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Salmonella Transfer Potential onto Tomatoes during Laboratory-Simulated In-Field Debris Removal

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ABSTRACT

Florida Tomato Good Agricultural Practices (T-GAPs) mandate the removal of dirt and debris from tomatoes during harvest but do not provide any specific regulations or guidance; thus, the current practice of using cloths needs to be evaluated. This study examined *Salmonella* transfer from inoculated green tomatoes to uninoculated cloths and from inoculated cloths to uninoculated tomatoes, upon single and multiple touches. Tomatoes were spot inoculated with a rifampin-resistant *Salmonella* cocktail (10^7 CFU per tomato) and were touched with cloth (clean, dirty-dry, dirty-wet) at 0, 1, or 24 h postinoculation. *Salmonella* was enumerated on tryptic soy agar, followed by enrichments when necessary. The transfer direction was then reversed by touching freshly inoculated cloths with uninoculated tomatoes. Transfer coefficients (TCs) were then calculated. *Salmonella* TCs from inoculated tomato and cloth were highest when the inoculum was wet (0.44 ± 0.13 to 0.32 ± 0.12), regardless of the condition of the cloth. Although *Salmonella* TCs from inoculated tomato to uninoculated cloth decreased significantly when the inoculum was dried (0.17 ± 0.23 to 0.01 ± 0.00), low levels of *Salmonella* were detected on cloth even after 24 h of drying. Inoculated dirty cloth did not transfer more *Salmonella* compared with inoculated clean cloth, and *Salmonella* survival was not higher on dirty cloth. When inoculated clean cloth (wet) was touched with 25 tomatoes, significantly higher levels of *Salmonella* were transferred to the first, second, and fourth tomatoes (0.03 ± 0.10 to 0.09 ± 0.02). However, inoculated dirty-wet (below limit of detection) and dirty-dry (0.00 to 0.04 ± 0.01) cloths transferred similar levels of *Salmonella* to all 25 tomatoes. Results indicate a low risk of potential *Salmonella* contamination when the same cloth is used multiple times for debris removal, especially under high moisture levels. Results also show that the use of dirty cloths did not increase the risk of *Salmonella* cross-contamination.

Fresh produce has been associated with numerous foodborne illness outbreaks in the United States *(5, 6)*. Minimal processing and increased consumption of fresh produce increases the potential for these outbreaks. Consumption of raw tomatoes has been linked to numerous illnesses, the majority of which were caused by nontyphoidal *Salmonella (7, 13, 32)*.

Salmonella contamination of tomatoes can occur in the field, during harvest, handling, and postharvest processing in packinghouses, or during transportation *(8, 27, 29)*. In the field, *Salmonella* contamination can occur through the application of manure that has not been properly processed, irrigation with contaminated water, or animal contact *(16, 24, 28)*. Previous studies have shown that, under laboratory conditions, *Salmonella* can persist on the surface of contaminated tomatoes *(33)* and be internalized into the fruit during processing and handling *(12, 19, 33)*, which protects the bacteria from further action of surface sanitizers *(23)*. Previous studies have also reported that single contaminated leafy greens can cross-contaminate multiple uninoculated products *(9)*, resulting in an increased risk of foodborne illness. Cross-contamination can occur during packing or during harvesting due to the use of contaminated equipment or to improper handling by farm workers. Formation and/or participation in formation of biofilms by *Salmonella* can result in better survival of the pathogen on inert surfaces it comes in contact with *(15)*, leading to subsequent cross-contamination of fresh produce *(18, 21)*. *Salmonella*'s ability to survive under suboptimal conditions in which it is unable to grow *(2, 11)* also increases the risk of cross-contamination. Minimal processing of tomatoes makes it difficult to remove pathogens once the contamination occurs; thus, prevention of contamination is the most effective way to ensure food safety and to control foodborne illnesses outbreaks.

In Florida, workers hand harvest tomatoes at the mature green stage. The fruits are often rubbed on clothing or with cloth to remove dirt, debris, and/or stems; then they are placed in plastic buckets and carried out to field trucks, where they are emptied into pallet bins or gondolas. The field trucks transport tomatoes to the packinghouse, where they are dumped into chlorinated dump tanks, moved by conveyor belts, and sorted, graded, and packed into corrugated boxes for distribution.

