## Supplemental Materials

### Table S1: Calculation of the risk of recall.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | Value | Unit | Source | Justification |
| Production per year of leaf and romaine lettuce in the U.S | 3,971,000,000 | lb. | Total production in the US  USDA ERS (2023) | The total production of romaine and leaf lettuce from 2021 was taken from Table 26. |
| Production per month romaine and leaf in the US | 330,916,666 | lb. | Calculated | Calculated as the annual production divided by 12 months of the year. |
| Surveillance period length in Yuma | 2 | months | FDA (2021); USDA ERS (2023) | 2021 sampling assignment report shows that samples were taken in February and March. Based on the [ERS](https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=106516) lettuce production shifts regionally by season. In these 2 months, most production is from AZ. |
| Total production in AZ in these two months of surveillance | 661,833,333 | lb. | Calculated  (USDA - Economic Research Service (ERS), 2023) | Production of romaine and leaf lettuce shifts completely almost completely to AZ in February and March ([ERS](https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=106516)). We can make simplifying assumptions on the production of romaine and leaf during these two months equals to two months’ worth of production. |
| Total tests taken | 5,040 | unitless | FDA (2021) | A total of 504 tests were taken, each test consisted of 10 subsamples. |
| Total sample mass | 300 | g | FDA (2021) | Each subsample was at least 300g in weight. |
| Total positive samples | 1 | unitless | FDA (2021) | One of the samples resulted positive for STEC. |
| Total fields produced in AZ during these 2 months | 4,136 | fields | Calculated | We assume that every field is 5 acres and that an acre of production yields 160,000 lb. |
| Risk of recall | 1/4,136 = 0.000242  One recall per 4,136 fields produced | unitless | Calculated |  |

