFU/ml	**Reduction** of 0.95–1.90 log CFU/g		Effect of treatment time and surfactant addition on efficacy of 5% H_2O_2 in reducing population of *E. coli* NRRL B-766 on dip-inoculated tomatoes held 24 h at 20°C prior to treatment.	Sapers and Jones, 2006

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Firm tomato at the light-red stage of ripeness, free of external defects	Unknown	*E. coli* NRRL B-766 (ATCC 9637), a nonpathogenic surrogate for *Salmonella* (USDA-ARS-NCAUR – L.K. Nakamura)	(h) 24 48	1% or 5 % H_2O_2 (2 min or 15 min)	20 60	5.62 log CFU/g (48 h)	**Reduction** of 1.12 to 2.04 log CFU/g (48 h)		Efficacy of H_2O_2 in reducing the population of *E. coli* NRRL B-766 on dip-inoculated tomatoes, as affected by post-inoculation storage at 20°C.	Sapers and Jones, 2006
Firm tomato at the light-red stage of ripeness, free of external defects	Unknown	*E. coli* NRRL B-766 (ATCC 9637), a nonpathogenic surrogate for *Salmonella* (USDA-ARS-NCAUR - L.K. Nakamura)	48 h	200 ppm chlorine	4	3.98 log CFU/mL	**Reduction** of 1.16 CFU/g		Efficacy of water rinse and 200 ppm Cl_2 treatment in reducing the population of *E. coli* NRRL B-766 on dip-inoculated tomatoes, as affected by post-inoculation storage at 4°C.	Sapers and Jones, 2006
Red, ripe	No	*E. coli* O157:H7 CR-3, MN-28, MY-29, DT-66 (Bovine feces) (Japan) 100 μl spot inoculated	30 min	Calcinated calcium 0.5% (wt/vol), 200 ppm chlorine water, or sterile distilled water	22	7.63 -7.85 log CFU/tomato for *E. coli* O157:H7;	**Reduction:** Treatment with 200 ppm chlorine and calcinated calcium resulted in 3.40 and 7.85 log reductions of *E. coli* O157:H7, respectively.	Antimicrobials were sprayed on.		Bari et al., 2002
Roma (*Lycopersicon esculentum*)	Unknown	A 3-strain mixture of *L. monocytogenes* (Scott A, F5069 and LCDC 81-861) Spot inoculated	NA	X-ray (#kGy/16 min) 0.1 0.5 0.75 1.0 1.5	22	Three or two strains of each bacterium were mixed with an equal volume to give approximately $10^{7\text{-}9}$ CFU/ml	**Reduction:** ~2.3 log CFU/tomato reduction of *L. monocytogenes* were achieved by treatment with 0.75 kGy X-ray, respectively. More than a 5 log CFU/tomato reduction was achieved at 1.0 or 1.5 kGy X-ray for all tested pathogens.	Relative humidity: 55–60%	Inactivation of inoculated *Listeria monocytogenes* on whole Roma tomato surfaces.	Mahmoud, 2010

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Vine-ripened (*Lycopersicon esculentum* Mill. cv Rutgers)	No	*L. monocytogenes* strains G1091 (Coleslaw), F8255 (Peach/plum), F8369 (Corn), HO222 (Potato), and F8027 (Celery) 50 µl spot inoculated or dip inoculated in 5 liters for 1 min or 50 µl spray inoculated for 2 sec with thin- layer chromatography reagent sprayer at 22°C for 1 or 24 h	Agitated at 150 rpm for 5 min	Sterile deionized water (control) or chlorine (200 mg/ml) solution	NA	*L. monocytogenes* spot and spray inocula to each tomato were 7.37 log CFU/ml. Dip could not be determined.	**Reduction:** Spot reduced by 1.00 and 1.54 log CFU/ml within 1 and 24 h. Reductions on spray-inoculated tomatoes were 0.52 and 1.45 log CFU/ml for 1 and 24 h.		*L. monocytogenes* is known to be more resistant than *E. coli* O157:H7 and *Salmonella* to stresses. Higher numbers of cells were recovered from dip-inoculated tomatoes compared with spot- or spray-inoculated tomatoes, regardless of drying time or treatment.	Lang et al., 2004
Red, ripe	No	*Listeria monocytogenes* ATCC 43256, ATCC 49594, JCM 7676, JCM 7672, JCM 7671 100 µl spot inoculated	30 min	Calcinated calcium 0.5% (wt/vol) 200 ppm chlorine water sterile distilled water	22	7.54 -7.59 log CFU/tomato for *L. monocytogenes*	**Reduction:** Treatment with 200 ppm chlorine and calcinated calcium reduced *L. monocytogenes* numbers by 2.27 and 7.59 log CFU per tomato, respectively.	Antimicrobials were sprayed on		Bari et al., 2002
Roma Untreated (no washing, oiling, or waxing)	No	*E. carotovora* ATCC 495, ATCC 15359, ATCC 25272 300 µl spot inoculated	(s) 2 4 6 10	ClO_2 – (ppm) (High) 20 10 5 (Low) 0 1 3 5 10	23	7 log CFU/ml *E. carotovora.*	**Reduction:** A full minute of contact with ClO_2 at 20 and 10 ppm was required to achieve a 5 log reduction of *E. carotovora* on freshly spot-inoculated tomatoes. Immersing wet-inoculated tomatoes in water (0 ppm ClO_2) for 1 min alone reduced *E. carotovora* by about 1.9 log CFU/cm^2. On inoculated fruit surfaces, populations decreased >3 log CFU/cm^2 during desiccation at 24°C for 24 h. Populations of air-dried *Erwinia* were not significantly reduced by ClO_2 at ≤20 ppm after 1 min.	For each treatment, nine inoculated tomatoes were immersed in 2 liters of ClO_2 or water for 20 to 60 s. Relative humidity: 40–50%	Researchers investigated the sanitizing effects of a ClO_2 solution on *E. carotovora* in water, on tomato surfaces, and between tomato loads.	Pao et al., 2007