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The substantial economic burden associated with these outbreaks prompted the Florida tomato industry, in collaboration with the Florida Department of Agriculture and Consumer Services, to develop Tomato Good Agricultural Practices (T-GAPs), and Tomato Best Management Practices (T-BMPs) *(10)*. The enforcement of T-GAPs is required for any establishment involved in tomato production in Florida. The T-GAPs mandate removal of dirt and debris from the tomatoes to the best degree possible in the field. However, the document does not suggest any specific method to aid in the removal. As a result, the workers use various methods, including wiping the tomatoes with cloths in the field. Using the same cotton cloth multiple times to remove dirt and debris from harvested tomatoes may be a potential route for *Salmonella* cross-contamination. Condition of the cloth used for debris removal is an important consideration during this process (e.g., if the tomato surface is moist during harvest from rain or dew, the cloth will become wet during the course of the day). Further, continued use will result in fouling of the cloth due to plant debris, and using the same cloth without cleaning between days may result in enhanced survival of *Salmonella* and may increase the risk of cross-contaminating subsequently harvested tomatoes. To our knowledge, no studies have been conducted to evaluate the risk of microbial cross-contamination associated with dirt and debris removal in the field using cloth material.

The objective of this study was to evaluate the potential transfer of *Salmonella* from tomato to cloth to tomato under laboratory conditions. The transfer risk of *Salmonella* from tomatoes to clean and dirty cotton cloth (similar to ones used in the field for debris removal) and from cloth to tomatoes is quantified. Further, the effect of various factors on the transfer of *Salmonella,* including the wetness of the inoculum, the condition of the cloth, and the intensity of rubbing for debris removal, were also evaluated under laboratory conditions. The transfer potential of *Salmonella* from inoculated cloth to 25 sequentially touched uninoculated tomatoes was also examined, along with the survival of *Salmonella* on inoculated cloth for a period of 7 days under different temperature conditions. The data generated from this study will help evaluate the safety of using cloth in the field for debris removal and will provide appropriate recommendations to tomato growers.

MATERIALS AND METHODS

***Salmonella* strains and inoculum preparation.** Five rifampin-resistant *Salmonella enterica* serovars, including Montevideo (strain LJH 614, tomato outbreak, human isolate), Poona (strain LJH 631, cantaloupe outbreak, human isolate), Michigan (strain LJH 615, cantaloupe outbreak), Saintpaul (strain BAC no. 158, orange juice), and Newport (isolate from tomato outbreak, environmental), were used as a cocktail to conduct all experiments *(3)*. The strains were stored in 15% glycerol at −80°C and were streaked on tryptic soy agar (TSA; unless otherwise noted, all culture media used were from Difco, BD, Sparks, MD) plates supplemented with 80 ppm of rifampin. After growing the cultures at 37°C for 24 h, a single colony from each plate was transferred to tryptic soy broth (TSB) supplemented with 80 ppm of rifampin and was incubated overnight at 37°C. The five-strain cocktail of the *Salmonella* strains was prepared by combining 5 ml of each of the cultures, centrifugation (Sorvall RC-5B, DuPont Instruments, Wilmington, DE) for 20 min at 4,000 × *g,* washing the pellets twice in 25 ml of 0.1% peptone water, and resuspension in 25 ml of 0.1% peptone water, resulting in approximately 9 log CFU/ml *Salmonella* cocktail. The cocktail was stored for up to 1 h on ice before it was used to inoculate cloths or tomatoes.

Tomatoes and cotton cloths. Round, mature, green unwashed tomatoes (*Solanum lycopersicum*) were purchased from local packinghouses in Florida and were stored at room temperature for up to 3 days before use. To perform experiments using cotton cloths similar to the ones used in the field for debris removal during tomato harvest, 100% cotton T-shirts (Hanes-Brands, Winston Salem, NC) were purchased from local sources. The T-shirts were then subjected to a quick rinse without detergents in a consumer washing machine to remove all sizing material, dried in a laundry dryer, and cut into pieces (8 by 8 cm) using sterile scissors. The cloth pieces were then wrapped in aluminum foil (20 pieces per set) and were autoclaved for 15 min to sterilize them. To obtain dirty cloths, the autoclaved pieces of cloths were rubbed with a tomato leaf for 20 s and were used immediately (dirty-wet) or were dried under the biosafety hood for 1 h (dirty-dry).

Survival of *Salmonella* on clean and dirty cloths. The centers of clean and dirty cloths were spot inoculated with 10 drops of 10 μl (100 μl total) of the *Salmonella* cocktail (10^5 CFU per cloth). The cloth pieces were incubated at three different temperatures (15, 25, and 35°C) at 40 to 45% humidity. On days 0, 1, 3, 5, and 7, the cloth pieces were transferred to Whirl-Pak sampling bags (Fisher Scientific, Springfield, NJ) for enumeration. The experiment was conducted in triplicate and was repeated twice ($n = 6$).