### Table S2: Model Steps and Parameter Table involved in the baseline system.

| Symbol | Variable | Distribution, value, or formula | Unit | Source | Justification |
| --- | --- | --- | --- | --- | --- |
| Contamination Event | | | | |  |
| **µ** | **Contamination means** | **-2.65** | **Log(CFU/g)** | **(United Fresh Produce Association, 2021)** |  |
| **σ** | **Contamination standard deviation** | **0.8** | **Log(CFU/g)** | **(ICMSF (International Commission on Microbiological Specifications for Foods), 2018)** |  |
| **CH0** | **Initial contamination** | **Normal (µ, σ)** | **Log(CFU/g)** | **Calculated** |  |
| Process Stage 1: Primary Raw Material Production (PRMP) | | | | |  |
| **µΔPRMP\*** | **Assumed Mean change at PRMP** | **0** | **Log(CFU/g)** | **Assumed** | **Assume GAPs at PRMP** |
| **σ ΔPRMP** | **Assumed Standard Deviation change at PRMP** | **0** | **Log(CFU/g)** | **Assumed** |
| **ΔPRMPagg** | **Aggregated Total Change due to PRMP** | **Normal (µΔPRMP, σΔPRMP)** | **Log(CFU/g)** | **Calculated** |
| **CH** | **Contamination at Harvest** | **CH0 + ΔPRMP** | **Log(CFU/g)** | **Calculated** |
| Process Stage 2: Harvest (H) to calculate potential cross contamination | | | | |  |
| ECsoil | *E. coli* concentration in soil | 10^Normal(0.928,1.11,  Truncate (0,3.67)) | CFU/g | QMRA: (Pang et al., 2017)  Data: (Lenehan et al., 2005) |  |
| Rsoil | *E. coli* O157:H7 ratio to *E. coli* in soil | 10^Normal(1.9,0.6,  Truncate (,0)) | unitless | QMRA: (Pang et al., 2017)  Data: (Ottoson et al., 2011) |  |
| mS-B | Soil attached to harvesting blade | 10.22 | g | QMRA: (Bozkurt et al., 2021; Pang et al., 2017)  Data: (Yang et al., 2012) |  |
| Nb | No. of E. coli O157:H7 cells in soil attached on blade | ECsoil × Rsoil × mS-B | CFU | Calculated |  |
| TrB-P | Transfer coefficient from harvesting blades to lettuce | 0.0013 | unitless | QMRA: (Bozkurt et al., 2021; Pang et al., 2017)  Data: (Yang et al., 2012) |  |
| ECTrL | Population changes due to Harvesting | (Nb × TrB-P)/1500 | CFU/g |  |  |
| ΔH | Log Population change due to harvesting | Log (ECTrL) | Log10 CFU/g | Calculated |  |
| **µΔH** | **Fitted Mean change at H** | **0.0006** | **Log10 CFU/g** |  |  |
| **σΔH** | **Fitted Standard Deviation change at H** | **0.018** | **Log10 CFU/g** |  |  |
| **ΔHagg** | **Aggregated total Change due to H** | **Normal(µΔH, σΔH)** | **Log10 CFU/g** | **Calculated** |  |
| **CM** | **Contamination at Manufacturing** | **CH + ΔHAgg** | **Log10 CFU/g** | **Calculated** |  |
| Process Stage 3: Processing | | | | | |
| dPW | Log Reduction Pre-wash | Uniform(1.1, 1.4) | Log10 CFU/g | Data: (Pahariya et al., 2022) |  |
| CPW | Levels after Prewash | CM + dPW | Log10 CFU/g | Calculated |  |
| dW | Log Reduction Wash | Pert(0.6,1,1.4) | Log10 CFU/g | QMRA: (Pang et al., 2017).  Data: (Keskinen & Annous, 2011; Luo et al., 2012; Stopforth et al., 2008; Zhang et al., 2009) |  |
| CW | Levels after Wash | CPW + dW | Log10 CFU/g | Calculated |  |
| TrL\_FW | Tr from contaminated lettuce to flume | Triangular(0, 0.01, 0.02) /100 | Fraction | (Pérez Rodríguez et al., 2011) |  |
| TrL\_Sh | Tr from contaminated lettuce to shredder | Triangular(0, 0.02, 0.02) /100 | Fraction | (Pérez Rodríguez et al., 2011) |  |
| TrL\_ST | Tr from contaminated lettuce to shaker | Triangular(0, 0.01, 0.02) /100 | Fraction | (Pérez Rodríguez et al., 2011) |  |
| TrL\_C | Tr from contaminated lettuce to centrifuge | Triangular(0, 0.04, 0.08) /100 | Fraction | (Pérez Rodríguez et al., 2011) |  |
| TrL\_CB | Tr from contaminated lettuce to conveyor | Triangular(0, 0.1, 0.24) /100 | Fraction | (Pérez Rodríguez et al., 2011) |  |
| TrE\_L | Overall transfer coefficient from facilities to uncontaminated lettuce | Triangular(9.9, 15.33, 19.83) /100 | Fraction | (Pérez Rodríguez et al., 2011) |  |
| CW | Levels after Wash | CPW + dW | Log10 CFU/g | Calculated |  |
| NTrL\_F | Total cells transferred from lettuce to facility per gram of produce | (10^CPW) \* (TrL\_FW + TrL\_Sh +TrL\_ST + TrL\_C +TrL\_CB) | CFUs/g produce | Calculated as (Pang et al., 2017) |  |
| NTrF\_L | Total transfer from facility to lettuce per gram of produce | NTrL\_F \* TrE\_L | CFUs/g produce | Calculated as (Pang et al., 2017) |  |
