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The Effect of Steps in the Food Production Process on Microbial Quality of High-Risk Produce Collected Near the U.S.-Mexico Border.

By

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Master of Science in Public Health

Environmental Health and Epidemiology

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B.S., The Ohio State University - Columbus, Ohio, 2012

Thesis Committee Chair: Juan Leon, PhD, MPH

An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Science in Public Health
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Abstract

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The burden of foodborne disease attributed to fresh produce in the U.S. is substantial in terms of costs and human health implications. Currently, Mexico is one of the major traders of produce with the U.S., and therefore it is important to understand the nature of this relationship as it relates to food safety. However, few epidemiological studies have assessed the routes by which microbial contamination is introduced into the food chain during production of fruits and vegetables. It is essential to identify these routes in order to implement targeted food safety interventions and ultimately reduce foodborne illnesses. The study goals were to evaluate the effects of production step on microbial concentration and prevalence of fecal indicator organisms on high-risk produce (cantaloupe melons, jalapeño peppers, and tomatoes) and farm workers' hands over multiple growing seasons from 2010-2011. Produce samples (n=254) and farmer workers' hand rinses (n=171) were collected from 11 farms and packing sheds near the U.S.-Mexico border and enumerated by culture methods for *E. coli*, fecal coliforms, *Enterococcus* spp., and somatic coliphages. Linear regression and logistic regression modeling approaches were employed to quantify differences in microbial quality of produce and hands at different production steps. The final packing shed step, melons, and year of sample collection were significantly and positively correlated with fecal indicator concentration and prevalence on produce. However, contamination was still present, but at significantly lower concentrations in the field steps, indicating that contamination may originate in the field and be amplified in the packing shed, especially for melons. Both regression methods produced estimates of similar direction and significance. In summary, the packing shed step, melons, and year of sample collection were significantly associated with microbial concentrations on produce. This investigation highlights several potential routes of produce contamination in the production environment and demonstrates the need to implement food safety interventions in packing shed facilities on produce farms, as well as the need for extra care be taken to adequately clean melons prior to shipment.

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INTRODUCTION

PRODUCE AS FOODBORNE DISEASE VEHICLE

The incidence of foodborne disease outbreaks in the U.S. has been increasing in recent years *(5)*. The U.S. annual estimation of illnesses caused by contaminated food is 48 million cases, with roughly 1000 reported disease outbreaks, 128,000 hospitalizations, and 3000 deaths *(5)*. Societal costs related to foodborne illnesses are significant, especially economic burdens such as hospitalization costs for sick individuals, works days lost to employee illness, and widespread food recalls for contaminated products *(5)*. The full magnitude of the U.S. population suffering from foodborne illness is unknown and is likely larger than current estimates, as only individuals who are significantly ill enough to seek medical care and submit a laboratory specimen for analysis are likely to become entered as a case in foodborne surveillance systems *(5)*. Throughout the last three decades, these reported foodborne outbreaks have increasingly been associated with fresh produce that is uncooked before consumption *(37, 46)* In a study analyzing produce-associated outbreaks, foodborne pathogen-contaminated items that have been commonly implicated include salad, lettuce, juice, melon, sprouts, berries, peppers, tomatoes, and spinach *(37, 46)*.

CHANGING NATIONAL FOOD CONSUMPTION PATTERNS

The observed increase in outbreaks could be a result of several recent trends in food consumption, including increased consumption of fresh produce per capita in the U.S. and year-round consumer demand for different types of produce regardless of the usual growing season *(37)*. Due to this increased demand, this often requires the U.S. to import the majority of its fresh produce from foreign countries during the cold season, especially from the subtropics or the other hemisphere *(37)*. In a 2014 trade review conducted by the Congressional Research Service, U.S. fruits and vegetable imports have more than tripled in value since the 1990's *(32)*. Although fresh produce imports constitute 25% of the total volume of produce currently sold in supermarkets nationwide, this percentage is projected to increase to well over 30% within the next five years *(33)*. The largest supplier of fresh produce imports to the U.S. is Mexico, which accounted for 36% of the U.S.'s total import value in 2011 *(32)*. The increase in Mexican produce trade presents significant challenges in terms of new food safety risks and the potential for distribution of contaminated products across the U.S. that can be implicated in foodborne outbreaks. As an example, the consumption of Mexican cantaloupe during the spring seasons of 2000-2002 caused a multi-state outbreak of *Samonella enterica* serovar Poona *(13)*. Additional outbreaks that have occurred include Hepatitis A associated from consumption of contaminated frozen Mexican strawberries in 1997 *(12)*, as well as an outbreak causing nearly 1500 cases of cyclosporiasis due to contaminated raspberries that had also originated from Mexico *(11)*. Overall, this increase in fresh produce imports and consumption may present opportunities and heightened risks for introduction of novel foodborne pathogenic microorganisms in production processes and widespread food distribution networks *(7)*.

CHALLENGES IN FOOD SAFETY POLICY

Under the Food Safety Modernization Act, the U.S. Food and Drug Administration (FDA) is granted the authority to impose the same U.S. food safety standards on food imports coming into the country *(20)*. Additionally, the Produce Safety Rule will be the first to grant authority to enforce a federal standard on U.S. fruit and vegetable production *(17)*. However, FDA officials lack the capacity to fully monitor and enforce these standards across the sheer number of foods being imported daily into the country *(17, 33)*. Although the FDA proposed the Produce Safety rule, based on previously published voluntary guidelines in 1998 *(18, 19, 49)*, Good Agricultural Practices (GAPs) and Good Manufacturing Practices (GMPs), provides a framework to identify potential foodborne pathogen contamination pathways and implement food safety practices throughout the production process, several gaps in knowledge remain *(17, 18, 20)*. While many previous studies have focused on developing decontamination methods, few have attempted to quantify the risk of introducing microbial contamination onto produce along the farm-to-fork chain, or evaluate the effectiveness of practices to mitigate risks throughout the production processes and transport of fresh fruits and vegetables.

PRODUCTION PROCESSES AS INTRODUCTION POINTS OF CONTAMINATION

There are several points along the fresh produce production process in which microbial contamination can occur, from prior to harvest in the field through harvest, packaging, retail, and preparation in the kitchen. Studies on field conditions have shown that factors such as poor quality irrigation water, runoff from storm water, entry of animals onto premises, and application of feces to the fields as fertilizer have been implicated as sources of contamination *(21, 23, 24)*. Risky initial field conditions may be compounded as increased demand for fresh produce can cause changes in farm land management practices, including having to plant produce next to animal production lots and wild animal zones (reviewed in *(37)*). In the post-harvest stages of production, microbial hazards included contaminated surfaces in the final packing shed step, deficiencies in farm workers' hygiene, and improper cooling of produce for shipment *(36, 45)*. However, the majority of these studies drew their conclusions from outbreak data, and while these findings are still valuable in identifying potential hazardous steps, they do not enable assessment of the relative risk contributed by various production practices or steps to identify those best to target with food safety interventions. Furthermore, these conclusions were published retrospectively after widespread distribution of contaminated food products to large consumer population or large-scale sale bans have been placed on implicated produce *(1)*. Therefore, by identifying critical contamination steps before the produce reaches the consumer, this aid in preventing foodborne pathogen illnesses and ultimately save both time and resources for consumers, medical profession, and food production companies *(5)*.

FECAL INDICATORS AS MODELS FOR PATHOGEN CONTAMINATION

To better understand the influence of production steps in the food production process on microbial quality of this high-risk Mexican produce, we chose to assess produce quality through quantifying fecal indicators rather than directly testing for foodborne pathogens. This is because these pathogens are often present at undetectable levels and are only focally distributed in the environment, making them difficult to locate by laboratory testing methods *(3, 33, 34)*. Microbes that are typically assayed in investigations of the microbial quality of food and the environment include *Escherichia coli*, fecal coliforms, total *Enterococcus*, and somatic coliphage. All of these organisms serve as indicators of fecal contamination, or fecal indicators. Therefore, they are also indicators of potential presence of enteric pathogens of fecal origin, and are the standard test organisms to assess the quality and hygienic conditions of the production process. Fecal indicators, while not usually harmful to human health, are commonly found in both human and animal feces, more numerous in the environment compared to other human pathogens, and are easier to detect by laboratory culture methods. *(3, 28, 30)*

PREVIOUS RESEARCH GROUP FINDINGS

There is a strong need to understand how international food production processes in particular introduce microbial contamination and how this affects to food safety, as people are at high risk for illness if fresh produce is consumed raw *(10)*. In order to address this knowledge gap, the Clean Greens Research Group focuses its studies on understanding the enteric pathogen contamination of produce items considered "high-risk" that have been implicated in several recent foodborne outbreaks in the U.S., i.e. cantaloupe melons, tomatoes, and jalapeño peppers. From previous pilot studies, we found that contamination on produce increases in the final packing shed steps of the production process, but that U.S. and Mexican produce arrive at U.S. sheds contaminated (data not shown). Due to these findings, we chose to focus on contamination routes of Mexican produce contamination in the field through harvest steps leading up to the packing shed. We previously conducted two cross-sectional field epidemiological studies in both farms and packing sheds located near the U.S.-Mexico border *(3, 33, 34)*. We chose to assess produce quality through quantifying and testing for the presence of fecal indicators. Overall, we found that produce samples that were taken from the packing shed were more contaminated compared to those in the fields. For melons in particular, microbial indicator concentrations differed significantly between different production steps, especially for generic *E. coli* in general throughout the general packing process and

Enterococcus concentrations were found to increase between the conveyor belt (post-washing) and the packing box steps *(33, 34)*.

RESEARCH GOAL

To build upon our previous epidemiological studies, there still remains a need to understand the impact of different steps in the food production chain on the levels of contamination by fecal indicators on produce. Our goal is to quantify concentrations and prevalence of fecal indicators on produce and rinse samples collected from farm workers' hands at several production steps on farms and packing sheds. Previous studies have yet to address the link between potential contamination to produce that occurs throughout the production process and how it relates to the hygiene practices of farm workers who handle this produce at each step. These findings can then be applied to developing evidence-based, food-safety interventions on farms to ultimately reduce foodborne illness burden.

MATERIALS AND METHODS

Institutional review board approval was granted by the lead institution (Emory University) covering the duration of this cross-sectional study (approval number IRB00035460). From the period of May to December in 2011 and 2012, produce and workers' hand rinse samples were collected from 11 farms in the Mexican states of Nuevo León and Coahuila on the United States-Mexico border. This region is a major agricultural area that regularly exports to the United States and has high production volumes of some crops that are considered at elevated risk for contamination with enteric pathogens: cantaloupe melons (referred to as melons from here forth), tomatoes, and jalapeño peppers *(15)*. Five farms produced cantaloupes, five farms produced tomatoes, and five farms produced jalapeños, with four farms producing both tomatoes and jalapeños.

DESCRIPTION OF FIELD CONDITIONS AND AGRICULTURAL PRACTICES IN PRODUCTION PROCESS

Information on general production process practices on study farms were gathered from interviews with farm managers and observational surveys comparing conditions to the standards set by the U.S. Food and Drug Administration (FDA) *(39)*.

All of the farms used deep well water as their main source of irrigation. The farmers used drip irrigation, which can be described as hoses running down the length of the field. The hoses have small holes in them, allowing the water to drip slowly out, directly into the soil, without touching the produce. Farmers irrigated their fields every one to four days for several hours. Farmers also added synthetic fertilizer, fungicide and insecticides to irrigation water.

Harvesting was done by hand, without gloves. Farm workers were paid by the piece, i.e. they were paid by the quantity of produce they picked, rather than by the hour. Jalapeños and tomatoes were packed into nylon net bags, burlap sacks (domestic), or plastic bins. Some workers used knives to cut the stalks. The produce was then either sent directly to the distributor, to an off-site certified packing house, or to on-farm packing sheds with machinery to sort them by size. Some farms reported only using new bins if the produce was being exported to the U.S. Melons were cut by hand and field packed or sent to packing sheds. Several farms had conveyor belts that loaded the melons into trucks for transport, and on other farms melons were passed via a line of people down the field. In the packing sheds, melons were sprayed with a chlorine solution, moved down rollers made of PVC pipe, passed through a set of brushes to remove residual dirt, and then rinsed by a spraying system. Next, melons were hand selected by farm workers based on quality, sent up a conveyor belt for a second quality selection by workers, put onto a ramp to be manually packed in plastic boxes, and then finally put in cold room storage until shipment to distributors *(39)*.

PRODUCE SAMPLE COLLECTION

Produce samples were collected at four different steps in the production process: before harvest (i.e. Before Harvest), immediately after harvest (i.e. After Harvest), during distribution away from the field (i.e. Distribution), and at the packing shed (i.e. Packing Shed) if present. At each of these steps, produce samples were collected at three random locations in the field (Before Harvest and After Harvest), on the transport truck (Distribution), or the packing shed (Packing Shed), and triplicate samples were composited. Rinses were collected in Whirl-Pak bags (Nasco, Fort Atkinson, WI) containing 500 ml 0.15% sterile peptone water (PW). Produce was shaken for 30 seconds, massaged for 30 seconds, and then shaken once more for 30 seconds. Composite samples represented rinses from 54 tomatoes, 42 jalapeños, or 6 melons in 1500 ml of PW. The specific numbers of tomatoes, jalapeños, and melons were chosen to provide an equivalent surface area across produce types.

FARM WORKERS' HAND RINSE SAMPLE COLLECTION

Before sample collection, researchers obtained written consent from farm managers and oral consent from farm workers to collect a hand rinse sample that was matched to each of the pieces of produce that were picked as follows. Workers were asked to first give pick the produce samples for collection, and then asked to give their hand rinses samples. The worker placed his or her hand in a Whirl-Pak bag containing 750ml PW. The worker was asked to shake the hand for 30 seconds, and then the hand was massaged for an additional 30 seconds. The first hand was removed, the second hand was placed in the same bag, and the process was repeated. Three individual hand rinse samples (representing the hands of three pickers or packers) were combined to create a composite sample of 2,250 ml that was divided into smaller subsamples for specific microbiological testing.

MICROBIAL ANALYSIS

Composite samples were partitioned into smaller subsamples for microbial indicator testing. For bacterial indicator analyses, samples were concentrated by membrane filtration. Sample volumes, ranging from 10 µl to 50 ml for produce and from 0.01 µl to 250 ml for hand rinses were vacuum filtered through a 47 mm, 0.45 µm pore size S-Pack filter (Millipore, Billerica, MA). Following filtration, filters were placed on selective media for microbial quantification. *Enterococcus spp.* were enumerated using KF Streptococcus agar (Oxoid Limited, Basingstoke, Hampshire, UK) incubated at 37°C for 48 hours. Generic *E. coli* and fecal coliforms were enumerated on RAPID'E. coli 2 agar (Bio-Rad Laboratories, Inc., Hercules, CA) incubated at 44°C for 24 hours. Somatic coliphage was quantified using FastPhage MPN Quanti-tray (Charm Sciences, Inc., Lawrence, MA) incubated at 37°C for 6 hours. Samples were mixed with fluorescence-based media inoculated with *E. coli* and then partitioned into Most Probable Number (MPN) compartments. Because compartments with at least one plaque forming unit (PFU) fluoresce under UV light, the number of fluorescing compartments was used to determine MPN using a conversion table *(4)*. Depending on the concentration of particulates in the original sample, 100 ml of sample or 10 ml of sample diluted with 90 ml of PW was used for analysis.

MICROBIAL QUANTIFICATION

The number of colony forming units (CFU) per filtered volume was used to quantify bacterial indicator concentrations (*E. coli*, *Enterococcus*, fecal coliforms) in each sample. The most probable number (MPN) was used to quantify somatic coliphage. Indicator concentrations on produce were measured in CFU or MPN per fruit. Measuring concentrations per ml (equivalent to per 736 cm^2) served to correct for differences in fruit surface area.

An indicator was determined to be present in a sample if the sample had any positive assay for that indicator. The limits of detection for *E. coli* and fecal coliform assays were 2.778 CFU/tomato, 3.571 CFU/jalapeño pepper, 25 CFU/melon, and 37.5 CFU/hand. The limits of detection for *Enterococcus* were 0.555 CFU/tomato, 0.714 CFU/jalapeño pepper, 5 CFU/melon, and 5 CFU/hand. The limits of detection for coliphages were 0.278 MPN/tomato, 0.357 MPN/jalapeño, 2.5 MPN/melon, and 2.5 MPN/hand. Samples below the limit of detection were assigned a concentration value halfway between zero and the limit of detection (0.5 CFU per largest filtered volume; 0.5 MPN per effective volume) *(44)*.. The quantifiable range was 25 to 250 CFU per plate (bacteria) and 1 to 2420 MPN per tray (coliphage), although in some instances values below or above this CFU range were observed and recorded. Based on the observed CFU per plate across replicate assays, each produce or hand rinse sample was assigned a type: below quantifiable range, within, or above. For samples with plate counts not equal to zero but below the quantifiable range, plates with the largest effective volumes were used for estimation. For samples with one or more plates within the quantifiable range, only such plates were used for quantification. For samples with countable plates above the quantifiable range, values from plates with the smallest effective volumes were used for estimation. Samples with concentrations so far above the limit of quantification that no CFU value could be determined were assigned a concentration value equal to two times the limit of quantification (500 CFU per smallest filtered volume; 4840 MPN per effective volume).

For statistical purposes, all produce and hand rinse sample types were used for analysis. Statistical analyses conducted using only samples within the quantifiable range (type 3) and analyses conducted using all sample types produced the same results (data not shown). At times, statistical analyses could not be run using only type 3 samples, due to small sample size. Thus, it was advantageous to consider all samples.

STATISTICAL ANALYSIS

To answer our original study question, statistical analyses were performed using the SAS version 9.3 statistical analysis software package (SAS Institute, Inc., Cary, NC) at an alpha level of 0.05. To assess the normality of the data distribution of our samples' fecal indicator concentrations, a Shapiro-Wilk test was performed. All sample groups were found to be non-normally distributed (data not shown), and thus the concentrations (CFU/fruit) of fecal indicators *E. coli*, fecal coliforms, *Enterococcus*, and somatic coliphage within produce and hand-rinse samples were $\log_{10}$ transformed before statistical analyses. Descriptive analyses were performed to compare the prevalence (presence/absence) and geometric mean concentrations ($\log_{10}$ CFU/fruit) of all four of these fecal indicators amongst all produce samples and hand-rinse samples at different steps in the food production process (Before Harvest: "Before," After Harvest: "After," Loading onto Distribution Truck: "Distribution," Packing Shed: "Packing Shed").

To begin the analysis, linear regression was performed to analyze correlations of the $\log_{10}$ transformed concentrations of the four fecal indicator organisms and steps in the food production process. The preliminary models for this portion of the analysis included produce type, year of sample collection, and the interaction term between production step and produce type. The final analysis was then performed by stratifying both the produce and hand rinse samples by produce type (tomatoes, jalapeños, and melons), and including in the model the production step and year of sample collection variables. For linear regression models, the reference group for production steps was the packing shed step, while the reference group for sampling year was Year 2. Models were considered statistically significant if the 95% confidence limits surrounding the resulting beta estimates did not contain the null value of 0.