Inoculation and *Salmonella* transfer between tomatoes and clean, dirty-dry, and dirty-wet cloths. Tomatoes (~220 g) were placed on aluminum rings to prevent rolling. Circles (2 to 3 cm in diameter) were drawn on one side of the tomato surface on the day of inoculation. For inoculation, 100 μl of the *Salmonella* cocktail was used, and 10 drops of the inoculum were placed on the center of the cloth or on the circled area of tomatoes, resulting in a final concentration of 10^7 CFU per surface. The inoculum was dried under a biosafety hood for 0, 1, or 24 h.

Preliminary experiments were conducted to evaluate three contact times (5, 10, and 20 s) with mild rubbing (one swipe per second with gentle pressure) to determine transfer coefficient (TC) from inoculated cloth material to the uninoculated tomato surface and from inoculated tomatoes to uninoculated cloth material. After drying the inoculum for 0, 1, or 24 h, the inoculated surface (e.g., tomato) was mildly rubbed with the uninoculated surface (e.g., cloth), for 5, 10, or 20 s. Three degrees of rubbing were also evaluated: none (touched surface gently once without swiping), mild (one swipe per second with gentle pressure), and vigorous (two swipes per second with moderate pressure), each with a single contact time of 20 s. Each experiment was conducted using five replications and was repeated twice ($n = 10$). In each replication, uninoculated tomatoes and cloths were used as negative controls, and inoculated tomatoes and cloths not subjected to rubbing were used as positive controls.

Transfer from inoculated clean, dirty-wet, and dirty-dry cloths to multiple tomatoes. Clean, dirty-wet, and dirty-dry cloths were inoculated with the *Salmonella* cocktail, and the inoculum

TABLE 1. *Survival of* Salmonella *on inoculated clean and dirty cloths for up to 7 days at three temperatures*

Cloth condition	Days postinoculation	Survival of *Salmonella*[a]		
		15°C	25°C	35°C
Clean	0	6/6 A[b]	6/6 A	6/6 A
	1	6/6 A	6/6 A	6/6 A
	3	6/6 A	6/6 A	4/6 AB
	5	6/6 A	6/6 A	4/6 AB
	7	6/6 A	1/6 B	0/6 B
Dirty	0	6/6 A	6/6 A	6/6 A
	1	6/6 A	6/6 A	6/6 A
	3	6/6 A	3/6 A	2/6 AB
	5	6/6 A	6/6 A	1/6 B
	7	6/6 A	0/6 B	1/6 B

[a] Number of positive enrichments/total number of enrichments.
[b] Letters represent significant differences within the same temperature and cloth condition only; same letters represent no significant differences ($P \geq 0.05$; Fisher's exact test).

was dried for 0, 1, or 24 h as described above. The inoculated cloths were then touched (without rubbing) sequentially with 25 tomatoes. Each tomato was then placed in a Whirl-Pak sampling bag for enumeration. The experiment was conducted using three replications and was repeated three times ($n = 9$).

Enumeration and enrichment. After contacting the inoculated surface, the uninoculated tomato or cloth was immediately placed in a Whirl-Pak bag, and 100 ml of 0.1% peptone water was added to the bag. The bags containing cloths were placed in a homogenizer (AES Chemunex, Inc., Cranbury, NJ) and were macerated for 90 s. The tomatoes in Whirl-Pak bags were subjected to a rub-shake-rub process for 90 s: the contacted surface was rubbed for 30 s, the Whirl-Pak bag containing tomatoes was shaken for 30 s, and then the contacted surface was rubbed again for 30 s. One milliliter of the sample was drawn from each bag, and serial dilutions were made using 0.1% peptone water. The dilutions were surface plated (100 μl per plate) in duplicate on TSA containing 80 ppm of rifampin. To increase the limit of detection, when the inoculum was dried for 1 or 24 h, 1 ml was plated directly from the sample bag (250 μl per plate). The plates were incubated at 37°C for 24 h, and colonies were counted.

TCs were calculated by dividing the *Salmonella* log CFU on the touched surface by that on the inoculated surface. To calculate TCs, the equation TC = Pt/Pi was used, where Pt is the *Salmonella* population (log) on a touched surface (log CFU per surface on tomato or cloth), and Pi is the *Salmonella* population (log) on an inoculated surface prior to the transfer (log CFU per surface). Final TCs were averaged across the 10 replications.