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Roma, diced at the light-red to red stages	Unknown	*S.* Agona (Alfalfa sprouts) *S.* Baildon (Diced tomato) *S.* Gaminara (Orange juice) *S.* Michigan (Canataloupe) *S.* Montevideo (Tomato) Acid- and non-acid adapted environment, 5ml inoculation of inoculums in 450 g diced tomatoes	(d) 0 3 6 9	NA	4 12 21	Acid low 0.88 log CFU/g Acid high 2.88 log CFU/g No acid low 0.99 log CFU/g No acid high 2.99 log CFU/g	**Growth** at 10 days for: Acid low at 12°C and 21°C, ~1.32 and ~8.22 log CFU/g. Acid high at 12°C and 21°C, ~3.62 log CFU/g and ~5.32 log CFU/g. No acid low at 12°C and 21°C, ~1.61 log CFU/g and ~7.71 log CFU/g. No acid high at 12°C and 21°C, ~3.81 CFU/g, and ~4.81 log CFU/g		Survival and growth of acid-adapted and not acid-adapted cells in diced Roma tomatoes.	Beuchat and Mann, 2008
Diced	Unknown	Separately: *S.* Enteritidis NVI 153 (Cow) *S.* Infantis NVI 110 (Broiler chicken) *S.* Typhimurium NVI 199 (Broiler chicken) (Finland) Spot inoculated	6 24 48	NA	7 (only 48 h) 22 30	1–2 × 10^2 CFU/g	**Growth:** *S.* Infantis - No growth at 7°C; At 48 h, 2.4 × 10^8 CFU/g at 22°C, and 4.5 × 10^7 CFU/g at 30°C. *S.* Enteritidis - No growth at 7°C; At 48 h, 8 × 10^8 CFU/g at 22°C, and 6 × 10^7 CFU/g at 30°C. *S.* Typhimurium - No growth at 7°C; At 48 h, 1.1 × 10^8 CFU/g at 22°C, and 5 × 10^7 CFU/g at 30°C.			Asplund and Nurmi, 1991
Diced, Round, red, ripened tomato	Unknown	*S.* Braenderup (Tomato) (CDC) Diced tomatoes at room temp. (22°C) were spot inoculated (at stem scar) with 0.1 ml of inoculum.	120 s	High pressure processing (MPa) 350 450 550	20	Diced, 5.93 log CFU/g	**Reduction:** 550 MPa Diced, 3.65 log CFU/g reduction		To determine the effect of pressure to reduce or remove *S. enterica* from whole red Round tomatoes.	Maitland et al., 2011

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Diced grape tomato *Lycopersicon esculentum* mill.	Unknown	*S.* Poona (Cantaloupe) *S.* Stanley H 1256 (Alfalfa sprouts) *S.* Baildon (Tomato) *S.* Typhimurium DT 104 (Resistant to multiple antibiotics) *S.* Montevideo (Tomato) (University of Georgia – M. Harrison) Spot inoculated 100 µl	At 4°C and 10°C (d) 0 4 7 10 At 25°C (h) 0 4 7 10	Allyl isothiocyanate (AIT, from mustard and horseradish) Carvacrol (from oregano) Cinnamaldehyde (from cinnamon) 5, 10, and 15 µl (equivalent to 41.5, 83.3, and 125 µl/liter of air, respectively) of ≥97% pure carvacrol or ≥98% pure cinnamaldehyde or 1, 2, and 4 µl (equivalent to 8.3, 16.6, and 33.3 µl/liter of air, respectively) of ≥98% pure AIT	4 10 25	Sliced tomatoes, 100 µl 6.7 log CFU/ml placed on 10 separate spots	**Reduction:** AIT exhibited the highest antimicrobial activity followed by cinnamaldehyde. The lowest level of AIT (8.3 µl/liter of air) inactivated *Salmonella* on sliced tomatoes by 1.0 and 3.5 log at 4 and 10°C, respectively, in 10 days and by 2.8 log at 25°C in 10 h. Overall, greater inactivation occurred at 10 than at 4°C and on the tomato surface than between slices.		Elucidate the effect of antimicrobials' activity on pathogen inactivation on tomato skin (using whole tomatoes).	Obaidat and Frank, 2009
Stem scar tissue light red, Round	Unknown	*S.* Agona (Alfalfa sprouts) *S.* Baildon (Diced tomato) *S.* Gaminara (Orange juice) *S.* Michigan (Cantaloupe) *S.* Montevideo (Tomato) Acid- and non-acid adapted environment, 20 µl syringe inoculated	(d) 0 3 6 10	NA	12 21	Acid-adapted and not acid-adapted cells: Round, light red, 2.05 and 1.84 CFU/g	**Growth** at 10 days for *Light red, Round*: Acid-adapted stem at 12°C and 21°C, ~2.05 log CFU/g and ~4.05 log CFU/g Not acid-adapted stem at 21°C and 21°C, ~0.76 log CFU/g and ~2.66 log CFU/g		Survival and growth of acid-adapted and not acid-adapted cells in Round tomatoes.	Beuchat and Mann, 2008

Tomato shape or variety according to publication	**Waxed**	**Microbe**	**Time**	**Decontamination variable(s)**	**Temp. (°C)**	**Initial bacterial counts**	**Reduction or growth achieved; detection (positive or negative)**	**Parameters**	**Comments**	**Reference**
Stem scar tissue of light-red Roma	Unknown	*S.* Agona (Alfalfa sprouts) *S.* Baildon (Diced tomato) *S.* Gaminara (Orange juice) *S.* Michigan (Cantaloupe) *S.* Montevideo (Tomato) Acid- and non-acid adapted environment, 20 µl syringe inoculated	(d) 0 3 6 10	NA	12 21	Acid-adapted and not acid-adapted cells: Roma, light red, 2.00 and 2.01 CFU/g	**Growth** at 10 days, *Roma light red:* Acid-adapted stem at 12°C and 21°C, ~1.5 log CFU/g and ~3.8 log CFU/g Not acid-adapted stem at 21°C and 21°C, ~2.29 log CFU/g and ~4.19 log CFU/g		Survival and growth of acid-adapted and not acid adapted cells in Roma tomatoes.	Beuchat and Mann, 2008
Stem scar tissues of Round and Roma, initially at the turning and/or pink stages of ripeness	Unknown	*S.* Agona (Alfalfa sprouts) *S.* Baildon (Diced tomato) *S.* Gaminara (Orange juice) *S.* Michigan (Cantaloupe) *S.* Montevideo (Tomato) 20 µl syringe inoculated	12°C (d) 0 3 6 10 14 27 21°C (d) 0 3 6 10 14	NA	12 21	Pre-inoculation 4 log CFU/ml and post-inoculation 0.08 log CFU/g	**Growth:** *Salmonella* increased significantly in the stem scar of tomatoes stored at both temps. . Higher populations (4.9 to 8.4 log CFU/g) were reached at 21°C than at 12°C (3.3 to 4.9 log CFU/g) in tomatoes stored for 14 and 27 days, respectively	Tomatoes were held up to 27 days at 12 or 21°C with 15 and 36% relative humidity before experiment.	Survival and growth of *Salmonella* in Round and Roma tomatoes.	Beuchat and Mann, 2008
Stem scar on the skin surface of grape tomato	Unknown	*S.* Agona (Alfalfa sprouts) *S.* Baildon (Diced tomato) *S.* Gaminara (Orange juice) *S.* Michigan (Cantaloupe) *S.* Montevideo (Tomato) Not adapted to acidic environment 20 µl inoculated	14 d	NA	4 12 21	1.76 log CFU/ml (57 CFU/ml)	**Growth** at 14 days: Stem at 12°C and 21°C, ~2.65 and ~4.05 log CFU/g		Survival and growth of *Salmonella* in and on grape tomatoes.	Beuchat and Mann, 2008