| CPCC | Cells in unit batch after processing | Log (CW + NTrL\_F - NTrF\_L) | Log10 CFU/g | Calculated as (Pang et al., 2017) |  |
| ΔM | Log Population change due to Manufacturing | CPCC - CM | Log10 CFU/g | Calculated |  |
| **µΔM** | **Fitted Mean change at Manufacturing** | **-2.25** | **Log10 CFU/g** |  |  |
| **σΔM** | **Fitted Standard Deviation change at Manufacturing** | **0.17** | **Log10 CFU/g** |  |  |
| **ΔMagg** | **Aggregated total Change due to Manufacturing** | **Normal (µΔM, σΔM)** | **Log10 CFU/g** | **Calculated** |  |
| **CPC** | **Contamination at Presentation to consumer** | **CM + ΔMAgg** | **Log10 CFU/g** | **Calculated** |  |
| Process Stage 4: Presentation to Consumer (PC) | | | | | |
| Tmin | *E. coli* O157:H7 minimum growth temperature | 1.2 | °C | (McKellar & Delaquis, 2011) |  |
| b | *E. coli* O157:H7 growth model parameter, b | 0.023 | unitless | (McKellar & Delaquis, 2011) |  |
| Grate | Growth rate | (b x (TTrans - Tmin))2/2.303 | Log10 CFU g-1 h-1 | Calculated |  |
| k | Die off Rate | Lognorm(0.013,0.001,Shift(0.001))/2.303 | Log10 CFU g-1 h-1 | (Pang et al., 2017) |  |
| tTransF\_R | Transportation time | Triangular (6,12,24) | h | (Mokhtari et al., 2022) |  |
| TTransF\_R | Transportation temperature | Beta (1.5217, 1.3470, 2.8376, 4.9987) | °C |  |  |
| ΔT\_R | Population changes due to transportation from facility to retail | IF (TTrans>5°C, Grate\* tTrans, k\* tTrans) | Log10 CFU/g | Calculated |  |
| CT\_R | Contamination after transport to from facility to retail | CPC + ΔT\_R | Log10 CFU/g | Calculated |  |
| tR | Retail storage time | Triangular(0.5,4,7) x 24 | h | (Pang et al., 2017)  Data from EcoSure (2007) |  |
| TR | Retail storage temperature | Normal(3.8, 1.4,  Truncated (0, 5)) | °C | (Pang et al., 2017)  Data from EcoSure (2007) | To represent good practices the max temperature was truncated to 5°C from 13.6 |
| **µΔPC** | **Fitted Mean change at presentation to consumer** | **-0.92** | **Log10 CFU/g** |  |  |
| **σΔPC** | **Fitted Standard Deviation change at presentation to consumer** | **0.21** | **Log10 CFU/g** |  |  |
| **ΔPCagg** | **Aggregated total Change at presentation to consumer** | **Normal (µΔM, σΔM)** | **Log10 CFU/g** | **calculated** |  |
| **CCH** | **Contamination at Consumer Handling** | **CPC + ΔHAgg** | **Log10 CFU/g** | **Calculated** |  |
| Process Stage 5: Consumer Handling | | | | | |
| TbH | Temperature before putting in home refrigerator | Normal (8.386, 3.831,  Truncate (0,20)) | °C | (Bozkurt et al., 2021; Pang et al., 2017) |  |
| tTransH | Transportation time | Lognorm(1.421, 0.46478,  Truncate (0.1833, 3.8667),  Shift (-0.24609)) | h | (Pang et al., 2017) |  |
| TTransH | Transportation temperature from retail to home | 0.5 \* (TbH + TTransF\_R) |  | Calculated as Pang et al |  |
| GrateR\_H | Growth rate | (b x (TTransH - Tmin))2/2.303 | Log10 CFU g-1 h-1 | Calculated |  |
| ΔR\_H | Population change due to transportation from retail to home | IF (TTransH >5°C, GrateR\_H\* tTransH, k\* tTransH) | Log10 CFU/g |  |  |
| CR\_H | Contamination after transport to from retail to home | CPC + ΔR\_H | Log10 CFU/g |  |  |
| tHS | Home storage time | 0.5 \*((Weibull (1.13,2.84) × 24) +( Weibull (1.7,7.96) × 24  )) | h | (Bozkurt et al., 2021; Pang et al., 2017) |  |
| THS | Temperature at home storage | Normal (3.4517,2.4442,  Truncate (-5,17.22)) | °C | (Bozkurt et al., 2021; Pang et al., 2017)  Data from EcoSure (2007) |  |
| GrateH | Growth rate | (b x (TH - Tmin))2/2.303 | Log10 CFU g-1 h-1 | Calculated |  |
| ΔH | Population change due to home storage | IF (TH >5°C, GrateH\* tH, k\* tH) | Log10 CFU/g | Caulculated |  |
| CH | Contamination home storage | CR\_H + ΔH | Log10 CFU/g |  |  |
| ΔCH | Log Population change due to consumer handling | ΔR\_H + ΔH | Log10 CFU/g | Calculated |  |
| **µΔCH** | **Fitted Mean change at consumer handling** | **-0.57** | **Log10 CFU/g** |  |  |
| **σΔCH** | **Fitted Standard Deviation change at consumer handling** | **0.38** | **Log10 CFU/g** |  |  |
| **ΔCHagg** | **Aggregated total Change at consumer handling** | **Normal (µΔCH, σΔCH)** | **Log10 CFU/g** | **Calculated** |  |
| **CEND** | **Contamination at end of the process** | **CPC + ΔCHAgg** | **Log10 CFU/g** | **Calculated** |  |
|  |  |  |  |  |  |