When the bacterial counts were below detection limits (1.4 CFU per surface), enrichment was performed, following the U.S. Food and Drug Administration (FDA)'s *Bacteriological Analytical Manual* (BAM) protocol *(31)*. Tomato samples showing counts below the limit of detection were placed in Whirl-Pak bags, 20 ml of double-strength lactose broth (LB) was added to the bags, and the samples were incubated at 37°C. After 24 h, 100 μl and 1 ml of the mixture were transferred to 9.9-ml tubes of Rappaport-Vassiliadis R10 and tetrathionate broths, respectively. The Rappaport-Vassiliadis tubes were then incubated at 42°C for 48 h, and tetrathionate tubes were incubated at 37°C for 24 h. After incubation, 10-μl loopfuls were streaked on bismuth sulfite agar, xylose lysine desoxycholate agar, and Hektoen enteric agar and were incubated at 37°C for 24 h. Presumptive individual *Salmonella*-positive colonies were stab inoculated on triple sugar iron and lysine iron agar slants for confirmation.

Statistical analysis. Analysis of variance and Tukey's least-squares means significance test ($P \leq 0.05$) were performed on the TCs averaged across 10 replications, using SAS 9.2 (SAS Institute, Cary, NC). The results obtained following *Salmonella* enrichment were analyzed using Fisher's exact method in SAS.

RESULTS

***Salmonella* survival on clean and dirty cloths.** Enumerable levels of *Salmonella* were not present on either clean or dirty inoculated cloths after day 0, at any of the three incubation temperatures (data not shown). Enrichment of the cloth samples showed that *Salmonella* survival was highest at 15°C, at which temperature 100% of both the clean and dirty cloths showed presence of the bacterium (Table 1).

***Salmonella* transfer between inoculated tomatoes and uninoculated cloths during single touch.** Statistical analysis of the preliminary results to determine the optimum contact time for *Salmonella* transfer showed that the level of *Salmonella* transfer was not significantly ($P > 0.05$) affected by the contact time ($P \leq 0.05$), regardless of the condition of cloth and inoculum drying time. Hence, a 20-s contact time was selected for use in subsequent experiments.

The results indicated that the degree of rubbing did not significantly ($P > 0.05$) affect the level of *Salmonella* transfer, regardless of the inoculum drying time and condition of the cloth (Table 2). Inoculum drying time had the most significant effect on *Salmonella* transfer; the highest transfer occurred when the inoculum was wet (0 h), compared with when the inoculum was dried for 1 or 24 h (Table 2). In most cases, the *Salmonella* transfer levels were not significantly ($P > 0.05$) different when the inoculum was dried for 1 h or for 24 h. The only exception was that, when a clean cloth was used to contact inoculated tomatoes with a mild degree of rubbing, the transfer rate was significantly higher at 1 h than at 24 h. Similarly, the condition of the cloth did not significantly ($P > 0.05$) affect *Salmonella* transfer under any condition, except when the cloths were mildly rubbed on inoculated tomatoes 1 h postinoculation (Table 2). In this case, significantly ($P \leq 0.05$) higher levels of *Salmonella* were transferred to clean cloths than to dirty-wet and dirty-dry cloths. The degree of rubbing did not have a significant ($P > 0.05$) effect on *Salmonella* transfer, regardless of the inoculum drying time (0, 1, 24 h) and the condition of cloth used (clean, dirty-wet, dirty-dry) (letters for comparison not shown in Table 2).

Salmonella transfer from inoculated cloths (clean, dirty-wet, dirty-dry) to uninoculated tomatoes was also evaluated. A preliminary experiment revealed that, when the inoculum was dried for 1 or 24 h, enumerable levels of *Salmonella* were not transferred from inoculated cloth to tomatoes, regardless of the condition of the cloth (data not shown). Enrichment of these tomatoes following the FDA BAM method revealed that, after 1 h of inoculum drying, <30%

TABLE 2. Salmonella *log transfer coefficients from inoculated tomatoes to cloths as influenced by cloth condition, degree of rubbing, and drying time*[a]

Degree of rubbing	Cloth condition	Drying time: 0 h	1 h	24 h
None	Clean	0.37 ± 0.07 AX	0.04 ± 0.06 BX	0.02 ± 0.00 BX
	Dirty-wet	0.39 ± 0.13 AX	0.05 ± 0.06 BX	0.02 ± 0.00 BX
	Dirty-dry	0.41 ± 0.12 AX	0.02 ± 0.05 BX	0.02 ± 0.00 BX
Mild	Clean	0.35 ± 0.06 AX	0.17 ± 0.23 BX	0.01 ± 0.00 CX
	Dirty-wet	0.44 ± 0.13 AX	0.03 ± 0.05 BY	0.03 ± 0.03 BX
	Dirty-dry	0.39 ± 0.09 AX	0.01 ± 0.01 BY	0.04 ± 0.06 BX
Vigorous	Clean	0.32 ± 0.12 AX	0.05 ± 0.05 BX	0.02 ± 0.00 BX
	Dirty-wet	0.40 ± 0.11 AX	0.03 ± 0.05 BX	0.03 ± 0.03 BX
	Dirty-dry	0.39 ± 0.10 AX	0.02 ± 0.04 BX	0.02 ± 0.00 BX