Next, logistic regression was performed to compare the presence of the four fecal indicators for all produce rinse samples and all hand-rinse samples at different steps in the food production process. Additionally, the interaction between steps in the food production process and type of produce was investigated. The preliminary models for this portion of the analysis included produce type, year of sample collection, and the interaction term between production step and produce type. The final analysis was then performed by stratifying both the produce and hand rinse samples by produce type (tomatoes, jalapeños, and melons), and including in the model the production step and year of sample collection variables. For logistic regression models, the reference group for production steps was the packing shed step, while the reference group for sampling year was Year 2. Firth penalized likelihood approach was applied to models where the stratified sample groups had very small sample sizes, in order to correct potential biases to the parameter estimates *(22)*. Models were not able to be built in instances where produce or hand rinse samples were all positive for a particular fecal indicator. Models were considered statistically significant if the 95% Wald confidence intervals surrounding the resulting odds ratio did not contain the null value of 1.

RESULTS

DESCRIPTIVE STATISTICS

Escherichia coli, fecal coliform, *Enterococcous* spp., and somatic coliphages were quantified in rinse samples collected from each of the different produce types (tomatoes, jalapeño peppers, and melons) across several production steps (Before Harvest, After Harvest, Distribution, and Packing Shed) and three distinct time periods referred to as sampling years (Pilot, Year 1, and Year 2). All concentrations were $\log_{10}$ transformed prior to analysis. Normality of the data distribution was assessed using the Shapiro-Wilks test; microbial concentration data were found to be not normally distributed (data not shown). Descriptive statistics are presented by production step and produce type for each fecal indicator organism on produce (Table 1 [concentration units expressed per fruit] and Appendix Table A1 [concentration units expressed per ml sample]) and hands (Table 2). These tables also include produce and hand sample sizes and prevalence of each fecal indicator. Overall, most of the fecal indicators, especially for *E. coli* and fecal coliforms, there were increased concentrations and prevalence of these organisms observed in the packing shed step. *Enterococcus* had relatively stable distribution throughout each of the production steps. Additionally, concentrations and prevalence of these organisms were in general higher for melons compared to tomatoes and jalapeño peppers (Table 1 and Appendix Table A1).

MODEL CONSTRUCTION

In order to determine whether contamination concentrations observed throughout the production process differed significantly for different types of produce, multivariate linear and logistic regression models with interaction terms were evaluated. Models were constructed with the outcome of indicator concentration (linear) or prevalence (linear) predicted by production step, while adjusting for produce type, year of sample collection, and interaction of produce type and production step. After employing backwards selection, the models remaining significant predictor variables included the interaction between produce type and production step (Appendix Tables A2-A3). Therefore, the analysis was stratified by type of produce for all subsequent models described. Statistical significance was set at $\alpha = 0.05$ for all analyses. A subsequent analysis was conducted using CFU/ml or MPN/ml units on produce data, and the results of this analysis did agree with results from CFU/fruit analysis (See Appendix).

LINEAR MODEL RESULTS

The final stratified linear models included production step and year of sample collection as predictors of fecal indicator concentrations on produce and hands associated with each produce type. Effect estimates (β) and 95% confidence intervals of fecal indicator concentrations on produce and hands for each of the produce types are presented in Table 3.

PRODUCE

We found that *E. coli* concentrations on produce varied significantly between steps in the production of jalapeño peppers and melons (Figure 1 and Figure 3), but not tomatoes (Table 3). In general, for jalapeño peppers, all steps in the production process had concentrations that were significantly lower than the packing shed concentrations (Before Harvest: p=0.005; After Harvest: p=0.004; Distribution: p=0.007) (Figure 3). An increase of $\log_{10}$ 1 CFU/fruit in *E. coli* concentration on jalapeño peppers in the packing shed was associated with a decrease of 2.192 $\log_{10}$ CFU/fruit on jalapeños in the field prior to harvest, a decrease of 2.260 $\log_{10}$ CFU/fruit after harvesting, and a decrease of 2.118 $\log_{10}$ CFU/fruit at the point of distribution. This same trend was observed for melon produce rinse samples (Before Harvest: $p<0.0001$; After Harvest: $p<0.0001$; Distribution: $p<0.0001$). An increase of $\log_{10}$ 1 CFU/fruit in *E. coli* concentration on melons in the packing shed was associated with a decrease of 3.546 $\log_{10}$ CFU/fruit on melons in the field prior to harvest, a decrease of 3.654 $\log_{10}$ CFU/fruit after harvesting, and a decrease of 2.113 $\log_{10}$ CFU/fruit at the point of distribution.

For fecal coliform concentrations (CFU/fruit), only melons had a significantly lower concentrations at steps prior to the packing shed step (Before Harvest: $p=0.002$; After Harvest: $p<0.0001$; Distribution: $p=0.002$) (Figure 1 and Figure 3) (Table 3). An increase of $\log_{10}$ 1 CFU/fruit in fecal coliform concentration on melons in the packing shed was associated with a decrease of 0.796 $\log_{10}$ CFU/fruit on melons in the field prior to harvest, a decrease of 1.104 $\log_{10}$ CFU/fruit after harvesting, and a decrease of 0.835 $\log_{10}$ CFU/fruit at the point of distribution. No significant differences in were found in fecal coliform concentrations across production steps of jalapeño peppers or tomatoes.

Enterococcus (CFU/fruit) concentrations did not vary significantly between the packing shed step and the other production steps on any of the different types of produce (Before Harvest: $p=0.1133$-0.9610; After Harvest: $p=0.1181$-0.3357; Distribution: $p=0.0568$-0.3539) (Table 3).

Finally, for coliphage concentrations (MPN/fruit), tomatoes were the only produce type that had significantly different concentrations between the packing shed and the prior production steps (Before Harvest: $p=0.0038$; After Harvest: $p=0.0172$; Distribution: $p=0.0093$) (Figure 1 and Figure 3) (Table 3). An increase of $\log_{10}$ 1 MPN/fruit in coliphage concentration on tomatoes in the packing shed was associated with a decrease of 1.28 $\log_{10}$ MPN/fruit on tomatoes in the field prior to harvest, a decrease of 1.05 $\log_{10}$ MPN/fruit after harvesting, and a decrease of 1.16 $\log_{10}$ MPN/fruit at the point of distribution. In summary, we found a statistically significant relationship between *E. coli*, fecal coliforms, and somatic coliphage concentrations on produce and production steps, but not *Enterococcus* concentrations.

Finally, this same strategy of analysis was performed using the concentration data expressed per ml of produce rinse sample (Appendix Table A4). In general, the results agreed overall with the results of the analysis described for the CFU/fruit and MPN/fruit data. In summary, we found a statistically significant relationship between production steps and *E. coli* concentrations on jalapeño peppers and melons, fecal coliform concentrations on melons, and somatic coliphage concentrations on tomatoes, but no association was observed between production steps and *Enterococcus* concentrations.

HANDS

We found that *E. coli* concentrations on workers' hand rinses (CFU/hand) varied significantly between different production steps only from melon fields (Figure 2 and Figure 4) (Table 3). Hand rinses from all steps in the melon production process prior to the packing shed had concentrations that were significantly lower than the packing shed concentrations (After Harvest: $p<0.0001$, Distribution: $p<0.0001$). An increase of $\log_{10}$ 1

CFU/hand in *E. coli* concentration on workers' hands in the packing shed was associated with a decrease of 2.35 $\log_{10}$ CFU/hand on workers' hands in the field after harvesting melons, and a decrease of 2.19 $\log_{10}$ CFU/hand on hands at the point of distribution from melon fields.

Fecal coliform concentrations on workers' hand rinses (CFU/hand) varied significantly between the packing shed and prior production steps for both tomatoes and melons (Figure 2 and Figure 4). Workers' hand concentrations in tomato fields differed from most of the other trends seen previously, with the packing shed step actually having the lowest concentrations of fecal coliforms compared to the previous production steps (After Harvest: p=0.0066; Distribution: p=0.0344). An increase of $\log_{10}$ 1 CFU/hand in fecal coliform concentration on workers' hands in the packing shed was associated with an increase of 1.54 $\log_{10}$ CFU/hand on workers' hands in the field after harvesting tomatoes, and an increase of 1.18 $\log_{10}$ CFU/hand on hands at the point of distribution in tomato fields. The concentrations of fecal coliforms on workers' hands in melon fields reflected the same general trend as previously observed, where hands in the packing shed had significantly higher concentrations of fecal coliforms compared to the prior production steps (After Harvest: p=0.0128; Distribution: p=0.0030). An increase of $\log_{10}$ 1 CFU/hand in fecal coliform concentration on workers' hands in the packing shed was associated with an decrease of 0.73 $\log_{10}$ CFU/hand on workers' hands in the field after harvesting melons, and a decrease of 0.91 $\log_{10}$ CFU/hand on hands at the point of distribution in melon fields.

For both *Enterococcus* (CFU/hand) (After Harvest: p=0.2874-0.6013; Distribution: p=0.1826-0.6480) and coliphage (MPN/hand) (After Harvest: p=0.0994-0.6957;

Distribution: p=0.2415-0.9720) concentrations, none of the production steps had any significant association with the concentrations of these organisms on worker's hands, regardless of produce type. In summary, we found a statistically significant relationship between production steps and *E. coli* and fecal coliforms concentrations on workers' hands, but this association was not observed for *Enterococcus* or somatic coliphage concentrations.

LOGISTIC MODELS RESULTS

The final stratified logistic models included production step and year of sample collection as predictors of fecal indicator presence on produce and hands associated with each produce type. In some cases, Firth correction was applied in order to adjust analyses for small sample sizes. Odds ratios (OR's) and 95% confidence intervals of fecal indicator prevalence for each of the produce types are presented in Table 4.

<u>PRODUCE</u>

We found that *E. coli* prevalence on melons varied significantly between production steps (Before Harvest: p=0.0001; After Harvest: p<0.0001; Distribution: p=0.0008), but this was not true for tomatoes (Before Harvest: p=0.2486; After Harvest: p=0.0722; Distribution: p=0.6322) or jalapeños (Before Harvest: p=0.1804; After Harvest: p=0.0777; Distribution: p=0.2762) (Table 4). As indicated in the linear model results, melons from the packing shed were significantly more likely to be contaminated by *E. coli* than melons from the three preceding production steps (Figure 1 and Figure 5). Melons sampled before harvest were 500 times less likely to contain *E. coli* than melons sampled from the packing shed (Before Harvest: OR=0.002) (Table 4), with a 47%

increase in prevalence of *E. coli* observed for samples collected from the packing shed compared to samples collected before harvest (Table 1). Melons sampled after harvesting were more than 1000 times less likely to contain *E. coli* than melons sampled from the packing shed (After Harvest: OR=<0.001) (Table 4), with a 59% increase in prevalence of *E. coli* observed for samples collected from the packing shed compared to samples collected after harvest (Table 1). Melons sampled at the point of distribution from the field were 34.5 times less likely to contain *E. coli* than melons sampled from the packing shed (Distribution: OR=0.029) (Table 4), with a 34% increase in prevalence of *E. coli* observed for samples collected from the packing shed compared to samples collected at the point of distribution (Table 1). In summary, *E. coli* prevalence on melons varied significantly between production steps, and melons from the packing shed were significantly more likely to be contaminated, but *E. coli* prevalence between different production steps did not differ significantly for tomatoes or jalapeños.

Fecal coliform prevalence did not differ significantly between production steps for any of the types of produce. Because all melon samples were positive for fecal coliform presence, logistic models were not constructed for these data. For tomatoes and jalapeños, models were constructed and no significant differences were detected (Before Harvest: p=0.6629-0.8625; After Harvest: p=0.6887-0.8308; Distribution: p=0.6629-0.8625) (Table 4).

This same pattern was observed for *Enterococcus* (Before Harvest: p=0.3526-0.9898; After Harvest: p=0.5131-0.9851; Distribution: p=0.3080-0.8358).

An unusual result for somatic coliphage prevalence on jalapeño peppers was observed, where jalapeño peppers collected before harvest were significantly more likely to be contaminated by coliphages than jalapeños from any of the other three production steps (Before Harvest: p=0.0255; After Harvest: p=0.2604; Distribution: p=0.1996) (Figure 1 and Figure 5) (Table 4). Produce sampled before harvest was about 143 times more likely to contain coliphages than produce sampled from the packing shed (Before Harvest: OR=143.734) (Table 4), with a 50% decrease in prevalence of coliphages observed for samples collected from the packing shed compared to samples collected before harvest. However, this same observation was not seen for coliphage prevalence on tomatoes (Before Harvest: p=0.0559; After Harvest: p=0.0943; Distribution: p=0.0943) or melons (Before Harvest: p=0.5579; After Harvest: p=0.2343; Distribution: p=0.4772) (Table 4).

In summary, we found a statistically significant increase in *E. coli* prevalence on melons from the packing shed compared to other production steps, and somatic coliphage prevalence on jalapeño peppers was highest before harvesting, but no association was observed between production steps and fecal coliform or *Enterococcus* prevalence on any produce type.

HANDS

Melon field workers' hands were significantly more likely to be contaminated with *E. coli* at the packing shed compared to the preceding production steps (After Harvest: p=0.0038, Distribution: p=0.0210) (Figure 2 and Figure 5) (Table 4). Workers' hands sampled after harvesting melons were 7.19 times less likely to contain *E. coli* than workers' hands sampled from the packing shed (After Harvest: OR=0.139) (Table 4), with a 26% increase in prevalence of *E. coli* observed for hand rinse samples collected from the packing shed compared to samples collected from workers after harvesting melons (Table 2). Workers' hands sampled at the point of distribution in melon fields were 4.74 times less likely to contain *E. coli* than workers' hands sampled from the packing shed (Distribution: OR=0.139) (Table 4), with a 23% increase in prevalence of *E. coli* observed for hand rinse samples collected from the packing shed compared to samples collected at the point of distribution in melon fields (Table 2). Prevalence of *E. coli* in hand rinses from tomato and jalapeño workers did not differ significantly between production steps (After Harvest: p=0.5332-0.7030; Distribution: p=0.4508-0.8915) (Table 4). In summary, melon field workers' hands were significantly more likely to be contaminated with *E. coli* at the packing shed compared to the preceding production steps, but prevalence of *E coli* on field workers' hands from tomato and jalapeño farms did not differ significantly between any of the production steps.

Fecal coliform (After Harvest: p=0.4255-0.6189; Distribution: p=0.7443-0.8143), *Enterococcus,* and coliphage prevalence (After Harvest: p=0.1153-0.7348; Distribution: p=0.1510-0.7348) in hand rinses did not differ significantly between the production steps for any produce type (Table 4). *Enterococcus* was found on 100% of workers' hands, and thus no analyses could be performed on this set of indicator data. This also occurred with fecal coliform prevalence data on workers' hands from melon fields (Table 1).

In summary, we found a statistically significant relationship between production steps and *E. coli* prevalence on workers' hands who work in melon fields, but no association was observed between production steps and fecal coliform, *Enterococcus,* or somatic coliphage prevalence on workers' hands.

DISCUSSION

The primary goal of this study was to evaluate the influence that different steps in the production process have on the concentration and prevalence of microbial fecal indicators (*E. coli*, fecal coliforms, *Enterococcus,* and somatic coliphage) on both fresh produce and farm workers' hands, accounting for other produce-associated factors including produce type and year of sample collection. A secondary goal was to compare two approaches to model the microbial datasets for this project: standard Linear and Logistic regression models.

From these goals, we had five main findings. To address our primary goal, we first found that of all the production steps, produce samples and workers' hand rinse samples from the packing shed step had the highest overall concentrations and prevalence of fecal indicators in the majority of cases where a statistically significant difference was found among production steps. The only model that differed from this pattern was a linear model of *E. coli* on workers' hands from tomato fields. Our second main finding from our final models assessing the effect modification of produce type on production step was that melons and hand rinse samples from melon fields more often had statistically significant differences in fecal indicator contamination between production steps compared to jalapeño peppers and tomatoes (Refer to Table 3 and Table 4). Thus, the effect of production steps depended on the type of produce. Third, the overall relationship between fecal indicator contamination and production steps was not a positive, linear pattern that would be expected if the high concentrations and prevalence of indicators in packing shed samples had been the result of accumulation of contamination from previous steps. Our fourth main finding in investigating other produce-associated factors was that year of sample collection turned out to be a statistically significant predictor of fecal indicator contamination in the majority of our models (See Tables 3 and 4). Finally, to address our secondary goal, we found that in some instances of our final models, the linear and logistic regression models did not agree in their results. Each of these five main findings are discussed in subsequent sections of this document.

PACKING SHED AS PRODUCTION STEP OF CONCERN FOR MICROBIAL QUALITY OF PRODUCE AND WORKERS' HANDS

In the majority of the cases where a significant effect of production step was identified, produce and hand rinse samples from the packing shed step were found to have the highest concentration and prevalence of fecal indicator contamination. Several mechanisms related to packing shed operations and produce handling could provide insight into our observations, including increased contact between pieces of produce, contaminated equipment surfaces, and handling by farm workers' hands.

First, one possible explanation could include increased contact of produce with other pieces of produce that could potentially be contaminated. Procedures in the packing shed, such as dumping produce into communal rinse tanks, may increase the potential of one contaminated piece of produce to spread this contamination to other pieces of produce *(8)*. Good Agricultural Practices include monitoring and treatment (e.g. chlorination) of rinse tank water to reduce the risks of cross contamination *(18)*. This measure may not be completely effective in removing all contamination *(29)*. Several published studies have highlighted risks associated with use of water baths. In an outbreak of salmonellosis associated with eating uncooked tomatoes from a single tomato packing facility in South Carolina, contamination was found to likely have been distributed amongst other tomatoes when all of the tomatoes were dumped into a communal water bath *(29)*. The increase in contamination in packing sheds during washing stages compared to field conditions was also seen in melon production facilities. Rind of field fresh melons had 2.5 – 3.5 $\log_{10}$ CFU/g concentrations of total coliforms by aerobic plate counts, compared to washed melon rinds that had 4.0 – 5.0 $\log_{10}$ CFU/g concentrations *(23)*. Cilantro and parsley samples following wash steps have also been shown to have increases in total coliform contamination *(34)*. Overall, the concentrations of chlorine typically found in rinse steps has been shown to minimally reduce the microbial loads on produce items *(8)*, and rinsing additionally presents the possibility that contaminated pieces of produce become intermixed with clean produce, allowing for the propagation of contamination to other produce and equipment throughout processing.

Another possible mechanism for higher observed fecal indicator contamination in the packing sheds is increased contact of produce with equipment surfaces that may be contaminated (unpublished data *(43)*). If a single, focal source of contamination is introduced onto a piece of equipment in a packing shed, contamination may be transferred to all the pieces of produce that touch the equipment. Because this equipment may be used in the packaging process for many pieces of produce, the initially focal contamination can be amplified. In one study, produce samples collected from equipment in the packing shed were more likely to be contaminated with *E. coli* compared to produce samples from the field *(3)*. In another study, conveyor belts in the packing sheds were found to harbor *Listeria monocytogenes (41)*. An additional study hypothesized that conveyor belts are susceptible points to bacterial contamination in the packing facilities, as many consist of an abrasive, brush-like material that may prove difficult to thoroughly clean by workers *(34)*. Overall, produce contact with communal surfaces that may be contaminated can allow for dissemination of contamination throughout further processing steps and other pieces of produce.