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Stem scar tissue of green tomato	Unknown	*S.* Agona (Alfalfa sprouts) *S.* Baildon (Diced tomato) *S.* Gaminara (Orange juice) *S.* Michigan (Cantaloupe) *S.* Montevideo (Tomato) Acid- and non-acid adapted environment 20 µl syringe inoculated	(d) 0 3 6 10	NA	12 21	Acid-adapted and not acid-adapted cells: Green, 2.03 and 1.78 log CFU/g	**Growth** at 10 days for *Green*: Acid-adapted stem at 12°C and 21°C, ~0.067 log CFU/g and ~1.77 log CFU/g Not acid-adapted stem at 21°C, ~3.22 log CFU/g		Survival and growth of acid-adapted and not acid-adapted cells in green tomatoes.	Beuchat and Mann, 2008
Round - Pulp of light red	Unknown	*S.* Agona (Alfalfa sprouts) *S.* Baildon (Diced tomato) *S.* Gaminara (Orange juice) *S.* Michigan (Cantaloupe) *S.* Montevideo (Tomato) Acid- and non-acid adapted environment 20 µl syringe inoculated	(d) 0 3 6 10	NA	12 21	Acid-adapted and not acid-adapted cells: Round, light red, 2.05 and 1.84 CFU/g	**Growth** at 10 days for *Light red Round:* Acid pulp at 12°C and 21°C, ~3.95 log CFU/ml and ~5.45 log CFU/ml Not acid-adapted pulp at 12°C and 21°C, ~2.46 log CFU/g and ~5.56 log CFU/g.		Survival and growth of acid-adapted and not acid adapted cells in Round tomatoes.	Beuchat and Mann, 2008
Round and Roma tomato pulp (radial pericarp) initially at the turning and/or pink stages of ripeness	Unknown	*S.* Agona *S.* Baildon *S.* Gaminara *S.* Michigan *S.* Montevideo 20 µl syringe inoculated	12°C (d) 0 3 6 10 14 27 21°C (d) 0 3 6 10 14	NA	12 21	Pre-inoculation 4 log CFU/ml, and post-inoculation 0.08 log CFU/g	**Growth:** *Salmonella* increased significantly in the pulp tissues of tomatoes stored at both temps. Higher populations (4.9 to 8.4 log CFU/g) were reached at 21°C than at 12°C (3.3 to 4.9 log CFU/g) in tomatoes stored for 14 and 27 days, respectively.	Tomatoes were held up to 27 days at 12 or 21°C with 15 and 36% relative humidity before experiment.	Survival and growth of *Salmonella* in Round and Roma tomatoes.	Beuchat and Mann, 2008

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Pulp of light-red Roma tomato	Unknown	*S.* Agona *S.* Baildon *S.* Gaminara *S.* Michigan *S.* Montevideo Acid- and non-acid adapted environment 20 µl syringe inoculated	(d) 0 3 6 10	NA	12 21	Acid-adapted and not acid adapted cells: Roma light red 2.00 and 2.01 CFU/g	**Growth** at 10 days *Roma light red:* Acid-adapted pulp at 12°C and 21°C, ~3.5 log CFU/ml and ~6.0 log CFU/ml Not acid-adapted pulp at 12°C and 21°C, ~3.29 log CFU/g and ~5.19 log CFU/g		Survival and growth of acid-adapted and not acid-adapted cells in Roma tomatoes.	Beuchat and Mann, 2008
Pulp tissues on the skin surface of grape tomato	Unknown	*S.* Agona *S.* Baildon *S.* Gaminara *S.* Michigan *S.* Montevideo Acid- and non-acid adapted environment 20 µl syringe inoculated	14 d	NA	4 12 21	1.76 log CFU/ml (57 CFU/ml)	**Growth** at 14 days: Pulp at 12°C and 21°C, ~3.35 and ~4.85 log CFU/g		Survival and growth of *Salmonella* in and on grape tomatoes.	Beuchat and Mann, 2008
Pulp of green tomato	Unknown	*S.* Agona *S.* Baildon *S.* Gaminara *S.* Michigan *S.* Montevideo Acid- and non-acid adapted environment 20 µl syringe inoculated	(d) 0 3 6 10	NA	12 21	Acid-adapted and not acid-adapted cells: Green 2.03 and 1.78 log CFU/g	**Growth** at 10 days for *Green:* Acid-adapted pulp at 12°C and 21°C, ~1.47 log CFU/ml and ~3.77 log CFU/ml Not acid-adapted pulp at 12°C and 21°C, ~1.52 log CFU/g and ~4.02 log CFU/g.		Survival and growth of acid-adapted and not acid-adapted cells in green tomatoes.	Beuchat and Mann, 2008
Salsa with either fresh Roma tomato or canned whole tomato, different salsa recipes	Unknown	*S.* Typhimurium, DT 104 (Beef isolate) and PTC 1 (Poultry isolate) two *S.* Enteritidis, H4639 (Clinical iso- late) and MH24981 (Environmental isolate) one *S.* Heidelberg, MH27651 (Turkey isolate) 100 µl spot inoculated	(d) 0 1 2 3 7	NA	21	5-6 log CFU/ tomato	Salsa, depending on its ingredients, could be inhibitory to, or support the survival and possibly growth of, *Salmonella* during storage. Salsa can be formulated with ingredient combinations such as lime juice plus fresh garlic to prevent or suppress the growth of *Salmonella*.	Inoculated whole tomatoes, then chopped them	Fate of *Salmonella* in salsas.	Ma et al., 2010