[a] Letters A, B, and C indicate significant differences across the three different inoculum drying times, within the same degree of rubbing and cloth condition (comparisons within the same row). Letters X and Y indicate significant differences across the three different cloth conditions, within the same degree of rubbing and inoculum drying time (comparisons within the same column).

of the tomatoes were positive for *Salmonella* (data not shown). When the inoculum was dried for 24 h, none of the tomatoes in contact with inoculated cloth tested positive for *Salmonella*; thus, the degree of rubbing (none, mild, vigorous) on inoculum transfer from cloth to tomato was only evaluated using the wet inoculum (0 h drying).

The degree of rubbing significantly ($P \leq 0.05$) affected *Salmonella* transfer from inoculated cloth to tomato when clean and dirty-wet cloths were used, but not when dirty-dry cloths were used (Fig. 1). Touching the tomato on an inoculated clean cloth without rubbing resulted in a significantly ($P \leq 0.05$) higher transfer of *Salmonella* (0.48 ± 0.14), compared with mild (0.08 ± 0.07) or vigorous (0.12 ± 0.07) rubbing. However, when dirty-wet cloths were used, the TC was significantly ($P \leq 0.05$) higher when the cloths were rubbed mildly (0.01 ± 0.01), compared with no rubbing (0.00 ± 0.00) or vigorous rubbing (0.00 ± 0.00). The condition of the cloth also significantly affected *Salmonella* transfer rates when the tomatoes were touched on inoculated cloth without rubbing or with vigorous rubbing. When mild rubbing was used, there was no significant ($P > 0.05$) difference between the cloths. When the tomatoes were touched on inoculated cloth without rubbing, clean cloth transferred significantly ($P \leq 0.05$) higher levels of *Salmonella* (0.48 ± 0.14) compared with dirty-wet (0.00 ± 0.00) and dirty-dry (0.01 ± 0.01) cloths. Upon vigorous rubbing, inoculated clean cloth transferred the highest levels of *Salmonella* (0.12 ± 0.07), followed by dirty-dry (0.01 ± 0.01) and then by dirty-wet (0.00 ± 0.00) cloth.

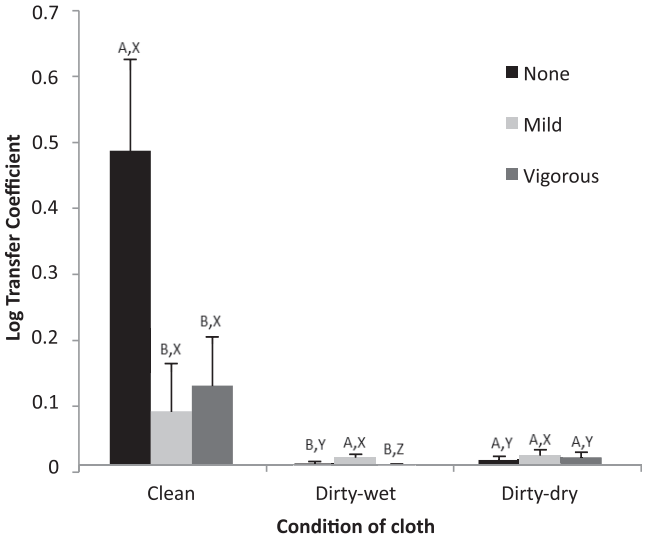

FIGURE 1. Salmonella *transfer from inoculated cloths (clean, dirty-wet, and dirty-dry) to tomatoes, subjected to three degrees of rubbing (none, mild, and vigorous), 0 h postinoculation. Letters A and B indicate significant (*$P \leq 0.05$*) differences across the three different degrees of rubbing, within the same cloth condition. Letters X, Y, and Z indicate significant (*$P \leq 0.05$*) differences across the three different cloth conditions, within the same degree of rubbing.*