A final proposed mechanism for the increased contamination on produce in the packing shed could be increased handling by workers which may be contaminated due to, for example, use of toilets without proper washing stations present toilet use. Survey data collected from farms participating in our study indicated that some of the packing facilities lack toilet facilities and hand washing stations (unpublished data). From this same survey data, farm worker activities in the packing sheds require more frequent handling of produce compared to those in the field including transportation of fruit from the truck to conveyor belts, sorting of produce based on quality, and packing into boxes for shipment (unpublished data *(39)*). This increased contact with hands that may potentially be contaminated due to lack of sanitary hand washing facilities introduces many routes of fecal indicator contamination throughout the production process.

SIGNIFICANTLY DIFFERENT MICROBIAL QUALITY OF MELONS BETWEEN PRODUCTION STEPS

After adjusting for produce-associated variables, the interaction term between production step and produce type was found to be significant in both linear and logistic models. This indicates that the effect of production step on microbial quality depends on the type of crop being produced. For our linear and logistic models, the majority of results from our final models identified melons as having significant associations between produce contamination and production steps. Using our same dataset, a study determining the effects of produce type on concentrations and prevalence of the same fecal indicators and associated drip irrigation water found that overall, melons had significantly higher concentrations of *E. coli*, fecal coliforms, *Enterococcus*, and somatic coliphage compared to jalapeños and tomatoes (Unpublished data *(27)*). Other studies have also observed increased contamination on melons compared other types of produce. A previous study conducted on two Texan farms that screened for the presence of *E. coli* and Salmonella in collected environmental samples and produce samples (melons, oranges, and parsley) found that melons were more likely to be tested positive for Salmonella presence and have higher concentrations of *E. coli* compared to the oranges and parsley *(16)*. In another study conducted on 15 farms and 8 packing sheds with 14 types of produce in the southern United States, melons also were found to have significantly higher prevalence and mean *E. coli* concentrations, as well as *Enterococcus* prevalence and concentrations compared to other types of produce that were screened for contamination *(3).*

Several mechanisms may contribute to the heightened susceptibility of melons to accumulate and retain microbial contamination throughout the production process. The physical properties of melons rinds, with a porous, netted hydrophobic surface structure can promote microbial attachment and protect microbes from environmental insults such as ultraviolet radiation or packing shed processes such as washing and antimicrobial agents *(38, 42, 47)*. Additionally, the natural low acidity of melons (pH>5.3) *(25)* compared to peppers (4.65 to 5.45) *(48)* and tomatoes (pH 4.0 to 4.5) *(35)* may support the growth of foodborne pathogens, which optimally grow at pH 7.0 *(6)*. Fecal indicator organisms also optimally grow in low-acidity conditions, such as *E. coli (6)*, *Enterococcus spp. (50)*, and total coliforms *(2)*.

Melons, grown on the ground, also have increased potential to acquire contamination from soil as compared to crops with edible portions that do not contact the soil *(19)*. Melon surfaces in direct contact with soil are susceptible to development of “ground spots”, or regions of the rind that are thinner and less developed than the rest of the melon surface. *(19)*. Melons with ground spots have been demonstrated to support larger microbial populations compared to melons without ground spots *(21, 40)*.

Finally, a prominent factor in increased contamination may be associated with the increased contact that melons have with farm workers’ hands throughout the production process. It is possible that due to the heavier nature of melons compared to other types of produce, as well as harvesting practices necessary to pick melons off the vine and turn them over throughout the growing season to prevent ground spot development *(19)*, this requires much more handling by farm workers throughout the production process. If workers lack proper access to toilet facilities or hand washing stations, harvesting steps that are labor intensive and require significant handling of the melons present potential introduction points of pathogens. Therefore, it is important that workers practice good hand hygiene measures and avoid working if they have personal illness to reduce the likelihood of contamination introduction into the growing environment *(21)*.

POSITIVE NON-LINEAR PATTERN OF FECAL INDICATOR CONTAMINATION THROUGHOUT PRODUCTION STEPS INDICATE THAT CONTAMINATION PRESENT IN FIELD STEPS

While the packing shed had significantly higher concentrations and prevalence of fecal indicator concentrations, contamination was not absent at preceding steps, as shown in our observations of non-linear increases in concentrations and prevalence of these indicators on produce and workers' hands throughout the production process. Several mechanisms can provide insight for these observations. Based on farm surveys from our study, farmers indicated that animals were present in or around several of the fields from which samples had been collected. This suggests potential for introduction of contamination in the field by animal fecal matter *(3) (31)*. Additionally, farm workers with lack of access to sanitary facilities or hand washing stations in the field may also contribute to observed levels of contamination on both produce and farm workers' hands at steps that take place prior to packing *(37)*. Agricultural water used in the field must also be taken into consideration. Previous studies on *E. coli* O157:H7 have implicated irrigation water as a source of contamination in several lettuce-related *E. coli* O157:H7 outbreaks *(14)*. Overall, farmers must be aware of and attempt to contain sources of contamination that may originate in the field and be amplified as produce moves through the production process.

YEAR OF SAMPLE COLLECTION AS STATISTICALLY SIGNIFICANT PREDICTOR OF MICROBIAL QUALITY

In our results, the year in which a produce or hand rinse sample was collected (Pilot and Year 1) appeared to be a statistically significant predictor of fecal indicator contamination

(Tables 3 and 4). In previous studies, the significance of ecological factors related to the sample collection year was investigated as a potential predictor of fecal indicator contamination (APC, total coliforms, and total *Enterococcus*). It was found that average daily temperature and daily total precipitation were positively associated with APC and *Enterococcus* concentrations (unpublished data *(51)*). Another study that used multivariate logistic regression models to identify factors associated with *E. coli* contamination on produce found that produce samples gathered during the autumn months of the year had significantly higher concentrations of *E. coli* compared to samples gathered throughout the rest of the year *(3)*. Other studies have indicated that warm temperatures can support the amplified growth, survival, and proliferation of foodborne pathogens *(9)*. Overall, environmental conditions present in the field steps of the production process may be strong predictors of fecal indicator contamination. Thus, more research is necessary to assess exactly how these conditions play a role in influencing microbial flora present in agricultural fields.

COMPARISON OF LINEAR AND LOGISTIC REGRESSION RESULTS

Linear and logistic regression modeling approaches did not always identify significant effects of production step for the same indicators and sample types. Linear and logistic regression analyses using *E. coli* data from melon rinses agreed with each other. Both regression analyses modeling *E. coli* on workers' hands from melon fields also agreed. However, the remaining five significant linear models and one logistic model did not support the findings of each other. Previous studies modeling biological data have also found this trend when comparing modeling methods. In a study conducted by Zhao et al. that compared the strengths of using logistic and linear regression to model types of percentage data commonly used in food microbiology (i.e. percent-growth-positive, germination extent, probability for one cell to grow, and maximum fraction of positive tubes), logistic models had an overall lower deviation, more accuracy in predicting new data points, and stronger linear correlation between observations and logistic predictions than linear models *(52)*. However, in our study design it was important to include both prevalence and concentration data in our analysis due to a lack of information from one or the other type of data for some points. Examples of non-informative data include instances in our *E. coli* concentration data where a large number of samples had concentrations that were below the limit of detection. Additionally, several groups of samples from specific steps in the production process had *Enterococcus* prevalence of 100% (Refer to Table 1). Thus, in these examples, either concentration data or prevalence data were non-informative. Rather than throwing out these data points out and decreasing our overall sample size, we wanted to incorporate as much information as possible by using these two different approaches in order to conduct a more robust analysis. The models that did agree indicated contamination trends of similar significance and direction.

STRENGTHS AND LIMITATIONS OF STUDY

One of the main limitations of this study was that after stratification of our dataset by produce type and production step, many of our sample sizes in each stratum were quite small (Tables 1 and 2). However, a strength of our approach was that by having 11 farms in our study, we were able to enroll different farms with similar agricultural practices, and thus the results of our analysis could help us assess the effect of these comparable production steps on the microbial contamination on produce and workers' hands.

However, if this study were conducted again, we may try to collect a larger number of produce and workers' hand rinses to improve statistical power for model building, as well as involve a larger number of farms from different regions of Mexico to evaluate potential differences in agricultural practices across the region. It would be valuable to investigate whether farms that grow multiple types of produce in addition to our high-risk produce of interest within the same fields have instances of higher indicator contamination, due to harvest practices, and difference in microbial ecology of the soil or water environments of these fields.

A second limitation of our study design is using fecal indicator organisms as models for enteric pathogen contamination. Previous literature has indicated that *E. coli*, coliforms, and other *Enterobacteriaceae* can naturally be found in the food production environment, can become part of the microflora present in instances of poor sanitation settings, and therefore may not be accurate indicators of recent fecal contamination *(30)*. Additionally, there is conflicting evidence as to the reliability of using these fecal indicator organisms to predict the probability of enteric pathogens being present in the environment, or whether the absence of these indicators truly signifies that food or workers' hands are pathogen-free *(30)*. For the sake of this study, however, using these indicator organisms to assess the overall microbial quality and hygienic working conditions on these farms is the convention in the field of food safety research and facilitates comparison to previously published studies. The strength of our approach is that few studies before this one that have investigated microbial contamination in the food production process have screened for a large variety of fecal indicator organisms *(3, 23, 33, 34)*. Therefore, by collecting data on these numerous organisms, we are able to obtain an enriched perspective on the microbial ecology and microflora present in the working environment.

CONCLUSIONS, FUTURE STUDIES, AND PUBLIC HEALTH IMPLICATIONS

In summary, we found that amongst all of the examined production process steps in our study, the packing shed step had the highest concentrations and prevalence of fecal indicator organisms on fresh produce and workers' hands. Our second finding was that amongst our produce types, the effect of production step depends on the type of produce, and is more significant for melon than for tomato or jalapeño peppers. Third, we found that the pattern of increasing fecal indicator contamination amongst the production steps was positive, but was not linear, as would be expected if the contamination found in the packing shed had been a result of accumulated contamination from the previous production steps. Fourth, the year of sample collection was found to be a significant predictor of fecal indicator contamination. Finally, while the significant linear and logistic models did not completely match on both type of produce and fecal indicators, in general the significant models that did agree had similar magnitude and direction of estimates in some types of produce.

Future studies should be designed to investigate how environmental conditions (i.e. droughts, floods) present in different sampling years affect the amount of fecal indicator contamination present throughout different steps in the food production process. Environmental conditions present at different sampling locations throughout the study region could be explored as potential effect modifiers in determining the potential for microbial contamination. Additionally, because the packing shed step has been pinpointed as a processing step of concern for food safety interventions, it would be valuable to assess the effectiveness of an equipment sanitation intervention on reducing fecal indicator contamination by comparing facilities that do and do not practice this intervention. Other analysis techniques could also be employed to better model our biological data observed in this study, such as Tobit analysis. Finally, in the second phase of this study, the effect of a behavioral intervention on workers' hand hygiene practices should give us a better understanding whether improved farm worker hygiene can reduce the risk of contamination of fresh produce.

Based in our findings, it is recommended that produce farms employ proper hygiene and sanitation practices for equipment and workers. In regards to the implicated packing shed step that had the highest concentrations and prevalence of these fecal indicators, it is extremely important that all produce farmers, in particular melon farmers, focus intervention efforts on improving the hygiene status of this step. This targeted effort is critical in reducing the possibility of foodborne disease in the consumer population, as this is often the last contact that a piece of produce has before it is purchased in supermarkets for raw consumption by the consumer. However, fecal contamination was still observed in the three previous production steps on both produce and workers' hands. In order to prevent this contamination from being introduced into the packing shed, a multi-barrier approach should be employed to avoid amplification of these organisms from the field through the production process to the final stage of the packing shed. By employing the FDA's recommended produce safety rules and prevention programs of GAPs, GMPs, Sanitation Standard Operating Procedures (SSOPs) and an effective Hazard Analysis Critical Control Point plan during all stages of production, food safety can be improved throughout the production process *(26)*. Alternatively, farmers can consider field packing their produce and directly shipping to markets rather than processing produce in a packing facility. This measure would effectively decrease produce-produce contact, contact between produce and surfaces or water in the packing facility, and additional handling by workers *(34)*. This has been strongly recommended as a preventative contamination measure for the melon industry (reviewed in *(40)*). The design of targeted interventions for high risk points in the process of growing and packing produce can ultimately improve produce safety and reduce the burden of foodborne illness.

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Table 1: Produce rinse sample sizes (n), geometric mean indicator concentrations (Geo Mean) and associated 95% confidence intervals (95% CI), and prevalence (n and (%) of samples positive) of fecal indicators at different production steps.

Fecal Indicator	Produce Type	Statistic	Production Step			
			Before Harvest	After Harvest	Distribution	Packing Shed
Escherichia coli	All	n	84	84	73	38
		Geo Mean[a] (95% CI)	1.11 (0.71, 1.51)	1.06 (0.66,1.46)	1.56 (1.06, 2.06)	4.32 (3.45,5.19)
		Prevalence (%)	22 (26%)	14 (17%)	25 (34%)	29 (76%)
	Tomato	n	26	25	25	11
		Geo Mean[a] (95% CI)	0.11 (-0.35, 0.57)	0.07 (-0.42, 0.56)	0.10 (-0.34, 0.53)	1.09 (0.29, 1.88)
		Prevalence (%)	4 (15%)	2 (8%)	6 (24%)	5 (45%)
	Jalapeño	n	21	21	20	2
		Geo Mean[a] (95% CI)	0.19 (-0.37, 0.75)	0.12 (-0.36, 0.60)	0.29 (-0.19, 0.77)	2.41 (-12.10, 16.92)
		Prevalence (%)	3 (14%)	1 (5%)	4 (20%)	2 (100%)
	Melon	n	37	38	28	25
		Geo Mean[a] (95% CI)	2.34 (1.72, 2.96)	2.23 (1.61, 2.85)	3.78 (3.19, 4.36)	5.90 (5.24, 6.55)
		Prevalence (%)	15 (41%)	11 (29%)	15 (54%)	22 (88%)
Fecal coliforms	All	n	82	83	73	37
		Geo Mean[a] (95% CI)	5.40 (4.97, 5.83)	5.27 (4.82, 5.72)	5.08 (4.59, 5.58)	6.20 (5.24, 7.15)
		Prevalence (%)	79 (96%)	82 (99%)	70 (96%)	37 (100%)
	Tomato	n	25	25	25	11
		Geo Mean[a] (95% CI)	4.80 (4.07, 5.53)	4.89 (4.15, 5.64)	4.56 (3.81, 5.31)	3.05 (1.32, 4.78)
		Prevalence (%)	24 (96%)	25 (100%)	24 (96%)	11 (100%)
	Jalapeño	n	20	20	20	1
		Geo Mean[a] (95% CI)	4.11 (2.98, 5.24)	4.00 (2.68, 5.33)	3.55 (2.45, 4.65)	3.55 (NA, NA)
		Prevalence (%)	18 (90%)	19 (95%)	18 (90%)	1 (100%)
	Melon	n	37	38	28	25
		Geo Mean[a] (95% CI)	6.51 (6.17, 6.84)	6.18 (5.78, 6.59)	6.65 (6.29, 7.00)	7.68 (7.05, 8.32)
		Prevalence (%)	37 (100%)	38 (100%)	28 (100%)	25 (100%)

[a]Units for geometric means are log_{10} CFU/fruit for bacteria, or log_{10} MPN/fruit for coliphage

Table 1 continued: Produce rinse sample sizes (n), geometric mean indicator concentrations (Geo Mean) and associated 95% confidence intervals (95% CI), and prevalence (n and (%) of samples positive) of fecal indicators at different production steps.

Fecal Indicator	Produce Type	Statistic	Production Step Before Harvest	 After Harvest	 Distribution	 Packing Shed
	All	n	84	84	73	38
		Geo Mean[a] (95% CI)	4.98 (4.44, 5.53)	5.25 (4.75, 5.76)	5.04 (4.48, 5.59)	6.34 (5.42, 7.25)
Enterococcus		Prevalence (%)	70 (83%)	75 (89%)	60 (82%)	34 (89%)
	Tomato	n	26	25	25	11
		Geo Mean[a] (95% CI)	3.23 (2.58, 3.88)	3.78 (3.15, 4.41)	3.76 (3.11, 4.41)	2.76 (2.28, 3.24)
		Prevalence (%)	19 (73%)	21 (84%)	20 (80%)	7 (64%)
	Jalapeño	n	21	21	20	2
		Geo Mean[a] (95% CI)	3.31 (2.50, 4.11)	3.65 (2.76, 4.54)	3.69 (2.76, 4.61)	4.46 (-19.78, 28.71)
		Prevalence (%)	14 (67%)	16 (76%)	13 (65%)	2 (100%)
	Melon	n	37	38	28	25
		Geo Mean[a] (95% CI)	7.16 (6.65, 7.67)	7.11 (6.63, 7.60)	7.14 (6.50, 7.78)	8.06 (7.46, 8.67)
		Prevalence (%)	37 (100%)	38 (100%)	27 (96%)	25 (100%)
	All	n	64	64	53	25
Coliphage		Geo Mean[a] (95% CI)	2.36 (1.90, 2.81)	2.07 (1.58, 2.55)	1.97 (1.46, 2.48)	2.82 (2.18, 3.46)
		Prevalence (%)	57 (89%)	50 (78 %)	43 (81%)	24 (96%)
	Tomato	n	20	19	19	11
		Geo Mean[a] (95% CI)	0.68 (0.08, 1.28)	0.91 (0.28, 1.54)	0.81 (0.27, 1.35)	1.73 (0.95, 2.50)
		Prevalence (%)	15 (75%)	15 (79%)	15 (79%)	11 (100%)
	Jalapeño	n	15	15	14	2
		Geo Mean[a] (95% CI)	1.78 (1.07, 2.49)	0.76 (-0.07, 1.59)	1.10 (0.19, 2.02)	1.25 (-24.08, 26.57)
		Prevalence (%)	15 (100%)	10 (67%)	10 (71%)	1 (50%)
	Melon	n	29	30	20	12
		Geo Mean[a] (95% CI)	3.81 (3.42, 4.20)	3.45 (2.88, 4.03)	3.68 (3.11, 4.26)	4.08 (NA, NA) .
		Prevalence (%)	27 (93%)	25 (83%)	18 (90%)	12 (100%)

[a]Units for geometric means are $\log_{10}$ CFU/fruit for bacteria, or $\log_{10}$ MPN/fruit for coliphage

Table 2: Workers' hand rinse sample sizes (n), geometric mean indicator concentrations (Geo Mean) and associated 95% confidence intervals (95% CI), and prevalence (n and (%) of samples positive) of fecal indicators at different production steps.