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Salsa, ripened Roma tomato, intact	Unknown	*S.* Typhimurium, DT 104 (Beef isolate) and PTC 1 (Poultry isolate) two *S.* Enteritidis, H4639 (Clinical iso- late) and MH24981 (Environmental isolate) one *S.* Heidelberg, MH27651 (Turkey isolate) 20 µl spot inoculated, air dried 1 h RT	(d) 0 1 2 5 7	NA	4 12 21	Inoculated at 5.36 log CFU/g and after spot-inoculation was 2.47 log CFU/g	**Growth** on surface of raw whole tomato: At 21°C, 4-5 log CFU/g growth No growth observed at 4 and 12°C	Relative humidity: 55-65% Inoculated whole tomatoes, then chopped them	Survival and growth of *Salmonella* on intact tomato, jalapeño, and cilantro.	Ma et al., 2010
Salsa, ripened Roma tomato, diced	Unknown	*S.* Typhimurium, DT 104 (Beef isolate) and PTC 1 (Poultry isolate) two *S.* Enteritidis, H4639 (Clinical iso- late) and MH24981 (Environmental isolate) one *S.* Heidelberg, MH27651 (Turkey isolate) 100 µl spot inoculated	(d) 0 1 2 5 7	NA	4 12 21	~4 log CFU/g	**Growth** on chopped tomato: No growth at 4°C (kept at 3-4 log CFU/g) Growth at 12°C at 6.02 log CFU/g and a decrease in growth at <1 log CFU/g (day 2) at 21°C		Survival and growth of *Salmonella* in chopped tomatoes, jalapeño peppers, and cilantro.	Ma et al., 2010
Restaurant-made salsa with red tomato	Unknown	*S.* Enteritidis *S.* Typhimurium *S.* Thompson ATCC 8391 Spot inoculated on salsa container	For 20°C (h) 0 2 4 6 24 For 4°C (d) 0 1 3 5 7	NA	20 4	15-20 CFU/ sample			Comparison of detection methods between CHROMagar, XLD, and RapidCheck SELECT. RapidCheck SELECT was best to detect *Salmonella* under both temps. at all time points except 5 s, 7 d at 4°C.	Franco et al., 2010

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Restaurant-made salsa with red tomato	Unknown	*S. aureus* ATCC 29247, ATCC 12600-U, and ATCC 35548 Spot inoculated on salsa container	For 20°C (h) 0 2 4 6 24 For 4°C (d) 0 1 3 5 7	NA	20 4	Low (3.2 log CFU/g) High (4.2 log CFU/g)	**Reduction:** At 20°C, 1.1 log CFU/g for low and 0.6 log CFU/g for high At 4°C, 1.7 log CFU/g for low and 2.5 log CFU/g for high	pH at 4 °C ranged from 3.96 to 3.65 pH at 20°C ranged from 3.95 to 3.73	Survival study.	Franco et al., 2010
Cultivar Better Boy tomato seeds grown for 7 days or until cotyledons emerged	No	*S.* Montevideo (Tomato) *S.* Michigan (Cantaloupe) *S.* Poona (Cantaloupe) *S.* Hartford (Orange juice) *S.* Enteritidis (Eggs) (CDC) All ampicillin resistant Plants with intact or cut roots were then transferred to trays containing 4 liters of Hoagland solution inoculated with the five-serotype mixture.	7 d	NA	25°C	Hoagland solution modified to contain ampicillin (100 g/ml) in order to obtain a preparation containing 4.55 log CFU/ml	**Detection:** Within 1 day of exposure of plant roots to nutrient solution containing ca. 4.5 log CFU of the pathogen/ml, populations were 3.0 log CFU/g of hypocotyls and cotyledons, and 3.4 log CFU/g of stems. Populations > 3.4 log CFU/g of hypocotyl/cotyledon, stem, and leaf tissue of plants grown for 9 days were detected.	Hypocotyls, cotyledons, stem, leaves	Investigate the possibility of association of *Salmonellae* with hypocotyls, cotyledons, stems, and leaves of young plants grown in a hydroponic nutrient solution inoculated with the pathogen.	Guo et al., 2002 AEM

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Tomato seeds (*Lycopersicon esculentum* variety Abigail VFET)	Unknown	*S.* Javiana 5913 (Chicken feces) *S.* Javiana 6027 (Bovine feces) *S.* Montevideo (Tomato) *S.* Newport (Alfalfa sprouts) *S.* Enteritidis (Egg) *S.* Hadar (Poultry house) *S.* Typhimurium (Pork slaughter line) *S.* Dublin (Raw milk) *S.* Senftenberg (Alfalfa sprouts) *S.* Infantis (Clinical isolate) (University of Guelph) 100 µl spot inoculated	6-7 weeks	NA	NA	100-µl aliquots of *Salmonella* suspension (10^7 CFU/ml) were introduced onto the flowers of the plants.	**Detection:** The lowest recovery was observed for serovar Dublin (14%), and the highest was observed for Javiana 6027 (84%). *Salmonella* serovars introduced onto the flowers of growing plants were recovered on and within the developing tomato fruit. Of all the *Salmonella* serovars tested, Montevideo appeared to be more adapted to survival within tomatoes and was recovered from 90% of the fruit screened.	Batches (five batches per serovar, three fruits per batch) were screened for the presence of *Salmonella* on the surface and in internal tissue.	Inoculation of tomato plants with *Salmonella*.	Shi et al., 2007
Tomato plants 'Bonnie Select'	No	*S.* Montevideo ATCC 8387 Spot inoculated	48 h	NA	NA	6.6 log CFU/ leaflet	**Reductions** of 3-4 log CFU/leaflet occurred when leaves were dried after inoculation. When leaves were supported in a hydroponic nutrient medium and incubated at 100% RH, there was no significant reduction for at least six days.	*Salmonella* on the surface of excised leaves, leaf disks, and fruit pericarp disks under dry (60% RH) and high-humidity (100% RH) conditions	Examine the survival of *Salmonella* Montevideo on tomato leaves.	Rathinasabapathi, 2004
Tomato plants 'Bonnie Select'	No	*S.* Montevideo ATCC 8387 Spot inoculation	6 d		20		No significant effect on the survival of *Salmonella* on leaf surfaces	100 ppm Ethylene at 100% RH	With high relative humidity and the addition of ethylene, it was examined for the pathogen's survival on tomato leaves.	Rathinasabapathi, 2004

Tomato shape or variety according to publication	Waxed	Microbe	Time	Decontamination variable(s)	Temp. (°C)	Initial bacterial counts	Reduction or growth achieved; detection (positive or negative)	Parameters	Comments	Reference
Tomato plants 'Better Boy,' harvested when red-ripe color was achieved	No	Separately: *S.* Montevideo (Tomato) *S.* Michigan (Cantaloupe) *S.* Poona (Cantaloupe) *S.* Hartford (Orange juice) *S.* Enteritidis (Egg) (CDC) Brushed by using a small paintbrush saturated with inoculum, or 25-gauge syringe needle stem injected	27–49 d	NA	NA	Open flower: 9 log CFU/ml Stem injection before and after flowering: 7.5 log CFU/50 µl	**Detection:** Eleven of thirty tomatoes (37%) harvested from inoculated plants were positive for all *Salmonella* serotypes except *S.* Hartford. Presumptive *Salmonella* was detected in enriched samples of peptone wash water, stem scar tissue, and pulp of tomatoes from inoculated plants. *Salmonella* was detected on or in tomatoes from plants receiving stem inoculation before or after flower set and on or in tomatoes that developed from inoculated flowers.		Determine the fate of *Salmonella* inoculated into tomato stems and onto tomato flowers.	Guo et al., 2001

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Outbreaks of Foodborne Diseases Associated with Tomatoes[1]

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Fresh-market tomatoes are a popular commodity in homes and food service around the world. The inherent risks of contamination by foodborne pathogens present a challenge to the produce industry and regulators. Since fresh-market tomatoes are intended to be consumed fresh, there is no "kill-step" in the processing that would eliminate pathogens in the event that tomatoes become contaminated (Maitland et al., 2011). Public health officials often meet numerous challenges when conducting traceback investigations in the event of a produce outbreak, such as tomatoes. It is often difficult for them to isolate organisms from the raw product, when the raw product may have been consumed, discarded, or reached the end of its shelf-life (Lynch et al., 2009). It can be difficult for public health officials to determine where the implicated food was produced. As a consequence, recognizing unusual food vehicles, such as certain items of fresh produce, can delay the foodborne outbreak investigation (Lynch et al., 2009).