***Salmonella* transfer from cloth to multiple tomatoes.** When 25 uninoculated tomatoes (T1 through T25) were sequentially touched to the inoculated cloths, enumerable levels of *Salmonella* were transferred only when the inoculum was wet (0 h drying) (Table 3). When the inoculum was wet, *Salmonella* was transferred to all 25 tomatoes (determined by enrichment) regardless of the cloth condition, although enumerable levels of *Salmonella* were not present on all the tomatoes. TC was highest when tomatoes were rubbed on inoculated clean cloth, with significantly ($P \leq 0.05$) higher transfer rates on tomatoes T1, T2, and T4 ($P \leq 0.05$). When the tomatoes were rubbed on dirty-dry and dirty-wet cloths, there was no significant ($P > 0.05$) difference between the TCs on tomatoes T1 through T25. Because enumerable levels of *Salmonella* were not present in all the samples, enrichment using the FDA BAM protocol was also conducted; this revealed the presence of *Salmonella* on all 25 tomatoes when the inoculum was wet. Enumerable levels of *Salmonella* were not transferred to any of the 25 tomatoes when the inoculum was dried for 1 or 24 h. Enrichment of these samples revealed that the majority of the 25 tomatoes were positive (detection limit more than one cell per tomato) for *Salmonella* when the inoculum was

TABLE 3. Salmonella *transfer from inoculated (wet) cloth to 25 subsequently touched tomatoes*[a]

	Clean cloth			Dirty-wet cloth			Dirty-dry cloth		
		log TC			log TC			log TC	
Tomato no.	Population	Avg	Range	Population	Avg	Range	Population	Avg	Range
Cloth	5.7 ± 0.2	—	—	5.7 ± 0.3	—	—	5.7 ± 0.2	—	—
T1	4.2 ± 0.6	0.09 ± 0.20 A	0.00–0.47	<2.6 ± 0.5[b]	8/9	0.00–0.00	2.9 ± 1.2	0.04 ± 0.10 A	0.00–0.19
T2	<2.8 ± 1.2[b]	0.03 ± 0.10 AB	0.00–0.15	2.4 ± 0.4	9/9	0.00–0.00	<2.6 ± 1.3[b]	0.00 ± 0.10 A	0.00–0.19
T3	<2.4 ± 0.7[b]	0.00 ± 0.00 B	0.00–0.01	2.2 ± 0.3	9/9	0.00–0.00	<2.6 ± 1.4[b]	0.03 ± 0.10 A	0.00–0.14
T4	<2.3 ± 1.1[b]	0.03 ± 0.10 AB	0.00–0.28	2.3 ± 0.6	9/9	0.00–0.00	<2.4 ± 1.7[b]	7/9	0.00–0.01
T5	<2.0 ± 0.5[b]	7/9		2.1 ± 0.9	9/9	0.00–0.03	<2.0 ± 0.5[b]	7/9	0.00–0.00
T6	<1.7 ± 0.4[b]	5/9		<2.2 ± 1.0[b]	8/9	0.00–0.03	<2.2 ± 1.0[b]	0.01 ± 0.00 A	0.00–0.05
T7	<1.6 ± 0.3[b]	6/9		<2.1 ± 1.0[b]	7/9	0.00–0.05	<2.1 ± 0.7[b]	6/9	0.00–0.00
T8	<1.6 ± 0.3[b]	3/9		<2.4 ± 1.2[b]	6/9	0.00–0.03	<2.4 ± 1.0[b]	0.01 ± 0.00 A	0.00–0.02
T9	<1.7 ± 0.4	6/9		2.2 ± 1.0	9/9	0.00–0.04	<1.9 ± 0.6[b]	7/9	0.00–0.00
T10	<1.6 ± 0.4[b]	7/9		<2.2 ± 1.2[b]	8/9	0.00–0.02	<1.8 ± 0.4[b]	8/9	0.00–0.00
T11	<1.5 ± 0.1[b]	3/9		<2.3 ± 1.2[b]	8/9	0.00–0.04	<2.0 ± 1.0[b]	7/9	0.00–0.03
T12	<1.4 ± 0.0[b]	6/9		2.0 ± 0.9	9/9	0.00–0.02	<2.3 ± 1.1[b]	0.01 ± 0.00 A	0.00–0.06
T13	<1.5 ± 0.3[b]	3/9		<2.2 ± 1.1[b]	5/9	0.00–0.02	<1.8 ± 0.6[b]	6/9	0.00–0.01
T14	<1.6 ± 0.4[b]	4/9		<2.2 ± 1.4[b]	5/9	0.00–0.04	1.9 ± 0.2	9/9	
T15	<1.4 ± 0.1[b]	3/9		<2.2 ± 1.2[b]	6/9	0.00–0.02	<1.7 ± 0.7[b]	6/9	
T16	<1.5 ± 0.2[b]	4/9		<1.8 ± 1.1[b]	5/9	0.00–0.04	<1.8 ± 0.4[b]	8/9	
T17	<1.5 ± 0.2[b]	1/9		<1.6 ± 0.2[b]	6/9	0.00–0.00	<1.8 ± 0.4[b]	8/9	
T18	<1.4 ± 0.1[b]	3/9		<1.9 ± 0.9[b]	5/9	0.00–0.00	<1.7 ± 0.3[b]	7/9	
T19	<1.5 ± 0.2[b]	2/9		<1.6 ± 0.3[b]	5/9	0.00–0.00	<1.8 ± 0.4[b]	7/9	
T20	<1.5 ± 0.2[b]	2/9		<1.9 ± 0.9[b]	6/9	0.00–0.01	<1.8 ± 0.4[c]	5/9	
T21	<1.4 ± 0.0[b]	2/9		<1.5 ± 0.2[b]	3/9	0.00–0.00	<1.6 ± 0.4[b]	6/9	
T22	<1.5 ± 0.1[b]	3/9		<2.0 ± 1.1[b]	4/9	0.00–0.01	<1.9 ± 0.5[b]	8/9	
T23	<1.4 ± 0.0[b]	5/9		<1.4 ± 0.0[b]	4/9		<1.4 ± 0.0[b]	7/9	
T24	<1.4 ± 0.0[b]	2/9		<1.4 ± 0.0[b]	6/9		<1.4 ± 0.0[b]	6/9	
T25	<1.4 ± 0.0[b]	4/9		<1.4 ± 0.0[b]	3/9		<1.4 ± 0.0[b]	6/9	