Fecal Indicator	Produce Type	Statistic	Production Step After Harvest	 Distribution	 Packing Shed
Escherichia coli	All	n	84	74	38
		Geo Mean[a] (95% CI)	2.29 (1.91, 2.67)	2.16 (1.75, 2.56)	4.11 (3.48, 4.73)
		Prevalence (%)	31 (37%)	25 (34%)	21 (55%)
	Tomato	n	25	25	11
		Geo Mean[a] (95% CI)	1.77 (1.11, 2.44)	1.41 (0.83, 1.99)	1.91 (1.01, 2.81)
		Prevalence (%)	6 (24%)	5 (20%)	2 (18%)
	Jalapeño	n	21	20	2
		Geo Mean[a] (95% CI)	2.25 (1.53, 2.96)	2.10 (1.30, 2.90)	4.57 (NA, NA)
		Prevalence (%)	9 (43%)	7 (35%)	2 (100%)
	Melon	n	38	29	25
		Geo Mean[a] (95% CI)	2.66 (2.04, 3.28)	2.84 (2.15, 3.52)	5.04 (4.49, 5.58)
		Prevalence (%)	16 (42%)	13 (45%)	17 (68%)
Fecal coliforms	All	n	84	74	38
		Geo Mean[a] (95% CI)	5.83 (5.42, 6.24)	5.71 (5.31, 6.10)	6.22 (5.41, 7.04)
		Prevalence (%)	82 (98%)	70 (95%)	36 (95%)
	Tomato	n	25	25	11
		Geo Mean[a] (95% CI)	5.60 (4.85, 6.36)	5.25 (4.59, 5.91)	3.26 (2.11, 4.42)
		Prevalence (%)	24 (96%)	23 (92%)	9 (82%)
	Jalapeño	n	21	20	2
		Geo Mean[a] (95% CI)	4.94 (3.92, 5.97)	5.15 (4.16, 6.15)	4.57 (NA, NA)
		Prevalence (%)	20 (95%)	18 (90%)	2 (100%)
	Melon	n	38	29	25
		Geo Mean[a] (95% CI)	6.47 (5.97, 6.96)	6.48 (6.04, 6.92)	7.66 (7.09, 8.22)
		Prevalence (%)	38 (100%)	29 (100%)	25 (100%)

[a]Units for geometric means are log_{10} CFU/hand for bacteria, or log_{10} MPN/hand for coliphage

Table 2 continued: Workers' hand rinse sample sizes (n), geometric mean indicator concentrations (Geo Mean) and associated 95% confidence intervals (95% CI), and prevalence (n and (%) of samples positive) of fecal indicators at different production steps.

Fecal Indicator	Produce Type	Statistic	Production Step: After Harvest	Distribution	Packing Shed
	All	n	84	74	38
		Geo Mean[a] (95% CI)	6.5 (6.14, 6.86)	6.50 (6.16, 6.85)	7.06 (6.62, 7.50)
Enterococcus		Prevalence (%)	84 (100%)	74 (100%)	38 (100%)
	Tomato	n	25	25	11
		Geo Mean[a] (95% CI)	6.25 (5.65, 6.86)	6.22 (5.67, 6.77)	5.86 (5.10, 6.62)
		Prevalence (%)	25 (100%)	25 (100%)	11 (100%)
	Jalapeño	n	21	20	2
		Geo Mean[a] (95% CI)	5.81 (5.15, 6.47)	6.18 (5.40, 6.95)	6.42 (-10.77, 23.61)
		Prevalence (%)	21 (100%)	20 (100%)	2 (100%)
	Melon	n	38	29	25
		Geo Mean[a] (95% CI)	7.04 (6.48, 7.61)	6.98 (6.42, 7.54)	7.64 (7.22, 8.07)
		Prevalence (%)	38 (100%)	29 (100%)	25 (100%)
	All	n	65	55	25
Coliphage		Geo Mean[a] (95% CI)	2.34 (1.91, 2.78)	2.11 (1.65, 2.58)	1.93 (1.25, 2.62)
		Prevalence (%)	43 (66%)	37 (67%)	15 (60%)
	Tomato	n	19	19	11
		Geo Mean[a] (95% CI)	1.58 (0.96, 2.20)	1.47 (0.86, 2.09)	1.51 (0.94, 2.08)
		Prevalence (%)	12 (63%)	12 (63%)	8 (73%)
	Jalapeño	n	16	15	2
		Geo Mean[a] (95% CI)	1.40 (0.69, 2.10)	1.78 (0.94, 2.62)	2.27 (-23.06, 27.59)
		Prevalence (%)	8 (50%)	11 (73%)	1 (50%)
	Melon	n	30	21	12
		Geo Mean[a] (95% CI)	3.33 (2.69, 3.97)	2.93 (2.05, 3.81)	2.27 (0.94, 3.59)
		Prevalence (%)	23 (77%)	14 (67%)	6 (50%)

[a]Units for geometric means are $\log_{10}$ CFU/hand for bacteria, or $\log_{10}$ MPN/hand for coliphage

Table 3: Linear modeling statistics quantifying the influence of production step[a] and sampling year[b] on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Outcome: Fecal Indicator Concentration	Type of Produce	Predictor		Estimate	Standard Error	95% Confidence Limits (Lower, Upper)	p-value
Produce	*Escherichia coli* (CFU/fruit)	Tomato	Production Step	Before Harvest	-0.67	0.37	-1.393, 0.060	0.0715
				After Harvest	-0.73	0.37	-1.461, 0.004	0.0512
				Distribution	-0.70	0.37	-1.436, 0.029	0.0595
			Sampling Year	Pilot	-0.07	0.39	-0.846, 0.698	0.8494
				1	1.14	0.24	0.655, 1.620	<.0001*
		Jalapeño	Production Step	Before Harvest	-2.19	0.76	-3.709, -0.676	0.0054*
				After Harvest	-2.26	0.76	-3.776, -0.743	0.0042*
				Distribution	-2.12	0.76	-2.118, -2.118	0.0073*
			Sampling Year	Pilot	0.01	0.37	-0.730, 0.757	0.9721
				1	0.99	0.29	0.416, 1.564	0.0010*
		Melon	Production Step	Before Harvest	-3.55	0.46	-4.460, -2.632	<.0001*
				After Harvest	-3.65	0.46	-4.565, -2.744	<.0001*
				Distribution	-2.11	0.49	-3.073, -1.154	<.0001*
			Sampling Year	Pilot	NA	NA	NA	NA
				1	-0.05	0.32	-0.685, 0.577	0.8654
Produce	Fecal Coliforms (CFU/fruit)	Tomato	Production Step	Before Harvest	0.62	0.49	-0.349, 1.588	0.2070
				After Harvest	0.71	0.49	-0.257, 1.681	0.1474
				Distribution	0.38	0.49	-0.585, 1.352	0.4329
			Sampling Year	Pilot	-4.23	0.54	-5.293, -3.156	<.0001*
				1	-2.72	0.32	-3.353, -2.078	<.0001*
		Jalapeño	Production Step	Before Harvest	-0.12	2.20	-4.529, 4.288	0.9564
				After Harvest	-0.23	2.20	-4.634, 4.183	0.9186
				Distribution	-0.68	2.20	-5.090, 3.727	0.7578
			Sampling Year	Pilot	-3.80	0.85	-5.501, -2.100	<.0001*
				1	-2.50	0.61	-3.709, -1.280	0.0001*
		Melon	Production Step	Before Harvest	-0.80	0.25	-1.285, -0.307	0.0016*
				After Harvest	-1.10	0.25	-1.591, -0.617	<.0001*
				Distribution	-0.84	0.26	-1.348, -0.321	0.0016*
			Sampling Year	Pilot	NA	NA	NA	NA
				1	-1.46	0.17	-1.795, -1.121	<.0001*

[a]Relative to samples collected from the packing shed (referent group), [b]Relative to samples collected during year 2 (referent group), *Statistically significant ($p<0.05$)

Table 3 continued: Linear modeling statistics quantifying the influence of production step[a] and sampling year[b] on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Outcome: Fecal Indicator Concentration	Type of Produce	Predictor		Estimate	Standard Error	95% Confidence Limits (Lower, Upper)	p-value
Produce	*Enterococcus* (CFU/fruit)	Tomato	Production Step	Before Harvest	-0.03	0.50	-1.020, 0.971	0.9610
				After Harvest	0.49	0.51	-0.515, 1.493	0.3357
				Distribution	0.47	0.51	-0.534, 1.475	0.3539
			Sampling Year	Pilot	-1.76	0.53	-2.814, -0.697	0.0014*
				1	-1.36	0.33	-2.017, -0.694	0.0001*
		Jalapeño	Production Step	Before Harvest	-2.00	1.25	-4.500, 0.491	0.1133
				After Harvest	-1.66	1.25	-4.157, 0.835	0.1881
				Distribution	-1.69	1.25	-4.197, 0.818	0.1826
			Sampling Year	Pilot	-2.62	0.61	-3.841, -1.394	<.0001*
				1	-1.69	0.47	-2.633, -0.747	0.0007*
		Melon	Production Step	Before Harvest	-0.52	0.36	-1.229, 0.182	0.1444
				After Harvest	-0.56	0.36	-1.261, 0.144	0.1181
				Distribution	-0.72	0.37	-1.460, 0.021	0.0568
			Sampling Year	Pilot	NA	NA	NA	NA
				1	-1.44	0.25	-1.930, -0.957	<.0001*
Produce	Coliphages (MPN/fruit)	Tomato	Production Step	Before Harvest	-1.28	0.43	-2.132, -0.428	0.0038*
				After Harvest	-1.05	0.43	-1.915, -0.194	0.0172*
				Distribution	-1.16	0.43	-2.017, -0.295	0.0093*
			Sampling Year	Pilot	-1.33	0.42	-2.159, -0.497	0.0022*
				1	-1.78	0.48	-2.734, -0.817	0.0005*
		Jalapeño	Production Step	Before Harvest	0.12	1.15	-2.199, 2.432	0.9193
				After Harvest	-0.90	1.15	-3.216, 1.415	0.4365
				Distribution	-0.59	1.15	-2.920, 1.744	0.6132
			Sampling Year	Pilot	-0.78	0.60	-1.985, 0.430	0.2008
				1	0.01	0.63	-1.259, 1.277	0.9886
		Melon	Production Step	Before Harvest	-0.31	0.40	-1.106, 0.491	0.4458
				After Harvest	-0.67	0.40	-1.463, 0.126	0.0978
				Distribution	-0.36	0.43	-1.210, 0.488	0.4006
			Sampling Year	Pilot	NA	NA	NA	NA
				1	0.76	0.29	0.175, 1.337	0.0113*

[a]Relative to samples collected from the packing shed (referent group), [b]Relative to samples collected during year 2 (referent group), *Statistically significant ($p<0.05$)

Table 3 continued: Linear modeling statistics quantifying the influence of production step[a] and sampling year[b] on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Outcome: Fecal Indicator Concentration	Type of Produce	Predictor		Estimate	Standard Error	95% Confidence Limits (Lower, Upper)	p-value
Hand Rinse	*Escherichia coli* (CFU/hand)	Tomato	Production Step	After Harvest	-0.02	0.54	-1.113, 1.067	0.9666
				Distribution	-0.38	0.54	-1.473, 0.707	0.4843
			Sampling Year	Pilot	-0.64	0.70	-2.036, 0.765	0.3675
				1	0.69	0.43	-0.177, 1.552	0.1169
		Jalapeño	Production Step	After Harvest	-1.83	1.14	-4.134, 0.475	0.1164
				Distribution	-1.95	1.15	-4.267, 0.370	0.0970
			Sampling Year	Pilot	1.51	0.68	0.121, 2.892	0.0339*
				1	1.37	0.52	0.306, 2.427	0.0129*
		Melon	Production Step	After Harvest	-2.35	0.46	-3.261, -1.441	<.0001*
				Distribution	-2.19	0.48	-3.135, -1.240	<.0001*
			Sampling Year	Pilot	NA	NA	NA	NA
				1	-0.09	0.37	-0.824, 0.650	0.8152
Hand Rinse	Fecal Coliforms (CFU/hand)	Tomato	Production Step	After Harvest	1.54	0.54	0.445, 2.624	0.0066*
				Distribution	1.18	0.54	0.090, 2.269	0.0344*
			Sampling Year	Pilot	-3.05	0.70	-4.450, -1.649	<.0001*
				1	-1.91	0.43	-2.779, -1.050	<.0001*
		Jalapeño	Production Step	After Harvest	-0.35	1.48	-3.343, 2.637	0.8123
				Distribution	-0.18	1.49	-3.191, 2.825	0.9026
			Sampling Year	Pilot	-2.17	0.89	-3.970, -0.375	0.0192*
				1	-2.13	0.68	-3.507, -0.756	0.0033*
		Melon	Production Step	After Harvest	-0.73	0.29	-1.292, -0.158	0.0128*
				Distribution	-0.91	0.30	-1.497, -0.315	0.0030*
			Sampling Year	Pilot	NA	NA	NA	NA
				1	-1.72	0.23	-2.182, -1.263	<.0001*

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)
*-Statistically significant ($p<0.05$)

Table 3 continued: Linear modeling statistics quantifying the influence of production step[a] and sampling year[b] on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Outcome: Fecal Indicator Concentration	Type of Produce	Predictor		Estimate	Standard Error	95% Confidence Limits (Lower, Upper)	p-value
Hand Rinse	*Enterococcus* (CFU/hand)	Tomato	Production Step	After Harvest	0.26	0.49	-0.720, 1.233	0.6013
				Distribution	0.22	0.49	-0.753, 1.200	0.6480
			Sampling Year	Pilot	-1.52	0.63	-2.772, -0.262	0.0188*
				1	0.06	0.39	-0.713, 0.836	0.8738
		Jalapeño	Production Step	After Harvest	-1.20	1.10	-3.425, 1.044	0.2874
				Distribution	-0.88	1.11	-3.132, 1.363	0.4308
			Sampling Year	Pilot	-1.84	0.66	-3.179, -0.492	0.0087
				1	-0.65	0.51	-1.673, 0.383	0.2120
		Melon	Production Step	After Harvest	-0.35	0.37	-1.089, 0.393	0.3537
				Distribution	-0.52	0.39	-1.294, 0.250	0.1826
			Sampling Year	Pilot	NA	NA	NA	NA
				1	-0.92	0.30	-1.519, 0.318	0.0031*
Hand Rinse	Coliphage (MPN/hand)	Tomato	Production Step	After Harvest	0.18	0.44	-0.719, 1.068	0.6957
				Distribution	0.07	0.44	-0.823, 0.963	0.8749
			Sampling Year	Pilot	0.99	0.52	-0.057, 2.045	0.0631
				1	0.17	0.59	-1.028, 1.365	0.7779
		Jalapeño	Production Step	After Harvest	-0.45	1.14	-2.776, 1.876	0.6947
				Distribution	-0.04	1.14	-2.383, 2.302	0.9720
			Sampling Year	Pilot	0.70	0.71	-0.760, 2.154	0.3355
				1	-0.22	0.76	-1.780, 1.334	0.7714
		Melon	Production Step	After Harvest	0.97	0.58	-0.190, 2.137	0.0994
				Distribution	0.73	0.62	-0.504, 1.960	0.2415
			Sampling Year	Pilot	NA	NA	NA	NA
				1	1.79	0.51	0.783, 2.804	0.0008*

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)
*Statistically significant (p<0.05)

Table 4: Logistic modeling results summary modeling the influence of production step[a] and sampling year[b] on fecal indicator presence in produce and workers' hand rinse samples.

Sample Type	Outcome: Fecal Indicator Presence (+)	Type of Produce	Variable		OR Estimate	95% Wald Confidence Limits (Lower, Upper)	p-value
Produce	*Escherichia coli*	Tomato[θ]	Production Step	Before Harvest	0.38	0.08, 1.95	0.2486
				After Harvest	0.07	0.03, 1.16	0.0722
				Distribution	0.68	0.14, 3.28	0.6322
			Sampling Year	Pilot	7.53	0.27, 211.96	0.2358
				1	21.68	1.28, 367.52	0.0331*
		Jalapeño[θ]	Production Step	Before Harvest	0.06	0.00, 3.65	0.1804
				After Harvest	0.02	0.00, 1.53	0.0777
				Distribution	0.11	0.00, 6.08	0.2762
			Sampling Year	Pilot	28.24	1.36, 588.00	0.0310*
				1	7.54	0.41, 138.59	0.1738
		Melon[θ]	Production Step	Before Harvest	0.002	0.00, 0.04	0.0001*
				After Harvest	<0.001	0.00, 0.02	<.0001*
				Distribution	0.029	0.00, 0.23	0.0008*
			Sampling Year	Pilot	NA	NA	NA
				1	309.934	15.06, >999.99	0.0002*
Produce	Fecal Coliforms	Tomato[θ]	Production Step	Before Harvest	0.491	0.02, 12.03	0.6629
				After Harvest	1.512	0.03, 67.01	0.8308
				Distribution	0.491	0.02, 12.03	0.6629
			Sampling Year	Pilot	0.263	0.00, 10.63	0.4791
				1	0.305	0.02, 4.90	0.4019
		Jalapeño[θ]	Production Step	Before Harvest	1.518	0.01, 170.62	0.8625
				After Harvest	2.675	0.02, 329.87	0.6887
				Distribution	1.518	0.01, 170.62	0.8625
			Sampling Year	Pilot	1.399	0.05, 36.06	0.8396
				1	0.440	0.07, 2.88	0.3916
		Melon[Δ]	Production Step	Before Harvest	NA	NA	NA
				After Harvest	NA	NA	NA
				Distribution	NA	NA	NA
			Sampling Year	Pilot	NA	NA	NA
				1	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group), [b]Relative to samples collected during year 2 (referent group), [θ]Firth correction used to perform analysis, [Δ]Model not able to be built – all positive observations, *Statistically significant (p<0.05).

Table 4 continued: Logistic modeling results summary modeling the influence of production step[a] and sampling year[b] on fecal indicator presence in produce and workers' hand rinse samples.

Sample Type	Outcome: Fecal Indicator Presence (+)	Type of Produce	Variable		OR Estimate	95% Wald Confidence Limits (Lower, Upper)	p-value
Produce	*Enterococcus*	Tomato[θ]	Production Step	Before Harvest	0.835	0.17, 4.03	0.8219
				After Harvest	1.582	0.30, 8.37	0.5894
				Distribution	1.188	0.23, 6.04	0.8358
			Sampling Year	Pilot	0.017	0.00, 0.36	0.0089*
				1	0.045	0.00, 0.75	0.0307*
		Jalapeño[θ]	Production Step	Before Harvest	0.152	0.00, 8.05	0.3526
				After Harvest	0.266	0.01, 14.09	0.5131
				Distribution	0.126	0.00, 6.79	0.3080
			Sampling Year	Pilot	0.014	0.00, 0.30	0.0061*
				1	0.035	0.00, 0.62	0.0219*
		Melon[θ]	Production Step	Before Harvest	1.025	0.02, 45.98	0.9898
				After Harvest	1.037	0.02, 46.48	0.9851
				Distribution	0.297	0.01, 7.10	0.4537
			Sampling Year	Pilot	NA	NA	NA
				1	3.259	0.27, 39.59	0.3537
Produce	Coliphage~~s~~	Tomato[θ]	Production Step	Before Harvest	0.027	0.00, 1.10	0.0559
				After Harvest	0.042	0.00, 1.72	0.0943
				Distribution	0.042	0.00, 1.72	0.0943
			Sampling Year	Pilot	0.520	0.03, 10.58	0.6705
				1	0.015	0.00, 0.36	0.0095*
		Jalapeño[θ]	Production Step	Before Harvest	143.734	1.84, >999.99	0.0255*
				After Harvest	6.718	0.24, 185.33	0.2604
				Distribution	9.285	0.31, 279.53	0.1996
			Sampling Year	Pilot	4.519	0.44, 46.68	0.2055
				1	0.407	0.05, 3.05	0.3818
		Melon[θ]	Production Step	Before Harvest	0.374	0.01, 10.03	0.5579
				After Harvest	0.146	0.01, 3.48	0.2343
				Distribution	0.301	0.01, 8.23	0.4772
			Sampling Year	Pilot	NA	NA	NA
				1	5.303	1.34, 20.99	0.0175*

[a]Relative to samples collected from the packing shed (referent group), [b]Relative to samples collected during year 2 (referent group), [θ]Firth correction used to perform analysis, [Δ]Model not able to be built – all positive observations, *Statistically significant ($p<0.05$).