A "case" in a foodborne illness outbreak is identified as an infected patient carrying a strain that was isolated from a collected stool sample and documented to be associated with an outbreak. The number of sporadic cases linked to the consumption of contaminated fresh fruits and vegetables is unknown (Heaton and Jones 2008).

Figure 1. Tomatoes
Credits: USDA Photo by Scott Bauer

This document is intended to serve as a reference for everyone concerned about the safety of fresh-market tomatoes by highlighting tomato-related outbreaks in the United States and Europe and reviewing locations and venues of tomato preparations as well as the severity of outbreaks. Three tables are presented, separated by foodborne outbreaks where tomatoes are confirmed as the food vehicle (Table 1); confirmed as part of complex foods vehicles (Table 2); and suspected, but not specified or confirmed, as the food vehicle (Table 3).

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Table 1. Outbreaks of foodborne disease associated with tomatoes, 1990–2009

Year	Month	Location	Pathogen[b]	Location of consumption	Cases (deaths)	Food Vehicle	Reference
1990	NR[a]	US (multistate)	*S.* Javiana	Various	176 (0)	Tomato	Hedberg et al., 1999
1993	NR	US (multistate)	*S.* Montevideo	Various	100 (0)	Tomato	Hedberg et al., 1999
1994	NR	US (AK)	Hepatitis A	Food handler	92 (0)	Diced tomato	FDA, 2009
2002	February	US (CT)	*S.* Newport	Private home	7 (0)	Grape tomato	CDC, 2011
2004	June	US (multistate)	*S.* Braenderup	Private home; Restaurant – other or unknown type	137 (0)	Roma tomato	CDC, 2011
2004	July	US (multistate)	*S.* Anatum; Javiana; Muenchen; Thompson; Typhimurium	Restaurant – other or unknown type	429 (0)	Roma tomato	CDC, 2011
2005	July	US (multistate)	*S.* Newport	Restaurant – other or unknown type	52 (0)	Tomato	CDC, 2011
2005	November	US (multistate)	*S.* Braenderup	Restaurant – other or unknown type	84 (0)	Roma tomato	CDC, 2011
2006	September	US (ME)	*S.* Typhimurium	Unknown	8 (0)	Tomato	CDC, 2011
2006	January	US (PA)	*S.* Berta	Hospital; Nursing home, assisted living facility, home care; Restaurant – other or unknown type	16 (0)	Tomato	CDC, 2011
2007	June	US (multistate)	*S.* Newport	Private home; Restaurant – other or unknown type	65 (0)	Tomato	CDC, 2011
2009	May	US (MI)	*S.* Saintpaul	Private Home; Restaurant – "Fast-food" (drive-up service or pay at counter); Restaurant – Sit-down dining	21(0)	Tomato	CDC, 2011

[a]NR – Not reported
[b]Pathogens abbreviated and associated with outbreaks include various serotypes of *Salmonella* (*S.*).

Table 2. Outbreaks of foodborne disease associated with complex foods including tomatoes, 1979–2008

Year	Month	Location	Pathogen[b]	Location of consumption	Cases (deaths)	Food Vehicle	Reference
1979	NR[a]	US (MA)	*L. monocytogenes*	Hospitals	20 (5)	Tomato, lettuce, celery	FDA, 2009
1989	NR	US (multistate)	*G. lamblia*	Unknown	21 (0)	Lettuce, onion, tomato	FDA, 2009
1992	NR	UK	Norovirus	Hospital	NR	Lettuce, tomato	ACMSF, 2005; Hughes et al., 2007
1995	NR	UK	*S.* Typhimurium DT104	Hotel	NR	Sandwich of turkey and tomato	ACMSF, 2005; Hughes et al., 2007
1995	NR	UK	*E. coli* O157	Pub	NR	Lettuce, tomato	ACMSF, 2005; Hughes et al., 2007
1996	NR	UK	*Campylobacter*	Hotel	NR	Lettuce, tomato	ACMSF, 2005; Hughes et al., 2007
1996	NR	UK	Norovirus	Club	NR	Tomato and cucumber salad	ACMSF, 2005; Hughes et al., 2007
2003	NR	UK	*B. cereus*	Unknown	NR	Quiche (tomato, lettuce, mushroom)	ACMSF, 2005; Hughes et al., 2007
2008	July	US (CA)	*S.* Blockley	Private home	9 (0)	Mole (sauce); and, pasta with tomato sauce	CDC, 2011

[a]NR – Not reported
[b]Pathogens abbreviated and associated with outbreaks include various serotypes of *Bacillus* (*B.*), *Escherichia* (*E.*), *Giardia* (*G.*), *Listeria* (*L.*), and *Salmonella* (*S.*).

Table 3. Outbreaks of foodborne disease where tomatoes are suspected, but not specified or confirmed, 1998–2011