[a] Enrichment following FDA BAM protocol. Population, average *Salmonella* population (log CFU per tomato or cloth; $n = 9$) ± standard deviation. Log TC, log transfer coefficient, average ± standard deviation and range, or number of positive enrichments/total number of enrichments. Letters represent significant differences within columns only; same letters represent no significant differences ($P \geq 0.05$).
[b] Replications were occasionally below the limit of detection.

dried for 1 h (Table 4). None of the samples were positive when the inoculum was dried for 24 h (data not shown).

DISCUSSION

Prevention of *Salmonella* cross-contamination during harvest and postharvest handling of tomatoes is an important step in minimizing the microbial food safety hazard associated with tomatoes. As required by the Florida T-GAPs, harvesters in the field need to remove excess dirt and debris from the harvested tomatoes; however, it is necessary to validate whether this common practice of using cotton cloth to eliminate debris increases the risk of contamination. *Salmonella* was transferred from cloths to tomatoes under all conditions tested, regardless of cleanliness of the cloth. Cloths used during harvest should be considered food contact surfaces and a source of potential *Salmonella* cross-contamination.

The transfer of *Salmonella* from inoculated tomatoes to uninoculated cloths and from inoculated cloths to uninoculated tomatoes is highly dependent on the wetness of the inoculum, with increased transfer at higher moisture levels. Various studies have shown that drying the inoculum significantly affected microbial transfer between surfaces *(3, 17, 20, 26)*. A study by Sattar et al. *(25)* indicated that moisture increased the transfer of bacteria to and from cotton, and cotton and polyester (50/50 blend ratio) fabrics. In single touch studies, in which the inoculated tomatoes were touched with clean and dirty cloths, the degree of rubbing and condition of the cloth did not significantly ($P > 0.05$) affect *Salmonella* transfer. However, when the inoculated cloth was touched with a single tomato, the condition of the cloth and the degree of rubbing significantly ($P \leq 0.05$) affected *Salmonella* transfer, in addition to the wetness of the inoculum. The inoculum beaded up on the surface of the clean cloth and was not absorbed, contributing to the increased transfer observed from inoculated clean cloth to the uninoculated tomatoes. Presence of ''dirt'' (debris from tomato leaf used in this study) on the surface of the cloth made it more porous, increasing the inoculum absorption into the cloth, resulting in significantly ($P \leq 0.05$) less transfer of *Salmonella* to the tomatoes. This observation corresponds with previous studies that have shown that the presence of organic matter on the surface of gloves increases its porosity, which binds the *Salmonella* and leads to less transfer of *Salmonella* onto tomatoes *(3, 22)*. Under actual harvesting conditions, the

TABLE 4. Salmonella *transfer from inoculated (dried) cloth to 25 subsequently touched tomatoes*[a]