Table 4 continued: Logistic modeling results summary modeling the influence of production step[a] and sampling year[b] on fecal indicator presence in produce and workers' hand rinse samples.

Sample Type	Outcome: Fecal Indicator Presence (+)	Type of Produce	Variable		OR Estimate	95% Wald Confidence Limits (Lower, Upper)	p-value
Hand Rinse	*Escherichia coli*	Tomato[θ]	Production	After Harvest	1.412	0.24, 8.31	0.7030
			Step	Distribution	1.133	0.19, 6.83	0.8915
			Sampling	Pilot	0.385	0.02, 10.05	0.5665
			Year	1	1.814	0.43, 7.57	0.4143
		Jalapeño[θ]	Production	After Harvest	0.269	0.00, 16.71	0.5332
			Step	Distribution	0.204	0.00, 12.74	0.4508
			Sampling	Pilot	19.319	1.94, 192.01	0.0115*
			Year	1	3.360	0.65, 17.51	0.1502
		Melon[θ]	Production	After Harvest	0.139	0.04, 0.53	0.0038*
			Step	Distribution	0.211	0.06, 0.79	0.0210*
			Sampling	Pilot	NA	NA	NA
			Year	1	8.852	2.98, 26.33	<.0001*
Hand Rinse	Fecal Coliforms	Tomato[θ]	Production	After Harvest	2.508	0.26, 24.08	0.4255
			Step	Distribution	1.409	0.18, 11.08	0.7443
			Sampling	Pilot	0.064	0.00, 1.71	0.1010
			Year	1	0.306	0.02, 6.11	0.4384
		Jalapeño[θ]	Production	After Harvest	2.801	0.05, 161.98	0.6189
			Step	Distribution	1.610	0.03, 85.67	0.8143
			Sampling	Pilot	1.638	0.06, 41.92	0.7655
			Year	1	0.844	0.10, 7.15	0.8764
		Melon[Δ]	Production	After Harvest	NA	NA	NA
			Step)	Distribution	NA	NA	NA
			Sampling	Pilot	NA	NA	NA
			Year	1	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group),
[b]Relative to samples collected during year 2 (referent group)
[θ]Firth correction used to perform analysis,
[Δ]Model not able to be built – all positive observations, *Statistically significant ($p<0.05$).

Table 4 continued: Logistic modeling results summary modeling the influence of production step[a] and sampling year[b] on fecal indicator presence in produce and workers' hand rinse samples.

Sample Type	Outcome: Fecal Indicator Presence (+)	Type of Produce	Variable		OR Estimate	95% Wald Confidence Limits (Lower, Upper)	p-value
Hand Rinse	*Enterococcus*	Tomatoes[Δ]	Production	After Harvest	NA	NA	NA
			Step	Distribution	NA	NA	NA
			Sampling	Pilot	NA	NA	NA
			Year	1	NA	NA	NA
		Jalapeño Peppers[Δ]	Production	After Harvest	NA	NA	NA
			Step	Distribution	NA	NA	NA
			Sampling	Pilot	NA	NA	NA
			Year	1	NA	NA	NA
		Melons[Δ]	Production	After Harvest	NA	NA	NA
			Step	Distribution	NA	NA	NA
			Sampling	Pilot	NA	NA	NA
			Year	1	NA	NA	NA
Hand Rinse	Coliphages	Tomatoes[θ]	Production	After Harvest	0.700	0.09, 5.52	0.7348
			Step	Distribution	0.700	0.09, 5.52	0.7348
			Sampling	Pilot	9.294	1.30, 66.52	0.0264*
			Year	1	0.452	0.05, 4.38	0.4935
		Jalapeño Peppers[θ]	Production	After Harvest	3.247	0.14, 75.24	0.4628
			Step	Distribution	11.941	0.41, 352.48	0.1510
			Sampling	Pilot	6.225	0.66, 58.43	0.1095
			Year	1	0.442	0.05, 3.96	0.4650
		Melons[θ]	Production	After Harvest	3.410	0.74, 15.70	0.1153
			Step	Distribution	2.377	0.49, 11.63	0.2850
			Sampling	Pilot	NA	NA	NA
			Year	1	6.879	1.87, 25.29	0.0037*

[a]Relative to samples collected from the packing shed (referent group), [b]Relative to samples collected during year 2 (referent group)
[θ]Firth correction used to perform analysis, [Δ]Model not able to be built – all positive observations, *Statistically significant ($p<0.05$).

Figure 1: Distribution of fecal indicator concentrations in produce rinses amongst types of produce with significant differences between production steps (1-Before harvest, 2-After harvest, 3-Distribution, 4-Packing shed).

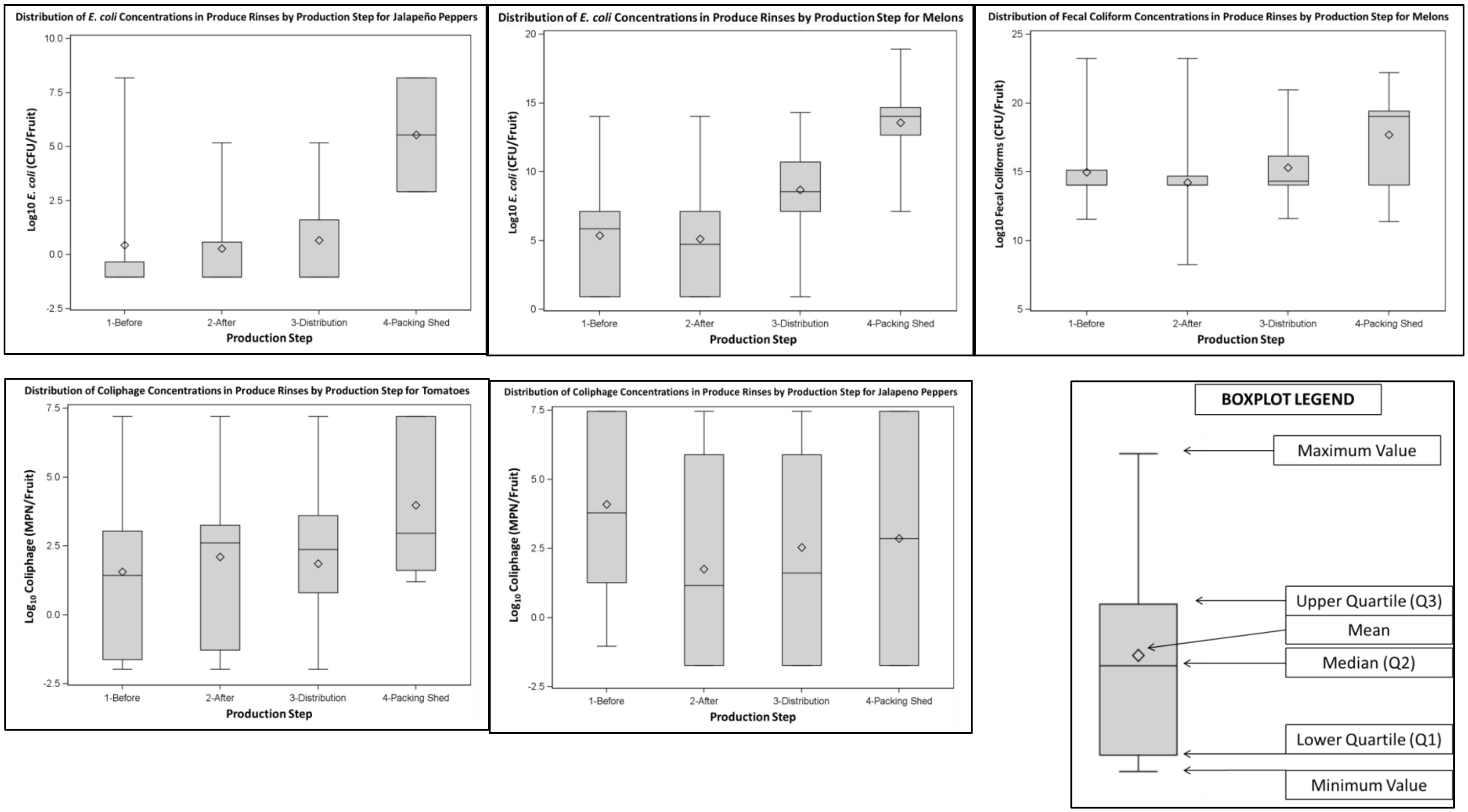


Figure 2: Distribution of fecal indicator concentrations in workers' hand rinses amongst types of produce with significant differences between production steps (1-Before harvest, 2-After harvest, 3-Distribution, 4-Packing shed).

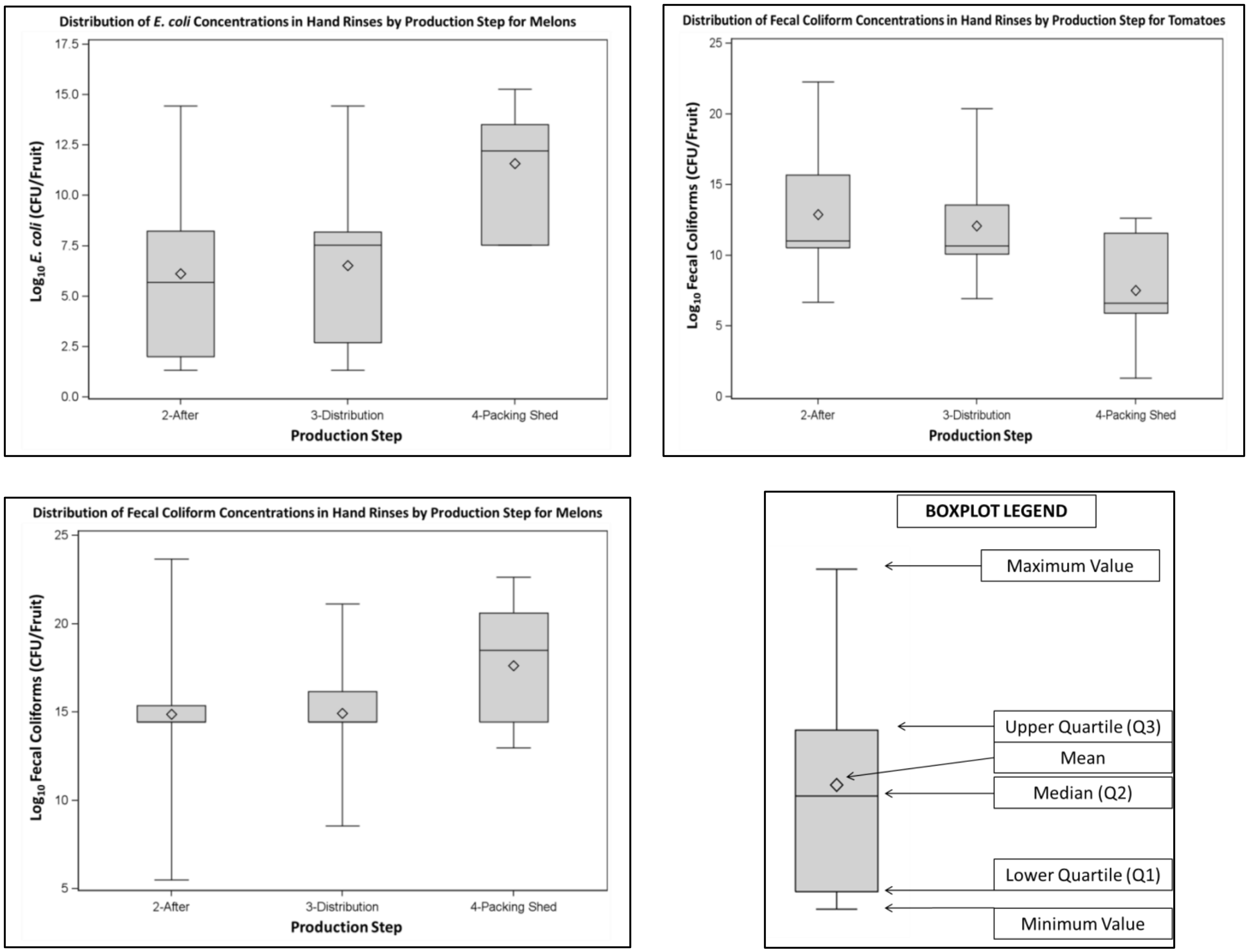
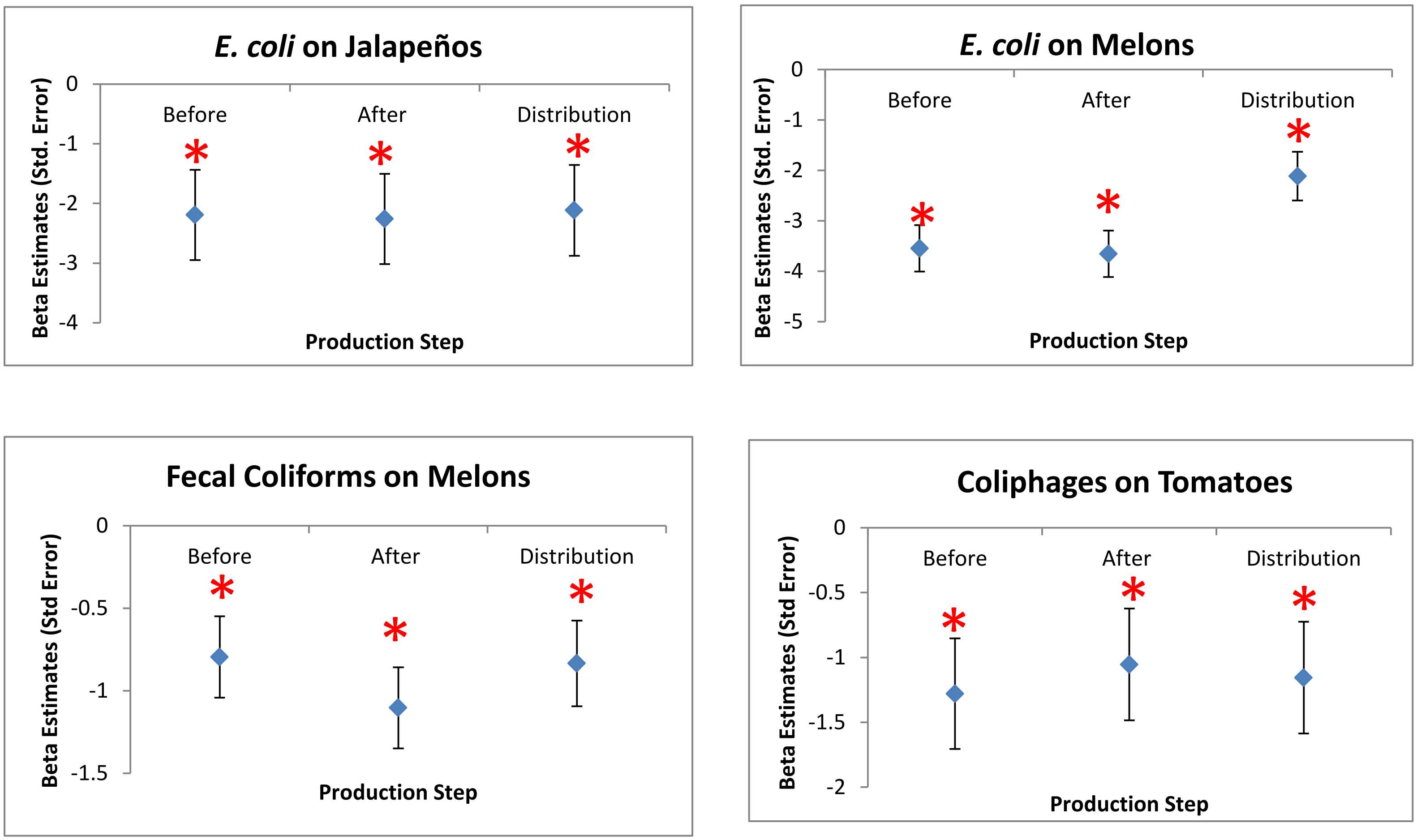
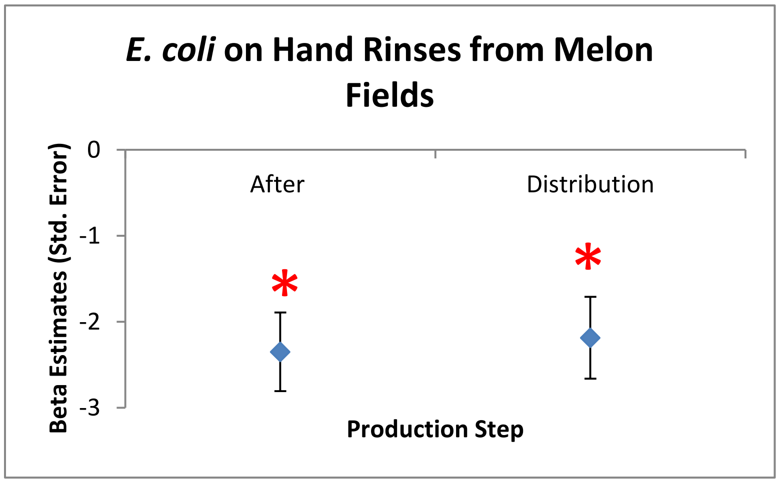


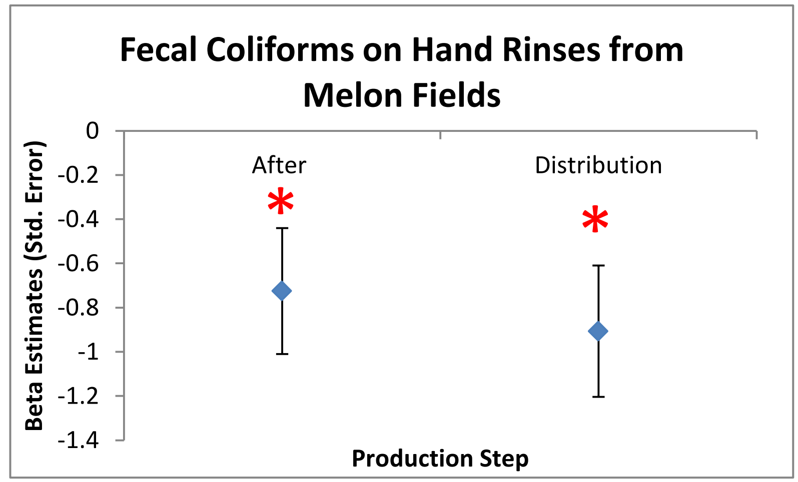
Figure 3: Stratified linear models by type of produce with statistically significant beta estimates of fecal indicator concentrations, comparing indicator concentrations from produce rinse samples at all steps to packing shed step.