Year	Month	Location	Pathogen[a]	Location of consumption	Cases (deaths)	Food Vehicle	Reference
1998/9	December/ January	US (multistate)	*S.* Baildon	Nursing home, assisted living facility, home care	86 (3)	Tomato, unspecified	CDC, 2011
2000	November	US (multistate)	*S.* Thompson	Private home	43 (0)	Tomato, unspecified	CDC, 2011
2002	July	US (multistate)	*S.* Newport	Hospital; Restaurant – other or unknown type; School	510 (0)	Tomato, unspecified	CDC, 2011
2002	June	US (MA)	*S.* Javiana	Other; Restaurant – other or unknown type	3 (0)	Tomato, unspecified	CDC, 2011
2002	June	US (FL)	*S.* Javiana	Restaurant – other or unknown type	159 (0)	Tomato, unspecified	CDC, 2011
2003	March	US (CA)	*S.* Virchow	Other	11 (0)	Tomato, unspecified	CDC, 2011
2003	June	US (CA)	*S.* Saintpaul	Private home; Restaurant – other or unknown type	17 (0)	Mango, unspecified; Tomato, unspecified	CDC, 2011
2003	November	US (multistate)	*S.* Saintpaul	Restaurant – other or unknown type	33 (0)	Chicken, unspecified; Iceberg lettuce, unspecified; Tomato, unspecified	CDC, 2011
2005	July	US (NY)	*S.* Newport	Grocery store; Picnic; Private home; Restaurant – other or unknown type	27 (0)	Onion, unspecified; Tomato, unspecified	CDC, 2011
2005	June	US (WY)	*S.* Enteritidis	Private home; Restaurant – other or unknown type	20 (0)	Egg, unspecified; Tomato, unspecified	CDC, 2011
2005	June	US (CA)	*S.* Enteritidis	Picnic; Private home; Restaurant – other or unknown type; Workplace, not cafeteria	85 (0)	Salsa, unspecified	CDC, 2011
2006	June	US (MD)	*S.* Typhimurium	Private home; Restaurant – other or unknown type	18 (0)	Lettuce, unspecified; Tomato, unspecified	CDC, 2011
2006	September	US (multistate)	*S.* Typhimurium	Private home; Restaurant – other or unknown type	192 (0)	Tomato, unspecified	CDC, 2011
2006	June	US (multistate)	*S.* Newport	Restaurant – other or unknown type	115 (0)	Tomato, unspecified	CDC, 2011
2007	June	US	*S.* Newport	Private home; Restaurant – other or unknown type	46 (0)	Avocado, unspecified; Cilantro; Guacamole, unspecified; Tomato, unspecified	CDC, 2011
2007	June	US (MD)	*S.* Javiana	Private home; Restaurant – other or unknown type	5 (0)	Cheese, unspecified; Chicken, unspecified; Tomato, unspecified; and, Unspecified fruit	CDC, 2011
2007	July	US (NY)	*S.* Newport	Unknown or undetermined	10 (1)	Tomato, unspecified	CDC, 2011
2007	October	US (MN)	*S.* Typhimurium	Restaurant – other or unknown type	23 (0)	Tomato, unspecified	CDC, 2011
2008	July	US (CA)	*S.* Braenderup	Restaurant – other or unknown type	17 (0)	Salsa, unspecified	CDC, 2011
2008	April	US (IA)	*S.* Braenderup	Restaurant – other or unknown type	12 (0)	Green salad; Tomato, unspecified	CDC, 2011
2011	October	Denmark	*S.* Strathcona	Various locations	43 (0)	Tomato, unspecified	SSI, 2012

[a]Pathogens abbreviated and associated with outbreaks include various serotypes of *Salmonella* (*S.*).

Transfer Potential of *Salmonella* Between Tomato Cartons and Tomatoes

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Introduction

Consumption of fresh tomato have been linked to large, multistate outbreaks, of salmonellosis (Lynch 2009). The most effective approach to reduce the risk of contamination when produced is consumed fresh, is to establish standards at each phase of crop management and post harvest handling.

A potential point of cross-contamination to tomatoes is during repacking operations. It is common practice in the industry to repack tomatoes into corrugated boxes from primary packinghouses. The risks of *Salmonella* contamination onto tomatoes from used cartons is not known. This information is needed to develop best practices for fresh tomato carton reuse.

Objectives

The objectives of this study were to determine *Salmonella* transfer coefficients (TCs) between (i) inoculated new, used, and dirty cartons and tomatoes; and (ii) inoculated tomatoes and new, used, and dirty cartons, under varying inoculation conditions, contact times, and temperatures.

Materials and Methods

Salmonella Strains

Salmonella Serovar	Source
Michigan	Cantaloupe Outbreak
Montevideo	Almond Survey
Newport	Tomato Outbreak
Poona	Cantaloupe Outbreak
Saintpaul	Orange Juice Outbreak

All strains are resistant to 80 µg/ml rifampicin (Ruiz et al., 2008)

Tomatoes

Mature green, round, washed and waxed tomatoes were purchased from a local supermarket.
Fruit was stored at 4°C prior to use and left overnight at ambient temperature (18-23°C) prior to inoculation.

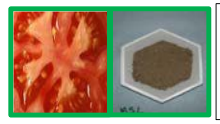
Cartons

New Cartons

Clean Used Cartons

Dirty Used Cartons

New and single use cartons were obtained from local suppliers



250 g of tomato (locular cavity) was extracted, combined with 50 g of sandy soil and mixed in a food processor for 1 min

Cut into 5 cm x 5 cm squares

Carton squares (5 cm x 5 cm) were painted with the slurry and allowed to dry overnight

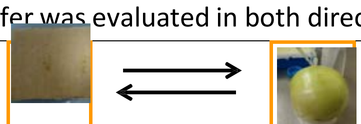
Inoculation

Tomato or carton was spot inoculated with 100 µl of the 5 strain *Salmonella* cocktail ca. 6 log CFU/item

The inoculum was allowed to dry for 0 (wet), 1, or 24 hours at ambient temperature

Transfer

Transfer was evaluated in both directions



Inoculated Carton → Tomato

Inoculated Tomato → Carton

Contacted Tomato/Cartons were subjected to three contact times 0 (touch), 1 and 7 days and stored at two temperatures 12 and 25°C.

Recovery

Samples were transferred to 530 ml Whirl-Pak bags and 20 ml of 0.1% peptone was added

Carton samples were stomached at high speed for 1 min

Tomatoes were shaken vigorously by hand for 15 s, rubbed for 30 s, and shaken for 15 s

Samples were plated onto TSA with 80 µg/ml rifampicin and incubated for 24h at 35 ± 2°C

Calculations

$$TC = \frac{P_G}{P_C}$$

TC - Transfer Coefficient; P_G - population enumerated from the uninoculated surface (CFU/surface); P_C - population enumerated from inoculated surface (CFU/surface)

Results

Inoculated Carton to Tomato

12°C

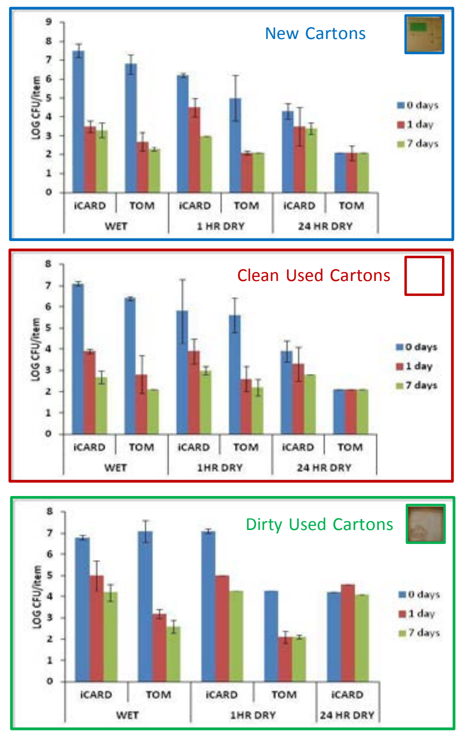


Figure 1. Transfer from inoculated cartons to tomatoes (n = 10)