Tomato no.	No. of positive samples/total no. of enrichments		
	Clean cloth	Dirty-wet cloth	Dirty-dry cloth
T1	2/9 AB	4/9 AB	3/9 AB
T2	5/9 A	4/9 AB	7/9 A
T3	0/9 B	3/9 AB	4/9 AB
T4	3/9 AB	4/9 AB	3/9 AB
T5	0/9 B	3/9 AB	3/9 AB
T6	2/9 AB	3/9 AB	4/9 AB
T7	0/9 B	3/9 AB	3/9 AB
T8	1/9 AB	2/9 AB	4/9 AB
T9	2/9 AB	3/9 AB	2/9 AB
T10	1/9 AB	3/9 AB	2/9 AB
T11	2/9 AB	3/9 AB	2/9 AB
T12	3/9 AB	1/9 AB	4/9 AB
T13	1/9 AB	5/9 A	4/9 AB
T14	2/9 AB	1/9 AB	4/9 AB
T15	4/9 AB	0/9 B	3/9 AB
T16	0/9 B	2/9 AB	3/9 AB
T17	2/9 AB	2/9 AB	3/9 AB
T18	2/9 AB	2/9 AB	1/9 B
T19	1/9 AB	2/9 AB	3/9 AB
T20	0/9 B	5/9 A	1/9 B
T21	1/9 AB	1/9 AB	2/9 AB
T22	1/9 AB	3/9 AB	1/9 B
T23	1/9 AB	2/9 AB	2/9 AB
T24	0/9 B	1/9 AB	3/9 AB
T25	0/9 B	4/9 AB	2/9 AB

[a] Enrichment following FDA BAM protocol. Cloths were inoculated with 10^7 CFU per cloth, and inoculum was dried for 1 h. Capital letters represent significant differences within columns only; same letters represent no significant differences ($P \geq 0.05$; Fisher's exact test).

material that builds up on a cloth will vary depending on a number of environmental conditions, including the soil and the variety of tomato being harvested. The results of this study suggest that the use of cloths that absorb any moisture that may be present or that have ''dirt'' built up on them will decrease the risk of *Salmonella* transfer from cloth to tomatoes. Touching the inoculated clean cloth with an uninoculated tomato transferred significantly ($P \leq 0.05$) higher levels of *Salmonella* to the tomatoes when compared with rubbing the inoculated surface. Mild or vigorous rubbing of the inoculated cloth resulted in further absorption of the inoculum into the clean cloth surface, decreasing the transfer. This study focused on 100% cotton cloth; the ability of the cloth material to absorb inoculum may influence the transfer from cloths to tomatoes during harvest.

In single touch studies, a higher level of variability was observed in the *Salmonella* TCs from inoculated tomato to uninoculated cloth when the inoculum was dried for 1 h, compared with when the inoculum was dried for 0 or 24 h. A drying time of 1 h caused nonuniform drying of the inoculum, resulting in varying amounts of moisture remaining on the inoculated surface. This may have resulted in variable transfer of the inoculum to the tomatoes. Variable moisture is likely to occur during tomato harvest and, hence, may be representative of most tomato harvest operations.

When a single inoculated cloth (wet, 0 h; or dried, 1 h) was touched sequentially with multiple tomatoes, low levels of *Salmonella* were transferred to up to 25 uninoculated tomatoes, regardless of the cloth condition. *Salmonella* was not transferred from inoculated cloth to uninoculated tomato when the inoculum was dried for 24 h, possibly due to the reduced survival of *Salmonella* on inoculated cloth after 24 h (as indicated by the results of the survival experiment conducted in this study). Thus, there was risk of potential contamination when a freshly contaminated (0 h drying) cloth was used to wipe debris from multiple tomatoes; however, the risk decreased as the cloth dried (from 1 to 24 h). The presence of debris did not significantly ($P > 0.05$) increase *Salmonella* survival, although storage in cold conditions improved *Salmonella* survival on inoculated cloth. Previous studies have also reported the ability of *Salmonella* to survive better in cold temperatures *(1, 4, 14, 30).*

Salmonella can transfer from cloths used during harvest to tomatoes; this practice increases the risk of cross-contamination. *Salmonella* transfer was significantly ($P \leq 0.05$) reduced when the inoculum was dried, highlighting the importance of harvesting and handling dry tomatoes. The presence of ''dirt'' on cloths did not pose a higher risk of *Salmonella* transfer than clean cloth. Although *Salmonella* populations decreased on cloths following drying, inoculum drying for even 1 day is not sufficient to eliminate *Salmonella* transfer to tomatoes. Washing and drying any cloths used during tomato harvest is an important step to prevent cross-contamination from one day to the next and should not be neglected.

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