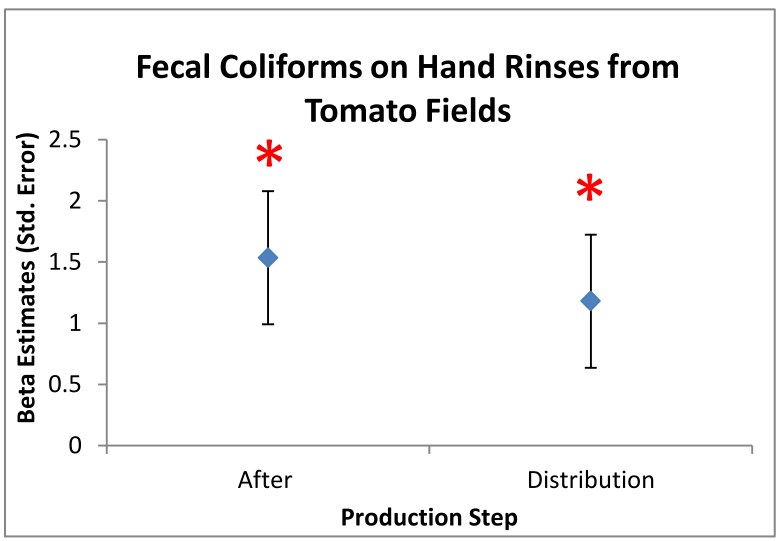


*÷Statistically significant estimates, α = 0.05

Figure 4: Stratified linear models by type of produce with statistically significant beta estimates of fecal indicator concentrations, comparing indicator concentrations from workers' hand rinse samples at all steps to packing shed step.

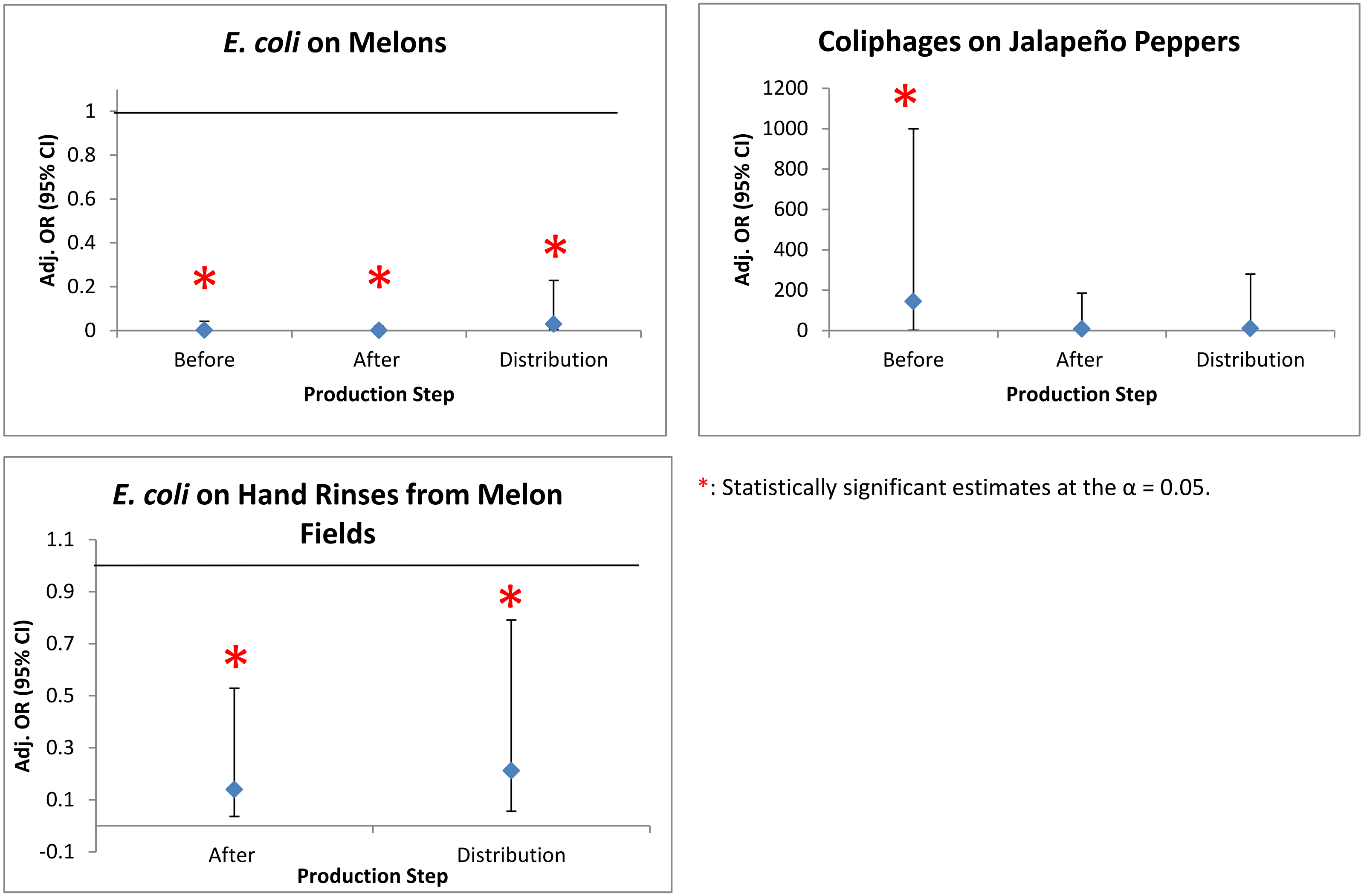






*Statistically significant estimates, α = 0.05.

Figure 5: Stratified logistic models by type of produce with statistically significant odds ratio estimates of fecal indicator presence comparing all step concentrations to packing shed step for produce and workers' hand rinse samples.



APPENDIX

Table A1: Produce rinse (CFU/ml) sample sizes, geometric means, and prevalence of fecal indicator concentrations at different steps in the production process.

			Production Step			
Fecal Indicator	Produce Type		Before Harvest	After Harvest	Distribution	Packing Shed
Escherichia coli	All	n	84	84	73	38
		Geo Mean[a] (95% CI)	-0.78 (-1.14, -0.43)	-0.84 (-1.20, -0.49)	-0.28 (-0.70, 0.14)	2.24 (1.49, 2.99)
		Prevalence (%)	22 (26%)	14 (17%)	25 (34%)	29 (76%)
	Tomato	n	26	25	25	11
		Geo Mean[a] (95% CI)	-1.34 (-1.80, 0.88)	-1.37 (-1.86, -0.88)	-1.35 (-1.78, -0.91)	-0.36 (-1.15, 0.44)
		Prevalence (%)	4 (15 %)	2 (8%)	6 (24%)	5 (45%)
	Jalapeño	n	21	21	20	2
		Geo Mean[a] (95% CI)	-1.36 (-1.92, -0.81)	-1.43 (-1.91, -0.95)	-1.27 (-1.75, -0.78)	0.86 (-13.65, 15.37)
		Prevalence (%)	3 (14%)	1 (5%)	4 (20%)	2 (100%)
	Melons	n	37	38	28	25
		Geo Mean[a] (95% CI)	-0.06 (-0.68, 0.56)	-0.17 (-0.79, 0.45)	1.38 (0.79, 1.96)	3.50 (2.84, 4.16)
		Prevalence (%)	15 (41 %)	11 (29%)	15 (54%)	22 (88%)
Fecal coliforms	All	n	82	83	73	37
		Geo Mean[a] (95% CI)	3.5 (3.11, 3.89)	3.362 (2.937, 3.787)	3.24 (2.80, 3.69)	4.10 (3.26, 4.95)
		Prevalence (%)	79 (96%)	82 (99%)	70 (96%)	37 (100%)
	Tomato	n	25	25	25	11
		Geo Mean[a] (95% CI)	3.35 (2.63, 4.08)	3.45 (2.70, 4.19)	3.12 (2.37, 3.87)	1.60 (-0.13, 3.34)
		Prevalence (%)	24 (96%)	25 (100%)	24 (96%)	11 (100%)
	Jalapeño	n	20	20	20	1
		Geo Mean[a] (95% CI)	2.56 (1.42, 3.69)	2.45 (1.13, 3.78)	1.99 (0.90, 3.09)	2.00 (NA, NA)
		Prevalence (%)	18 (90%)	19 (95%)	18 (90%)	1 (100%)
	Melons	n	37	38	28	25
		Geo Mean[a] (95% CI)	4.11 (3.77, 4.44)	3.79 (3.38, 4.19)	4.25 (3.89, 4.61)	5.29 (4.65, 5.92)
		Prevalence (%)	37 (100%)	38 (100%)	28 (100%)	25 (100%)

[a]Units for geometric means are $\log_{10}$ CFU/ml for bacteria, or $\log_{10}$ MPN/ml for coliphage

Table A1 continued: Produce rinse (CFU/ml) sample sizes, geometric means, and prevalence of fecal indicator concentrations at different steps in the production process.

Enterococcus	All	n	84	84	73	38
		Geo Mean (95% CI)	3.09 (2.62, 3.56)	3.35 (2.91, 3.79)	3.20 (2.71, 3.69)	4.26 (3.47, 5.05)
		Prevalence (%)	70 (83%)	75 (89%)	60 (82%)	34 (89%)
	Tomato	n	26	25	25	11
		Geo Mean (95% CI)	1.79 (1.14, 2.43)	2.33 (1.70, 2.96)	2.32 (1.66, 2.97)	1.32 (0.84, 1.79)
		Prevalence (%)	19 (73%)	21 (84%)	20 (80%)	7 (64%)
	Jalapeño	n	21	21	20	2
		Geo Mean (95% CI)	1.75 (0.95, 2.56)	2.10 (1.21, 2.99)	2.14 (1.21, 3.06)	2.91 (-21.34, 27.15)
		Prevalence (%)	14 (67%)	16 (76%)	13 (65%)	2 (100%)
	Melons	n	37	38	28	25
		Geo Mean (95% CI)	4.76 (4.25, 5.27)	4.71 (4.23, 5.20)	4.74 (4.11, 5.38)	5.66 (5.06, 6.27)
		Prevalence (%)	37 (100%)	38 (100%)	27 (96%)	25 (100%)
Coliphage	All	n	64	64	53	25
		Geo Mean (95% CI)	0.45 (0.08, 0.83)	0.15 (-0.27, 0.57)	0.14 (-0.29, 0.57)	0.91 (0.41, 1.41)
		Prevalence (%)	57 (89%)	50 (78%)	43 (81%)	24 (96%)
	Tomato	n	20	19	19	11
		Geo Mean (95% CI)	-0.77 (-1.36, -0.17)	-0.53 (-1.16, 0.09)	-0.64 (-1.18, -0.09)	0.28 (-0.49, 1.06)
		Prevalence (%)	15 (75%)	15 (79%)	15 (79%)	11 (100%)
	Jalapeño	n	15	15	14	2
		Geo Mean (95% CI)	0.23 (-0.49, 0.94)	-0.79 (-1.62, 0.04)	-0.45 (-1.37, 0.47)	-0.31 (-25.63, 25.02)
		Prevalence (%)	15 (100%)	10 (67%)	10 (71%)	1 (50%)
	Melons	n	29	30	20	12
		Geo Mean (95% CI)	1.41 (1.02, 1.80)	1.05 (0.48, 1.63)	1.29 (0.71, 1.86)	1.69 (NA, NA)
		Prevalence (%)	27 (93%)	25 (83%)	18 (90%)	12 (100%)

[a]Units for geometric means are $\log_{10}$ CFU/ml for bacteria, or $\log_{10}$ MPN/ml for coliphage

Table A2: Linear modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	**Fecal Indicator and Concentration Units**	**Variable**			**Estimate**	**95% Wald Confidence Limits (Lower, Upper)**	**p-value**
Produce	*Escherichia coli* (CFU/ Fruit)	Intercept			0.748621	-0.170, 1.667	0.1098
		Point in Production Chain (Chain Time)	Before Harvest		-0.86594	-1.881, 0.149	0.0943
			After Harvest		-0.92548	-1.948, 0.097	0.0759
			Distribution		-0.90069	-1.923, 0.122	0.084
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		1.607151	-0.557, 3.771	0.1449
			Melon		4.967347	3.925, 6.009	<.0001**
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		-0.38954	-1.099, 0.320	0.2808
			1		0.499681	0.136, 0.863	0.0072**
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	-1.46274	-3.774, 0.848	0.2137
				Melon	-2.82536	-4.086, -1.565	<.0001**
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	-1.47049	-3.782, 0.841	0.2115
				Melon	-2.87906	-4.144, -1.615	<.0001**
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	-1.35869	-3.676, 0.959	0.2494
				Melon	-1.29015	-2.576, -0.004	0.0493**
				Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)
* Reference group
** Statistically significant at α=0.05 ($p<0.05$)

Table A2 continued: Linear modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Fecal Indicator and Concentration Units	Variable			Estimate	95% Wald Confidence Limits (Lower, Upper)	p-value
Produce	*Escherichia coli* (CFU/ml)	Intercept			-0.6951	-1.614, 0.223	0.1374
		Point in Production Chain (Chain Time)	Before Harvest		-0.8659	-1.881, 0.149	0.0943
			After Harvest		-0.9255	-1.948, 0.097	0.0759
			Distribution		-0.9007	-1.923, 0.122	0.0840
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		1.4980	-0.666, 3.662	0.1741
			Melon		4.013104551	2.971, 5.055	<.0001**
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		-0.3895374	-1.099, 0.320	0.2808
			1		0.4996807	0.136, 0.863	0.0072**
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	-1.462741	-3.774, 0.848	0.2137
				Melon	-2.825356	-4.086, -1.565	<.0001**
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	-1.470485	-3.782, 0.841	0.2115
				Melon	-2.879063	-4.144, -1.615	<.0001**
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	-1.358691	-3.676, 0.959	0.2494
				Melon	-1.290148	-2.576, -0.004	0.0493**
				Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)
* Reference group
** Statistically significant at α=0.05 (p<0.05).

Table A2 continued: Linear modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

<table>
<tr><th>Sample Type</th><th>Fecal Indicator and Concentration Units</th><th colspan="3">Variable</th><th>Estimate</th><th>95% Wald Confidence Limits (Lower, Upper)</th><th>p-value</th></tr>
<tr><td rowspan="19">Produce</td><td rowspan="19">Fecal Coliforms (CFU/fruit)</td><td colspan="3">Intercept</td><td>5.364446</td><td>4.456, 6.273</td><td><.0001</td></tr>
<tr><td rowspan="4">Point in Production Chain (Chain Time)</td><td colspan="2">Before Harvest</td><td>0.858021</td><td>-0.152, 1.868</td><td>0.0956</td></tr>
<tr><td colspan="2">After Harvest</td><td>0.950852</td><td>-0.059, 1.961</td><td>0.0649</td></tr>
<tr><td colspan="2">Distribution</td><td>0.622482</td><td>-0.387, 1.632</td><td>0.226</td></tr>
<tr><td colspan="2">Packing Shed*</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="3">Produce Type</td><td colspan="2">Jalapeño</td><td>0.213568</td><td>-2.678, 3.105</td><td>0.8845</td></tr>
<tr><td colspan="2">Melon</td><td>3.048259</td><td>2.018, 4.078</td><td><.0001**</td></tr>
<tr><td colspan="2">Tomato*</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="3">Sampling Year</td><td colspan="2">Pilot</td><td>-3.62987</td><td>-4.385, -2.875</td><td><.0001**</td></tr>
<tr><td colspan="2">1</td><td>-2.02517</td><td>-2.384, -1.666</td><td><.0001**</td></tr>
<tr><td colspan="2">2*</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="9">Chain Time and Produce Type Interaction Terms</td><td rowspan="3">Before Harvest</td><td>Jalapeño</td><td>-0.76955</td><td>-3.780, 2.241</td><td>0.6152</td></tr>
<tr><td>Melon</td><td>-1.50552</td><td>-2.756, -0.2552</td><td>0.0185**</td></tr>
<tr><td>Tomato*</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="3">After Harvest</td><td>Jalapeño</td><td>-0.9676</td><td>-3.978, 2.043</td><td>0.5274</td></tr>
<tr><td>Melon</td><td>-1.90064</td><td>-3.149, -0.652</td><td>0.003**</td></tr>
<tr><td>Tomato*</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="3">Distribution</td><td>Jalapeño</td><td>-1.09502</td><td>-4.106, 1.916</td><td>0.4745</td></tr>
<tr><td>Melon</td><td>-1.37763</td><td>-2.648, -0.107</td><td>0.0336**</td></tr>
<tr><td>Tomato*</td><td>NA</td><td>NA</td><td>NA</td></tr>
</table>

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)
* Reference group
** Statistically significant at α=0.05 (p<0.05).

Table A2 continued: Linear modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Fecal Indicator and Concentration Units	Variable			Estimate	95% Wald Confidence Limits (Lower, Upper)	p-value
Produce	Fecal Coliforms (CFU/ml)	Intercept			3.920749	3.012, 4.829	<.0001
		Point in Production Chain (Chain Time)	Before Harvest		0.858021	-0.152, 1.868	0.0956
			After Harvest		0.950852	-0.059, 1.961	0.0649
			Distribution		0.622482	-0.387, 1.632	0.226
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		0.104423	-2.787, 2.996	0.9434
			Melon		2.094016	1.064, 3.124	<.0001**
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		-3.62987	-4.385, -2.875	<.0001**
			1		-2.02517	-2.384, -1.666	<.0001**
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	-0.76955	-3.780, 2.241	0.6152
				Melon	-1.50552	-2.756, -0.255	0.0185**
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	-0.9676	-3.978, 2.043	0.5274
				Melon	-1.90064	-3.149, -0.652	0.003**
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	-1.09502	-4.106, 1.916	0.4745
				Melon	-1.37763	-2.648, -0.107	0.0336**
				Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)
* Reference group
** Statistically significant at α=0.05 (p<0.05).

Table A2 continued: Linear modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	**Fecal Indicator and Concentration Units**	**Variable**			**Estimate**	**95% Wald Confidence Limits (Lower, Upper)**	**p-value**
Produce	*Enterococcus* (CFU/Fruit)	Intercept			4.363253	3.444, 5.283	<.0001
		Point in Production Chain (Chain Time)	Before Harvest		-0.08649	-1.103, 0.930	0.8671
			After Harvest		0.41407	-0.610, 1.438	0.4265
			Distribution		0.3958	-0.628, 1.419	0.4472
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		1.930022	-0.236, 4.096	0.0806
			Melon		4.229291	3.186, 5.272	<.0001**
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		-2.19077	-2.901, -1.480	<.0001**
			1		-1.47386	-1.838, -1.110	<.0001**
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	-1.78085	-4.094, 0.532	0.1308
				Melon	-0.42895	-1.690, 0.833	0.5038
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	-1.93757	-4.252, 0.377	0.1005
				Melon	-0.96437	-2.230, 0.301	0.1348
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	-1.93616	-4.256, 0.384	0.1015
				Melon	-1.11079	-2.398, 0.177	0.0906
				Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)

* Reference group
** Statistically significant at α=0.05 (p<0.05).

Table A2 continued: Linear modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Fecal Indicator and Concentration Units	Variable			Estimate	95% Wald Confidence Limits (Lower, Upper)	p-value
Produce	*Enterococcus* (CFU/ml)	Intercept			2.919556	2.000, 3.839	<.0001
		Point in Production Chain (Chain Time)	Before Harvest		-0.08649	-1.103, 0.930	0.8671
			After Harvest		0.41407	-0.610, 1.438	0.4265
			Distribution		0.3958	-0.628, 1.419	0.4472
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		1.820878	-0.346, 3.987	0.0991
			Melon		3.275048	2.232, 4.318	<.0001**
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		-2.19077	-2.901, -1.480	<.0001**
			1		-1.47386	-1.838, -1.110	<.0001**
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	-1.78085	-4.094, 0.532	0.1308
				Melon	-0.42895	-1.690, 0.833	0.5038
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	-1.93757	-4.252, 0.377	0.1005
				Melon	-0.96437	-2.230, 0.301	0.1348
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	-1.93616	-4.256, 0.384	0.1015
				Melon	-1.11079	-2.398, 0.177	0.0906
				Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)

* Reference group
** Statistically significant at α=0.05 (p<0.05).