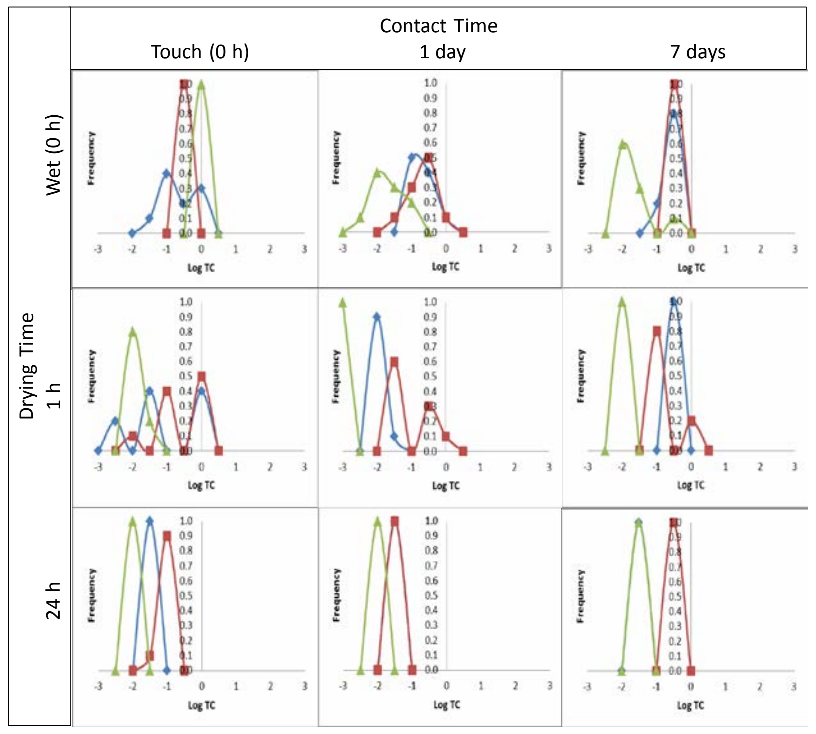


Figure 2. Distributions of transfer from inoculated new, used and dirty cartons to tomatoes (n = 10)

25°C

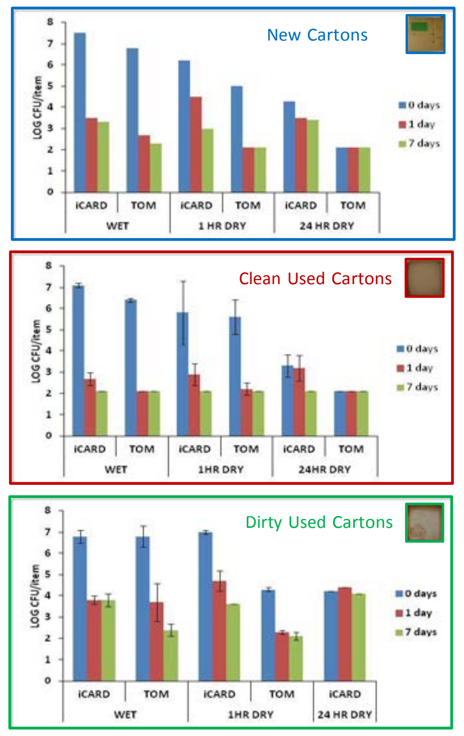


Figure 5. Transfer from inoculated cartons to tomatoes (n = 10)

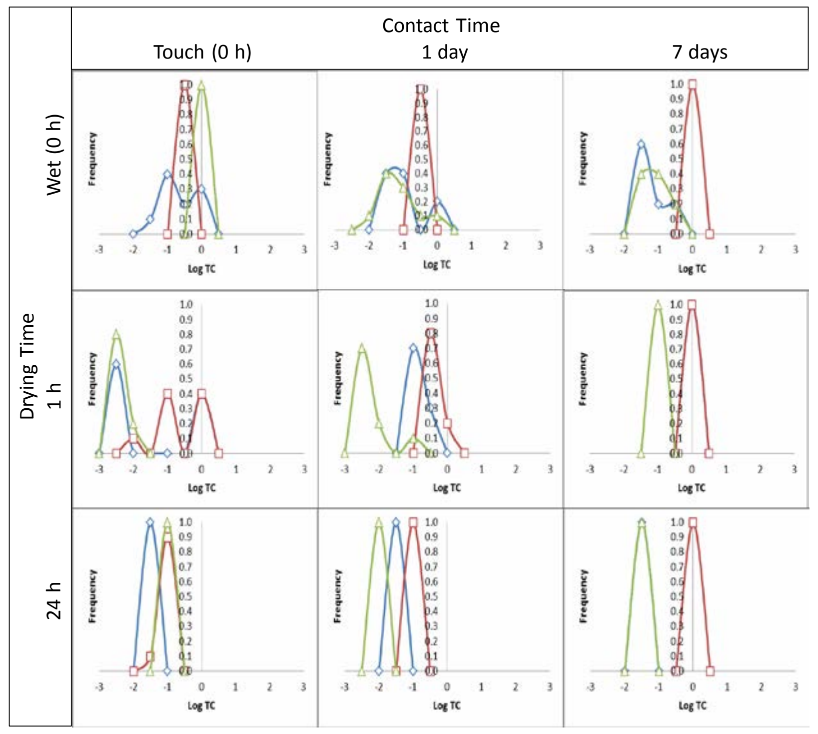


Figure 6. Distributions of transfer from inoculated new, used and dirty cartons to tomatoes (n = 10)

Inoculated Tomato to Carton

12°C

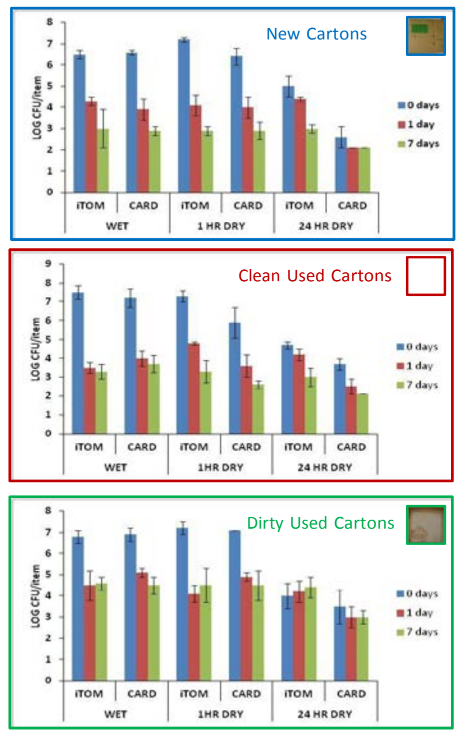


Figure 3. Transfer from inoculated cartons to tomatoes (n = 10)