\*The cells that are highlighted in light yellow are those that are added to the SCRM aggregative model. The Cells in white are those used to fit the aggregated changes.

### Figure S1: The fitted distribution for processing, developed using the RiskNormal distribution for Log changes at manufacturing (AIC of -565,729)

µ: -2.25; σ = 0.17



### Figure S2: The fitted distribution for Presentation to Consumer (Retail), developed using the RiskNormal distribution for Log changes at retail (AIC of -78,565)

µ: -0.92 Log (CFU/g); σ = 0.21 Log (CFU/g)



### Figure S3: The fitted distribution for Consumer Handling, developed using the RiskNormal distribution for Log Changes at manufacturing (AIC of -16,215)

µ: -0.57 Log (CFU/g); σ = 0.38 Log (CFU/g)



### Table S3: Number of lots that test positive baseline and additional product testing scenarios, categorized by the risk that a product test at retail would test positive.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Scenario | Number of positive product tests, categorized by the risk that a product test at retail would test positive | | | | | | Number of Non-contaminated and rejected lots |
| Total | >1 in 10 | >1 in 100 | >1 in 1,000 | >1 in 10,000 | < 1 in 10,000 |
| *Highest* | *High* | *Med-High* | *Med-Low* | *Low* |  |
| *High Variability Contamination Scenario (µ = -2.65, σ = 0.8, P(O) = 8.165%)* | | | | | | |  |
| Baseline | 18 | 2 | 7 | 8 | 1 | 0 | 91,835 |
| Improved Process Controls | 6 | 0 | 3 | 3 | 0 | 0 | 91,835 |
| Additional Product Testing\* | 950 | 16 | 295 | 452 | 170 | 17 | 92,785 |
| *Low Variability Contamination Scenario (µ = -2.65, σ = 0.2, P(O) = 8.165%)* | | | | | | |  |
| Baseline | 3 | 0 | 0 | 1 | 2 | 0 | 91,835 |
| Improved Process Controls | 1 | 0 | 0 | 1 | 0 | 0 | 91,835 |
| Additional Product Testing\* | 361 | 0 | 0 | 92 | 300 | -\*\* | 92,196 |

\*For Additional Product Testing, this is the number of positive product tests found by a product testing conducted at the end of the *Processing* stage. Here the total number of positive product tests is the direct output for the model, and these lots were allocated to risk categories based on changes from the baseline count of the number of lots with a given risk of a product test at retail. Such an estimation process was necessary because the model responded to an additional product test positive by setting contamination in that lot to 0 (rejecting the lot), which then made the predicted risk of a positive test non-contaminated or rejected.

\*\* Under the Additional Product Testing Scenario, this resulted in more *Low* risk lots (31), thus no estimate is provided for the number of additional lots rejected relative to the baseline. This can be explained by the minor fluctuations caused by random number generation when running the model. Therefore, this change is not the result of implementing this management practice.