Table A2 continued: Linear modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Fecal Indicator and Concentration Units	Variable			Estimate	95% Wald Confidence Limits (Lower, Upper)	p-value
Produce	Coliphages (MPN/Fruit)	Intercept			1.986053	1.075, 2.897	<.0001
		Point in Production Chain (Chain Time)	Before Harvest		-1.07212	-2.022, -0.123	0.0271**
			After Harvest		-0.8486	-1.807, 0.110	0.0824
			Distribution		-0.95012	-1.909, 0.009	0.0521
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		-0.35257	-2.297, 1.592	0.721
			Melon		2.030721	0.919, 3.142	0.0004**
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		-0.38873	-0.966, 0.188	0.1856
			1		0.088014	-0.396, 0.572	0.7204
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	1.369782	-0.765, 3.504	0.2071
				Melon	0.793439	-0.493, 2.079	0.2251
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	0.128947	-2.008, 2.266	0.9054
				Melon	0.213223	-1.077, 1.503	0.7448
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	0.55592	-1.590, 2.702	0.61
				Melon	0.555932	-0.773, 1.884	0.4102
				Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)

* Reference group
** Statistically significant at α=0.05 ($p<0.05$).

Table A2 continued: Linear modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	**Fecal Indicator and Concentration Units**	**Variable**			**Estimate**	**95% Wald Confidence Limits (Lower, Upper)**	**p-value**
Produce	Coliphages (MPN/ml)	Intercept			0.542356	-0.369, 1.454	0.2419
		Point in Production Chain (Chain Time)	Before Harvest		-1.07212	-2.022, -0.123	0.0271**
			After Harvest		-0.8486	-1.807, 0.110	0.0824
			Distribution		-0.95012	-1.909, 0.009	0.0521
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		-0.46171	-2.406, 1.482	0.64
			Melon		1.076479	-0.035, 2.188	0.0576
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		-0.38873	-0.966, 0.188	0.1856
			1		0.088014	-0.396, 0.572	0.7204
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	1.369782	-0.765, 3.504	0.2071
				Melon	0.793439	-0.493, 2.079	0.2251
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	0.128947	-2.008, 2.266	0.9054
				Melon	0.213223	-1.077, 1.503	0.7448
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	0.55592	-1.590, 2.702	0.61
				Melon	0.555932	-0.773, 1.884	0.4102
				Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)

* Reference group
** Statistically significant at α=0.05 ($p<0.05$).

Table A2 continued: Linear modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Fecal Indicator and Concentration Units	Variable			Estimate	95% Wald Confidence Limits (Lower, Upper)	p-value
Hand Rinse	*Escherichia coli* (CFU/ Fruit)	Intercept			1.53588	0.446, 2.626	0.006
		Point in Production Chain (Chain Time)	After Harvest		-0.01277	-1.190, 1.164	0.983
			Distribution		-0.37295	NA	NA
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		2.763072	0.276, 5.250	0.0296**
			Melon		3.346132	2.136, 4.556	<.0001**
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		0.122479	-0.878, 1.123	0.8094
			1		0.427678	-0.072, 0.927	0.0929
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	After Harvest	Jalapeño	-2.26748	-4.920, 0.385	0.0934
				Melon	-2.47788	-3.938, -1.018	0.001**
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	-2.06036	-4.721, 0.600	0.1283
				Melon	-1.89524	-3.374, 0.417	0.0123**
				Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)

* Reference group
** Statistically significant at α=0.05 (p<0.05).

Table A2 continued: Linear modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Fecal Indicator and Concentration Units	Variable			Estimate	95% Wald Confidence Limits (Lower, Upper)	p-value
Hand Rinse	*Enterococcus* (CFU/ Hand)	Intercept			6.692438	5.762, 7.623	<.0001**
		Point in Production Chain (Chain Time)	After Harvest		0.047512	-0.958, 1.053	0.9258
			Distribution		0.015127	-0.990, 1.020	0.9763
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		0.971819	-1.152, 3.096	0.3679
			Melon		1.163838	0.131, 2.197	0.0275
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		-1.89404	-2.748, -1.040	<.0001**
			1		-0.59777	-1.024, -0.171	0.0063**
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	After Harvest	Jalapeño	-1.25542	-3.521, 1.010	0.2757
				Melon	-0.48236	-1.729, 0.765	0.4464
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	-0.9198	-3.192, 1.352	0.4255
				Melon	-0.58745	-1.850, 0.675	0.3598
				Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)

* Reference group
** Statistically significant at α=0.05 (p<0.05).

Table A2 continued: Linear modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Fecal Indicator and Concentration Units	Variable			Estimate	95% Wald Confidence Limits (Lower, Upper)	p-value
Hand Rinse	Coliphages (CFU/ Hand)	Intercept			0.089868	-1.059, 1.238	0.8772
		Point in Production Chain (Chain Time)	After Harvest		0.283735	-0.851, 1.419	0.6219
			Distribution		0.17941	-0.956, 1.315	0.7551
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		0.624923	-1.677, 2.926	0.5921
			Melon		1.375245	0.033, 2.717	0.0447**
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		1.551148	0.733, 2.370	0.0003**
			1		1.067768	0.381, 1.755	0.0026**
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	After Harvest	Jalapeño	-0.71048	-3.233, 1.813	0.5785
				Melon	0.725777	-0.802, 2.253	0.3491
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	-0.19478	-2.728, 2.338	0.8793
				Melon	0.523037	-1.042, 2.088	0.5098
				Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)

* Reference group
** Statistically significant at $\alpha=0.05$ ($p<0.05$).

Table A3: Logistic modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type and Units	**Fecal Indicator**	**Variable**			**Odds Ratio**	**95% Wald Confidence Limits (Lower, Upper)**	**p-value**
Produce	*Escherichia coli* (+/-)						
		Point in Production Chain (Chain Time)	Before Harvest		NA	NA	0.2318
			After Harvest		NA	NA	0.0698**
			Distribution		NA	NA	0.6863
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	0.9581
			Melon		NA	NA	0.6047
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		>999.999	<0.001, >999.999	0.6461
			1		>999.999	<0.001, >999.999	0.6493
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	NA	NA	0.9576
				Melon	NA	NA	0.6539
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	NA	NA	0.9558
				Melon	NA	NA	0.6530
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.9569
				Melon	NA	NA	0.0109**
				Tomato*	NA	NA	NA
Produce	Fecal Coliforms (+/-)[θ]						
		Point in Production Chain (Chain	Before Harvest		NA	NA	0.7323
			After Harvest		NA	NA	0.7845
			Distribution		NA	NA	0.7323
			Packing Shed*		NA	NA	NA

		Time)					
		Produce Type	Jalapeño		NA	NA	0.4836
			Melon		NA	NA	0.8621
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		1.190	0.064, 21.998	0.9072
			1		0.325	0.074, 1.427	0.1365
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	NA	NA	0.7318
				Melon	NA	NA	0.6343
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	NA	NA	0.8917
				Melon	NA	NA	0.9585
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.7318
				Melon	NA	NA	0.7454
				Tomato*	NA	NA	NA
Produce	*Enterococcus* (+/-)						
		Point in Production Chain (Chain Time)	Before Harvest		NA	NA	0.8348
			After Harvest		NA	NA	0.5458
			Distribution		NA	NA	0.8035
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	0.9546
			Melon		NA	NA	0.8896
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		0.013	0.001, 0.120	0.0001**
			1		0.041	0.005, 0.313	0.0021**
			2*		NA	NA	NA
		Chain Time and Produce Type	Before Harvest	Jalapeño	NA	NA	0.9537
				Melon	NA	NA	0.9938
				Tomato*	NA	NA	NA
			After	Jalapeño	NA	NA	0.9533

		Interaction Terms	Harvest	Melon	NA	NA	0.9994
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.9513
				Melon	NA	NA	0.9073
				Tomato*	NA	NA	NA
Produce	Coliphages (+/-)						
		Point in Production Chain (Chain Time)	Before Harvest		NA	NA	0.9097
			After Harvest		NA	NA	0.9126
			Distribution		NA	NA	0.9126
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	0.8912
			Melon		NA	NA	0.9923
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		7.317	1.799, 29.758	0.0054*
			1		0.501	0.164, 1.530	0.2248
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	NA	NA	0.8474
				Melon	NA	NA	0.9919
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	NA	NA	0.8940
				Melon	NA	NA	0.9991
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.8908
				Melon	NA	NA	0.9962
				Tomato*	NA	NA	NA
Hand Rinse	*Escherichia coli* (+/-)						
		Point in Production Chain (Chain Time)	After Harvest		NA	NA	0.3694
			Distribution		NA	NA	0.5393
			Packing Shed*		NA	NA	NA

		Produce Type	Jalapeño		NA	NA	0.9493
			Melon		NA	NA	0.0002**
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		8.267	2.015, 33.925	0.0034**
			1		5.973	2.671, 13.359	<.0001**
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	After Harvest	Jalapeño	NA	NA	0.9528
				Melon	NA	NA	0.0198**
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.9525
				Melon	NA	NA	0.0772
				Tomato*	NA	NA	NA
Hand Rinse	Fecal Coliforms (+/-)[θ]						
		Point in Production Chain (Chain Time)	After Harvest		NA	NA	0.3081
			Distribution		NA	NA	0.5525
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	0.8022
			Melon		NA	NA	0.2143
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		0.269	0.036, 1.998	0.1991
			1		0.530	0.107, 2.609	0.4346
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	After Harvest	Jalapeño	NA	NA	0.8038
				Melon	NA	NA	0.8101
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.7600
				Melon	NA	NA	0.8760
				Tomato*	NA	NA	NA
Hand Rinse	*Enterococcus* (+/-) [Δ]	Intercept					
		Point in	After Harvest		NA	NA	NA

		Production Chain (Chain Time)	Distribution		NA	NA	NA
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	NA
			Melon		NA	NA	NA
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		NA	NA	NA
			1		NA	NA	NA
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	After Harvest	Jalapeño	NA	NA	NA
				Melon	NA	NA	NA
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	NA
				Melon	NA	NA	NA
				Tomato*	NA	NA	NA
Hand Rinse	Coliphages (+/-)						
		Point in Production Chain (Chain Time)	NA		NA	NA	0.9085
			NA		NA	NA	0.9085
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	0.2347
			Melon		NA	NA	0.3706
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		38.550	8.996, 165.199	<.0001**
			1		2.634	0.955, 7.267	0.0614
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction	After Harvest	Jalapeño	NA	NA	0.3939
				Melon	NA	NA	0.2999
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.0895
				Melon	NA	NA	0.4884

		Terms		Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)
θ – Firth correction used to perform analysis
Δ - Model not able to be built – All positive observations
* Reference group
** Statistically significant at α=0.05 (p<0.05).

Table A4: Linear modeling statistics quantifying the influence of point in production chain[a] and sampling year[b] on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type	Fecal Indicator and Concentration Units	Type of Produce	Variable		Estimate	Standard Error	95% Wald Confidence Limits (Lower, Upper)	p-value
Produce	*Escherichia coli* (CFU/ml)	Tomatoes	Production Step	Before Harvest	-0.67	0.37	-1.393, 0.060	0.0715
				After Harvest	-0.73	0.37	-1.461, 0.004	0.0512
				Distribution	-0.70	0.37	-1.436, 0.029	0.0595
			Sampling Year	Pilot	-0.07	0.39	-0.846, 0.698	0.8494
				1	1.14	0.24	0.655, 1.620	<.0001*
		Jalapeño Peppers	Production Step	Before Harvest	-2.19	0.76	-3.709, -0.676	0.0054*
				After Harvest	-2.26	0.76	-3.776, -0.743	0.0042*
				Distribution	-2.12	0.76	-3.642, -0.595	0.0073*
			Sampling Year	Pilot	0.01	0.37	-0.730, 0.757	0.9721
				1	0.99	0.29	0.416, 1.564	0.0010*
		Melons	Production Step	Before Harvest	-3.55	0.46	-4.460, -2.632	<.0001*
				After Harvest	-3.65	0.46	-4.565, -2.744	<.0001*
				Distribution	-2.11	0.48	-3.073, -1.154	<.0001*
			Sampling Year	Pilot	NA	NA	NA	NA
				1	-0.05	0.32	-0.685, 0.577	0.8654
Produce	Fecal Coliforms (CFU/ml)	Tomatoes	Production Step	Before Harvest	0.62	0.49	-0.349, 1.588	0.2070
				After Harvest	0.71	0.49	-0.257, 1.681	0.1474

				Distribution	0.38	0.49	-0.585, 1.352	0.4329
			Sampling Year	Pilot	-4.22	0.54	-5.293, -3.156	<.0001*
				1	-2.72	0.32	-3.353, -2.078	<.0001*
		Jalapeño Peppers	Production Step	Before Harvest	-0.12	2.20	-4.529, 4.288	0.9564
				After Harvest	-0.23	2.20	-4.634, 4.183	0.9186
				Distribution	-0.68	2.20	-5.090, 3.727	0.7578
			Sampling Year	Pilot	-3.80	0.85	-5.501, -2.100	<.0001*
				1	-2.49	0.61	-3.709 ,-1.280	0.0001*
		Melons	Production Step	Before Harvest	-0.80	0.25	-1.285, -0.307	0.0016*
				After Harvest	-1.10	0.25	-1.591, -0.617	<.0001*
				Distribution	-0.83	0.26	-1.348, -0.321	0.0016*
			Sampling Year	Pilot	NA	NA	NA	NA
				1	-1.46	0.17	-1.795, -1.121	<.0001*
Produce	*Enterococcus* (CFU/ml)	Tomatoes	Production Step	Before Harvest	-0.02	0.50	-1.020, 0.971	0.9610
				After Harvest	0.49	0.50	-0.515, 1.493	0.3357
				Distribution	0.47	0.50	-0.534, 1.475	0.3539
			Sampling Year	Pilot	-1.76	0.53	-2.814, -0.697	0.0014*
				1	-1.36	0.33	-2.017, -0.694	0.0001*
		Jalapeño Peppers	Production Step	Before Harvest	-2.00	1.25	-4.500, 0.491	0.1133
				After Harvest	-1.66	1.25	-4.157, 0.835	0.1881
				Distribution	-1.69	1.25	-4.197, 0.818	0.1826
			Sampling Year	Pilot	-2.62	0.61	-3.841, -1.394	<.0001*
				1	-1.69	0.47	-2.633, -0.744	0.0007*
		Melons	Production	Before	-0.52	0.36		

			Step	Harvest			-1.229, 0.182	0.1444
				After Harvest	-0.56	0.35	-1.261, 0.144	0.1181
				Distribution	-0.72	0.37	-1.460, 0.021	0.0568
			Sampling Year	Pilot	NA	NA	NA	NA
				1	-1.44	0.25	-1.930, -0.957	<.0001*
Produce	Coliphages (MPN/ml)	Tomatoes	Production Step	Before Harvest	-1.28	0.43	-2.132, -0.428	0.0038*
				After Harvest	-1.05	0.43	-1.915, -0.194	0.0172*
				Distribution	-1.16	0.43	-2.017, -0.295	0.0093*
			Sampling Year	Pilot	-1.33	0.42	-2.159, -0.497	0.0022*
				1	-1.78	0.48	-2.734, -0.817	0.0005*
		Jalapeño Peppers	Production Step	Before Harvest	0.12	1.15	-2.199, 2.432	0.9193
				After Harvest	-0.90	1.15	-3.216, 1.415	0.4365
				Distribution	-0.59	1.15	-2.920, 1.744	0.6132
			Sampling Year	Pilot	-.78	0.60	-1.985, 0.430	0.2008
				1	0.01	0.63	-1.259, 1.277	0.9886
		Melons	Production Step	Before Harvest	-0.31	0.40	-1.106, 0.491	0.4458
				After Harvest	-0.67	0.40	-1.463, 0.126	0.0978
				Distribution	-0.36	0.43	-1.210, 0.488	0.4006
			Sampling Year	Pilot	NA	NA	NA	NA
				1	0.76	0.29	0.175, 1.337	0.0113*

Table A5: Logistic modeling statistics quantifying the influence of point in production chain[a], produce type, sampling year[b], and the interaction between type of produce and point in production chain on fecal indicator concentrations in produce and workers' hand rinse samples.