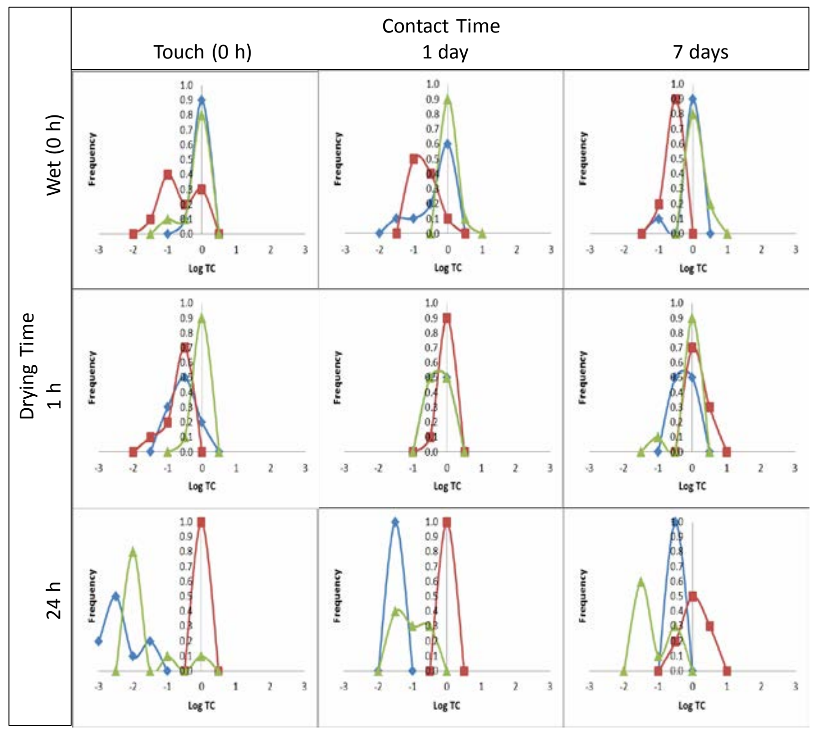


Figure 4. Distributions of transfer from inoculated new, used and dirty cartons to tomatoes (n = 10)

25°C

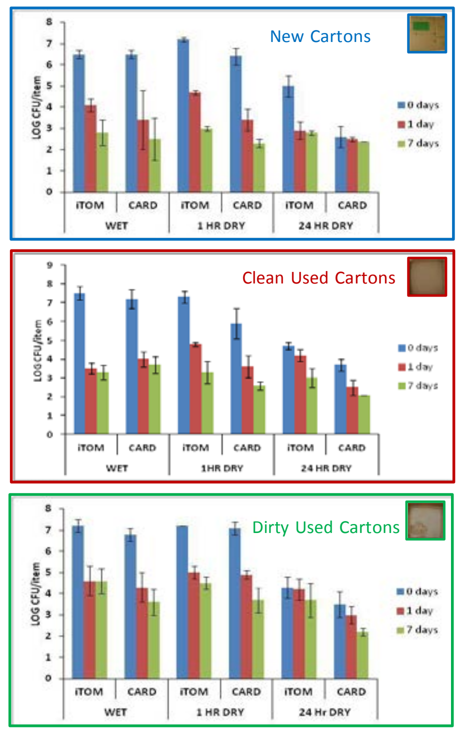


Figure 7. Transfer from inoculated cartons to tomatoes (n = 10)

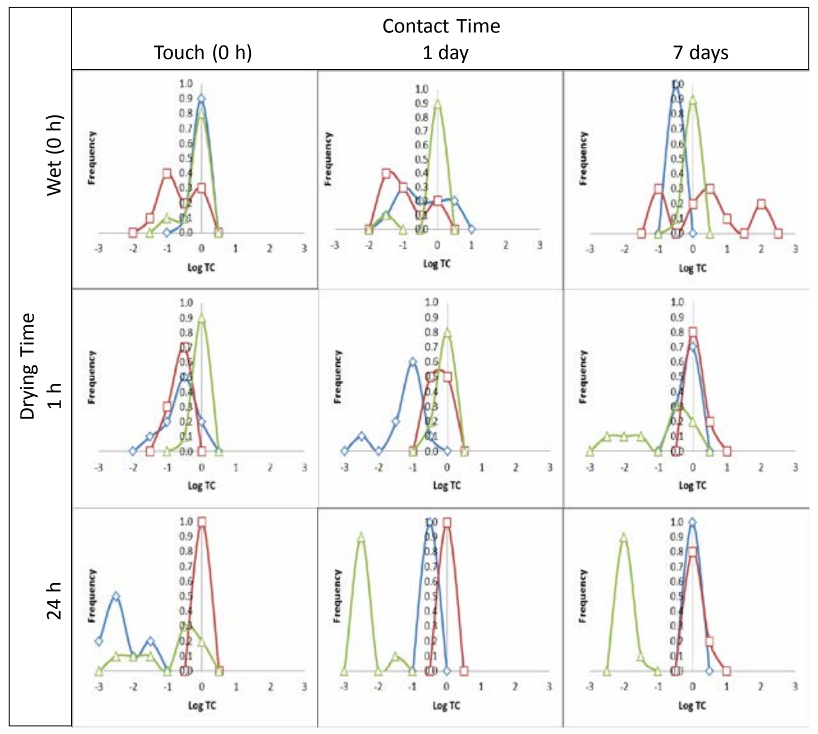


Figure 8. Distributions of transfer from inoculated new, used and dirty cartons to tomatoes (n = 10)

Summary

- Under all conditions tested, the transfer of *Salmonella* to/from tomatoes from used or dirty cartons was greater than or equal to that from new cartons.
- The worst case for *Salmonella* transfer for new cartons is under wet conditions with short contact times.
- The worst case for *Salmonella* transfer for used cartons is under wet conditions with a long contact time (0 h dry, 7 d contact, 25°C)
  - Equivalent to 1470% transfer
  - 16 times higher than from a new carton
- The worst case for *Salmonella* transfer for dirty cartons is also under wet conditions (0h, 1h dry).
- The Influence of moisture demonstrates the importance of keeping cartons and tomatoes dry.

Significance

Salmonella transfer between tomatoes and tomato cartons varies between new, used and dirty tomato cartons.

Cross-contamination risks may increase under some conditions when cartons are dirty or reused, especially under conditions where the carton or tomato are wet.

Recommendations

The practice of reusing tomato cartons may increase the risk of *Salmonella* cross-contamination to tomatoes under certain conditions. If repacking operations are reusing cartons, all efforts should be made to keep cartons and tomatoes dry.

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