Sample Type and Units	**Fecal Indicator**	**Variable**			**Odds Ratio**	**95% Wald Confidence Limits (Lower, Upper)**	**p-value**
Produce	*Escherichia coli* (+/-)						
		Point in Production Chain (Chain Time)	Before Harvest		NA	NA	0.2318
			After Harvest		NA	NA	0.0698**
			Distribution		NA	NA	0.6863
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	0.9581
			Melon		NA	NA	0.6047
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		>999.999	<0.001, >999.999	0.6461
			1		>999.999	<0.001, >999.999	0.6493
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	NA	NA	0.9576
				Melon	NA	NA	0.6539
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	NA	NA	0.9558
				Melon	NA	NA	0.6530
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.9569
				Melon	NA	NA	0.0109**
				Tomato*	NA	NA	NA
Produce	Fecal Coliforms (+/-)[θ]						
		Point in Production Chain (Chain	Before Harvest		NA	NA	0.7323
			After Harvest		NA	NA	0.7845
			Distribution		NA	NA	0.7323
			Packing Shed*		NA	NA	NA

		Time)					
		Produce Type	Jalapeño		NA	NA	0.4836
			Melon		NA	NA	0.8621
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		1.190	0.064, 21.998	0.9072
			1		0.325	0.074, 1.427	0.1365
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	NA	NA	0.7318
				Melon	NA	NA	0.6343
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	NA	NA	0.8917
				Melon	NA	NA	0.9585
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.7318
				Melon	NA	NA	0.7454
				Tomato*	NA	NA	NA
Produce	*Enterococcus* (+/-)						
		Point in Production Chain (Chain Time)	Before Harvest		NA	NA	0.8348
			After Harvest		NA	NA	0.5458
			Distribution		NA	NA	0.8035
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	0.9546
			Melon		NA	NA	0.8896
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		0.013	0.001, 0.120	0.0001**
			1		0.041	0.005, 0.313	0.0021**
			2*		NA	NA	NA
		Chain Time and Produce Type	Before Harvest	Jalapeño	NA	NA	0.9537
				Melon	NA	NA	0.9938
				Tomato*	NA	NA	NA
			After	Jalapeño	NA	NA	0.9533

		Interaction Terms	Harvest	Melon	NA	NA	0.9994
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.9513
				Melon	NA	NA	0.9073
				Tomato*	NA	NA	NA
Produce	Coliphages (+/-)						
		Point in Production Chain (Chain Time)	Before Harvest		NA	NA	0.9097
			After Harvest		NA	NA	0.9126
			Distribution		NA	NA	0.9126
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	0.8912
			Melon		NA	NA	0.9923
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		7.317	1.799, 29.758	0.0054*
			1		0.501	0.164, 1.530	0.2248
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	Before Harvest	Jalapeño	NA	NA	0.8474
				Melon	NA	NA	0.9919
				Tomato*	NA	NA	NA
			After Harvest	Jalapeño	NA	NA	0.8940
				Melon	NA	NA	0.9991
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.8908
				Melon	NA	NA	0.9962
				Tomato*	NA	NA	NA
Hand Rinse	*Escherichia coli* (+/-)						
		Point in Production Chain (Chain Time)	After Harvest		NA	NA	0.3694
			Distribution		NA	NA	0.5393
			Packing Shed*		NA	NA	NA

		Produce Type	Jalapeño		NA	NA	0.9493
			Melon		NA	NA	0.0002**
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		8.267	2.015, 33.925	0.0034**
			1		5.973	2.671, 13.359	<.0001**
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	After Harvest	Jalapeño	NA	NA	0.9528
				Melon	NA	NA	0.0198**
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.9525
				Melon	NA	NA	0.0772
				Tomato*	NA	NA	NA
Hand Rinse	Fecal Coliforms (+/-)[θ]						
		Point in Production Chain (Chain Time)	After Harvest		NA	NA	0.3081
			Distribution		NA	NA	0.5525
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	0.8022
			Melon		NA	NA	0.2143
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		0.269	0.036, 1.998	0.1991
			1		0.530	0.107, 2.609	0.4346
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	After Harvest	Jalapeño	NA	NA	0.8038
				Melon	NA	NA	0.8101
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.7600
				Melon	NA	NA	0.8760
				Tomato*	NA	NA	NA
Hand Rinse	*Enterococcus* (+/-)[Δ]	Intercept					
		Point in	After Harvest		NA	NA	NA

		Production Chain (Chain Time)	Distribution		NA	NA	NA
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	NA
			Melon		NA	NA	NA
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		NA	NA	NA
			1		NA	NA	NA
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction Terms	After Harvest	Jalapeño	NA	NA	NA
				Melon	NA	NA	NA
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	NA
				Melon	NA	NA	NA
				Tomato*	NA	NA	NA
Hand Rinse	Coliphages (+/-)						
		Point in Production Chain (Chain Time)	After Harvest		NA	NA	0.9085
			Distribution		NA	NA	0.9085
			Packing Shed*		NA	NA	NA
		Produce Type	Jalapeño		NA	NA	0.2347
			Melon		NA	NA	0.3706
			Tomato*		NA	NA	NA
		Sampling Year	Pilot		38.550	8.996, 165.199	<.0001**
			1		2.634	0.955, 7.267	0.0614
			2*		NA	NA	NA
		Chain Time and Produce Type Interaction	After Harvest	Jalapeño	NA	NA	0.3939
				Melon	NA	NA	0.2999
				Tomato*	NA	NA	NA
			Distribution	Jalapeño	NA	NA	0.0895
				Melon	NA	NA	0.4884

		Terms		Tomato*	NA	NA	NA

[a]Relative to samples collected from the packing shed (referent group)
[b]Relative to samples collected during year 2 (referent group)
θ – Firth correction used to perform analysis
Δ - Model not able to be built – All positive observations
* Reference group
** Statistically significant at $\alpha=0.05$ ($p<0.05$).

Key: The dependent variable labeled "log_ind" refers to the log_{10} transformation of all fecal indicator concentrations.

Figure A1: All unstratified boxplot results for *Escherichia coli* (A), fecal coliforms (B), *Enterococcus* (C), and somatic coliphage (D) concentrations from produce rinse samples, measured as CFU/fruit for all indicators except coliphage (MPN/fruit)

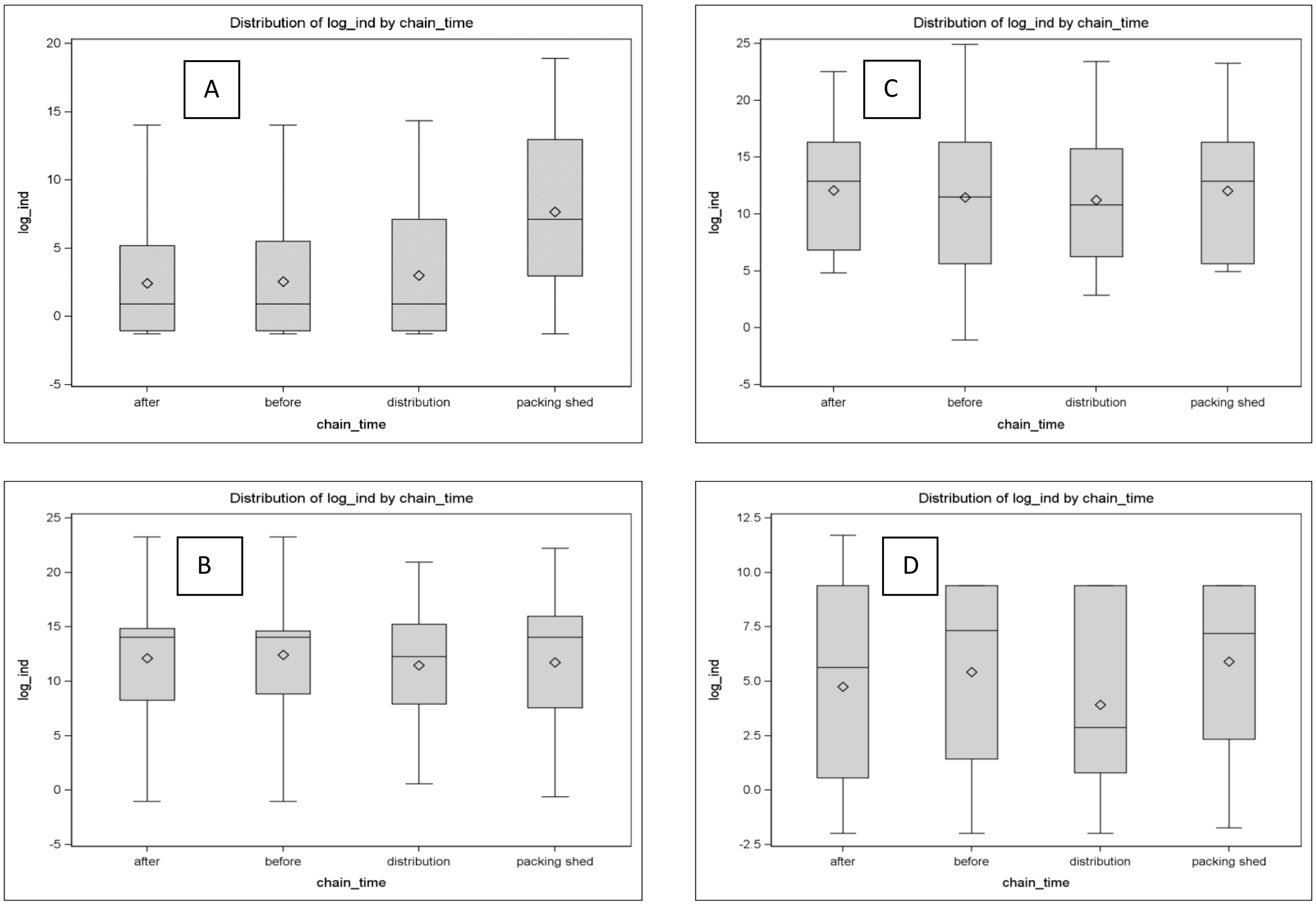


Figure A2: All unstratified boxplot results for *Escherichia coli* (A), fecal coliforms (B), *Enterococcus* (C), and somatic coliphage (D) concentrations from produce rinse samples, measured as CFU/ml for all indicators except coliphage (MPN/ml)

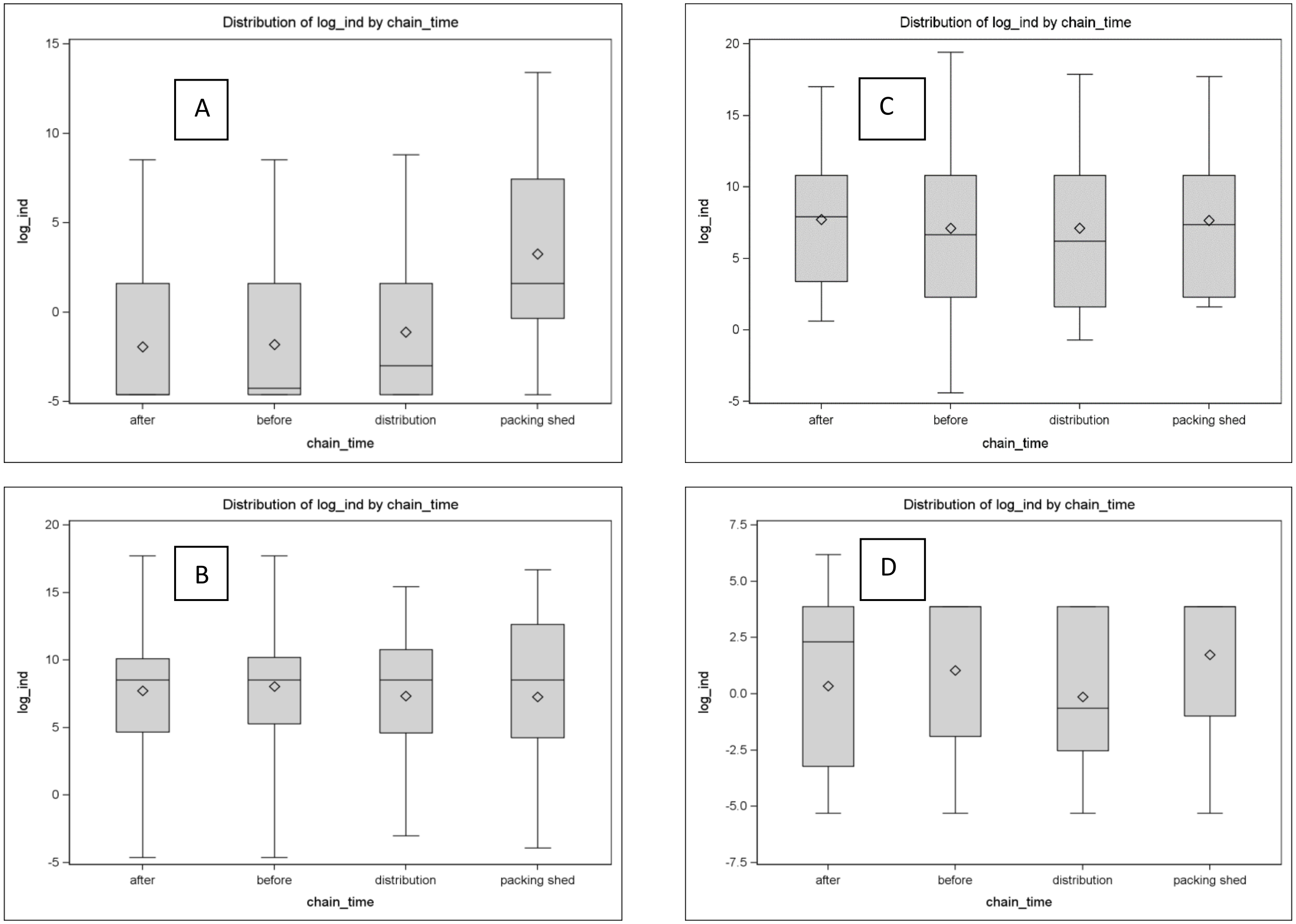


Figure A3: All unstratified boxplot results for *Escherichia coli* (A), fecal coliforms (B), *Enterococcus* (C), and somatic coliphage (D) concentrations from hand rinse samples, measured as CFU/hand for all indicators except coliphage (MPN/hand)

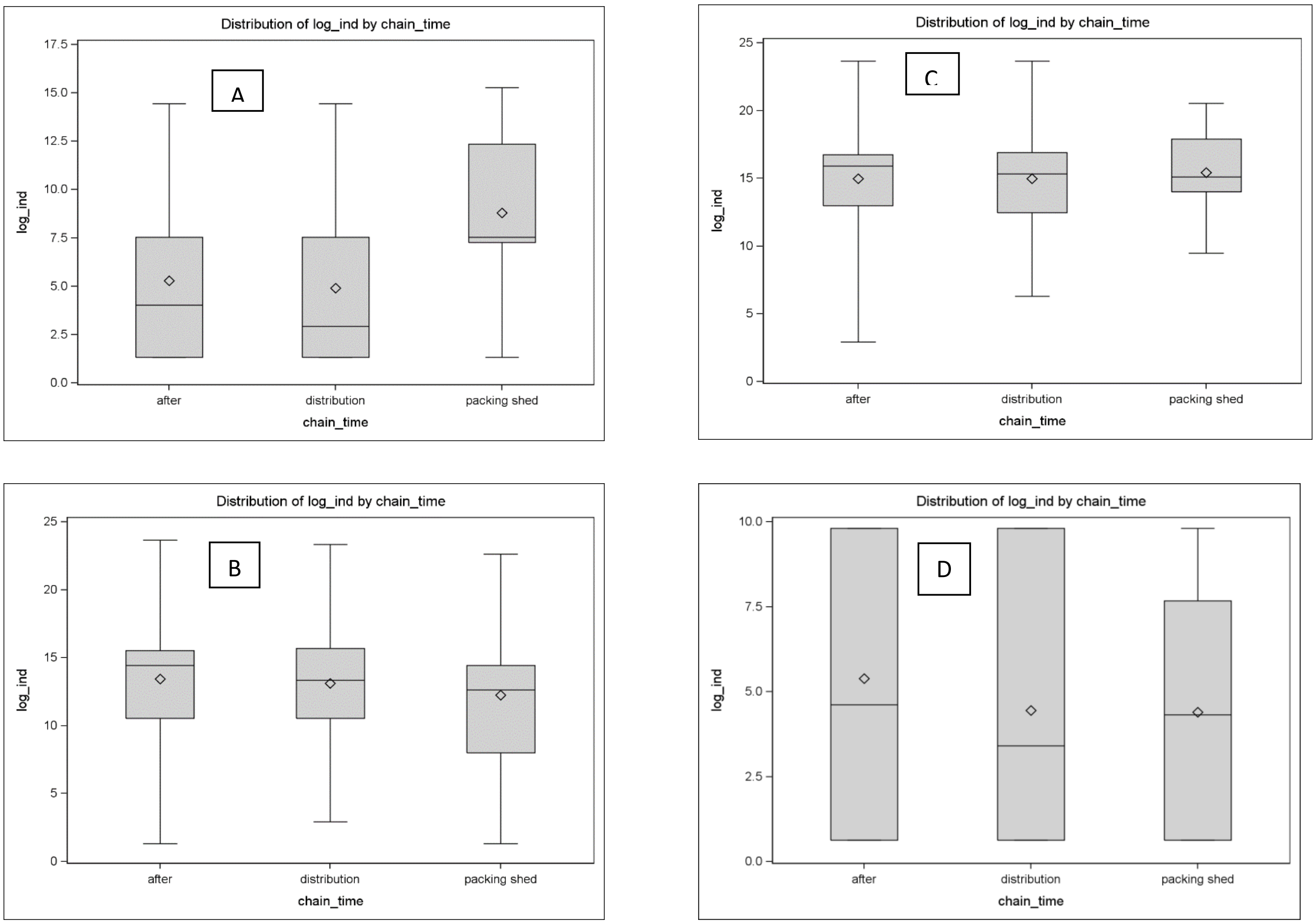


Figure A4: All stratified boxplot results for *Escherichia coli* concentrations (CFU/fruit) for tomatoes (A), jalapeño peppers (B), and melons (C) from produce rinse samples.

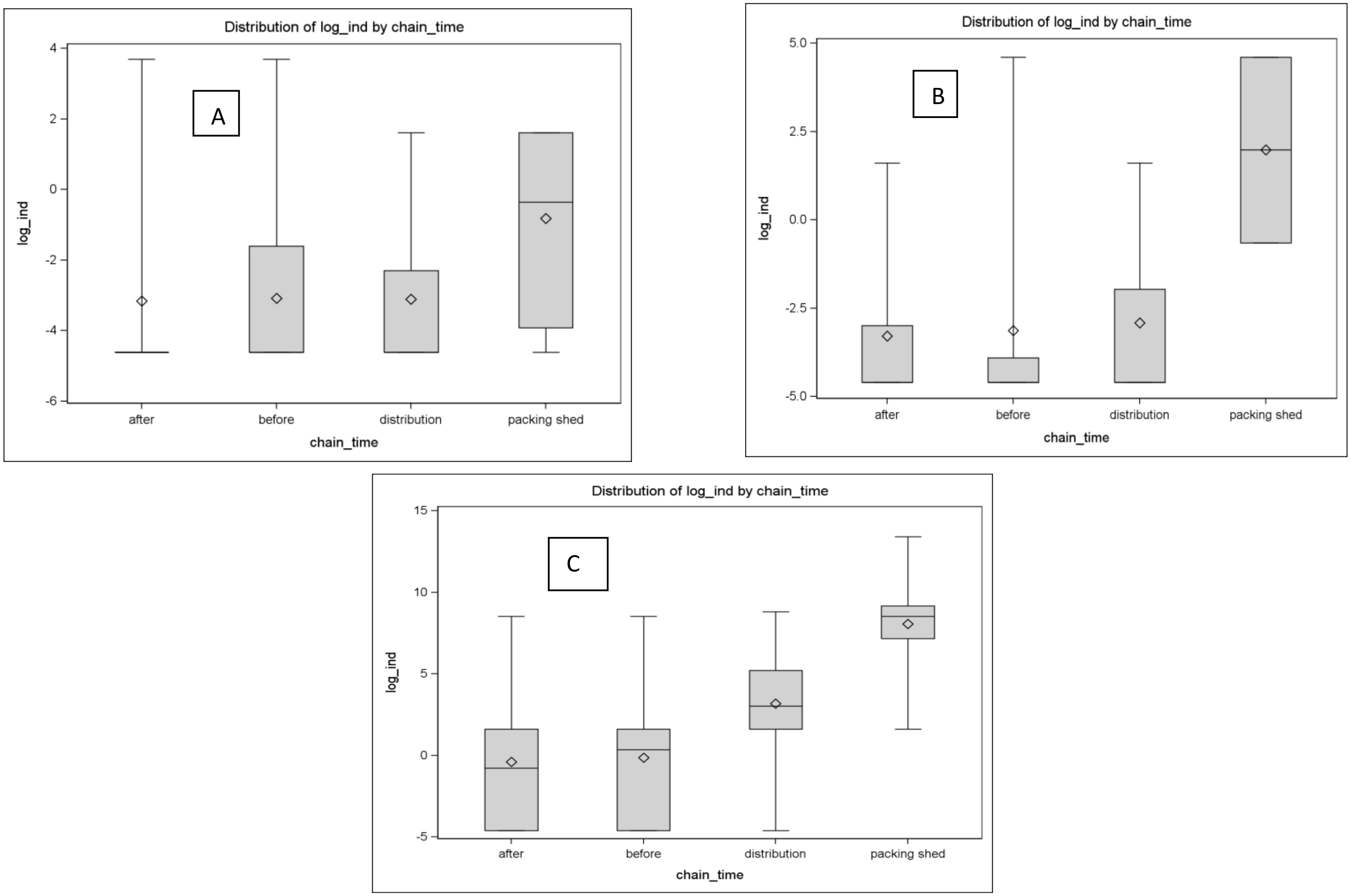


Figure A5: All stratified boxplot results for *Escherichia coli* concentrations (CFU/ml) for tomatoes (A), jalapeño peppers (B), and melons (C) from produce rinse samples.