Journal of Theoretical Biology 321 (2013) 28–35

Contents lists available at SciVerse ScienceDirect

Journal of Theoretical Biology

journal homepage: www.elsevier.com/locate/yjtbi

Enhanced surveillance on food-borne disease outbreaks: Dynamics of cross-contamination in biocidal wash procedure

Daniel Munther[a,*], Jianhong Wu[b]

[a] Centre for Disease Modelling, Department of Mathematics and Statistics, York University, Toronto, Canada M3J 1P3
[b] Centre for Disease Modelling, York Institute for Health Research, Department of Mathematics and Statistics, York University, Toronto, Canada M3J 1P3

HIGHLIGHTS

- SIR type model for contamination dynamics of fresh produce in commercial wash procedure.
- Express contamination and cross-contamination in terms of model parameters.
- Fit model parameters in the pre-wash and wash stage with *Escherichia coli* O157 data on romaine lettuce.
- Link source misidentification likelihood to mean wash time and sanitizer concentration.

ARTICLE INFO

Article history:
Received 5 October 2012
Received in revised form
18 December 2012
Accepted 29 December 2012
Available online 5 January 2013

Keywords:
Mathematical model
Fresh produce
Process water
Escherichia coli
Fresh-cut romaine lettuce

ABSTRACT

Understanding the geographic and temporal spread of food-borne diseases associated with fresh produce is crucial for informing adequate surveillance and control. As a first step towards this goal, we develop and analyze a novel three stage model at the processing/sanitization juncture in the fresh produce supply chain. The key feature of our model is its ability to describe the dynamics of cross-contamination during commercial wash procedures. In general, we quantify the degree of cross-contamination in terms of model parameters. Applying these results in the case of *Escherichia coli* O157:H7 contamination of fresh-cut romaine lettuce, we identify the mean wash time and free chlorine concentration as critical parameters. In addition to showing how these parameters affect contamination levels, we recommend that in order to prevent potential source misidentification, at least 2.2 mg/L of free chlorine should be used during a wash lasting at least 30 s.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

Food-borne diseases associated with the consumption of fresh produce continue to cause serious difficulties for public health. Recently, there have been a number of significant outbreaks both in North America and Europe. For instance, the 2006 *Escherichia coli* contamination of bagged spinach resulted in many hospitalizations in the US (and Canada) and three deaths (Sander, 2006). In 2008, an uncommon serotype of *Salmonella enterica*, known as Saintpaul, caused over 1000 cases of food poisoning across the US, finally being linked to jalapeño and serrano peppers from Mexico (Taylor et al., 2010). The year 2011 was particularly tough as the US suffered from at least six outbreaks associated to fresh produce, one of which involved cantaloupes contaminated with listeriosis, resulting in the second most deadly outbreak ever to occur in the US (CDC, 2011). Furthermore, in the summer of 2011, Europe was hit with the deadliest outbreak in recent history linked to sprouts grown from imported fenugreek seeds contaminated with *E. coli* O104:H4. Germany, being the epicenter, reported 45 deaths as of July 27 of that year (ECDC).

Clearly outbreaks in these countries have had tremendous socio-economic impact. In order to mitigate these effects, disease surveillance must be able to quickly detect both geographic and temporal occurrence of such contamination. As many studies highlight disinfection as a crucial juncture in the supply chain, we look to examine the contamination dynamics of fresh produce that can occur in commercial wash procedures (Gil et al., 2009). While washing is designed to ensure the safety of a product, wash water may provide a secondary source of contamination or promote cross-contamination (Tomás-Callejas et al., 2012). In line with this, we build and analyze a novel three stage model of a typical wash procedure in a fresh produce processing facility.

In terms of mathematics, we show that contamination levels converge rapidly to an equilibrium, which we can describe via closed form expressions involving only model parameters, in each of the three stages. For biological implications, we identify

* Corresponding author. Tel.: +1 416 736 2100x66084; fax: +1 416 736 5757.
E-mail addresses: munther@mathstat.yorku.ca (D. Munther), wujh@yorku.ca (J. Wu).

0022-5193/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jtbi.2012.12.024

parameters to which this equilibrium is sensitive. In particular, we show how the mean wash time and sanitizer concentration crucially affect the degree of produce contamination and further we provide guidelines on how these parameters can be practically controlled to avoid misidentification of the source of contamination during a potential disease outbreak.

The paper is organized as follows: in Section 2 we describe the basic assumptions, parameters and the three stage model. Next, in Section 3, we show that the model converges to a unique, component-wise positive equilibrium. Using these dynamics, in Section 4 we apply the model to a wash procedure involving fresh-cut romaine lettuce (or similar leafy greens) contaminated with *E. coli* O157:H7. Also in Section 4, we justify ranges for model parameters and perform sensitivity analysis. Determining the mean wash time and free chlorine concentration to be key parameters with regards to produce contamination, we explore how these can be constrained to prevent misidentifying the initial food vehicle associated to an outbreak. Finally, we discuss how our model can be augmented to be more realistic as well as its link-ability to global supply chain models. Note that in light of recent outbreaks in North America, a model framework similar to the one we adopt in this paper (for studying the contamination of fresh produce during processing) can be applied to contamination dynamics of meat (especially ready-to-eat products) at the processing juncture. For more details concerning meat hygiene and safety risks see Sofos and Geornaras (2010).

2. Three stage wash model

Suppose two farms produce either the same type of fresh produce or two different types (denoted by P1 and P2, respectively), which are transported to a processing center to be washed, packaged and then shipped along various routes in the supply chain. Suppose also that farm 1 has a source of contamination (possibly via compost or irrigation water) causing a portion of P1 to be contaminated before coming into the center (here we assume that contamination levels are sufficient to lead to a possible outbreak) (Beuchat, 2006). We want to study the dynamics of pathogen spread among P1 and the possible cross-contamination of P2 during the wash processing procedure. To do so, we propose the following three stage model: Before, Washing and After. The B stage includes the pre-washing of the produce, the W stage concerns the principle wash (with sanitizer) and the A stage reflects the dewatering step.

2.1. B stage

We suppose the pre-wash involves a non-immersion process, such as a municipal water spray. Because the produce is not submerged in water, we assume that the spread of contamination occurs via produce–produce contact. To model such transmission, we rely simply on the principle of mass action which, when applied in this context, states that the amount of contaminated produce grows at a rate proportional to the product of the amount of clean produce with the amount of contaminated produce. The underlying assumption here is that the contaminated produce totally mixes with the clean produce (while incoming contamination usually is "patchy", due to a lack of commercial processing data and because we do not want to overcomplicate the model, we assume uniform mixing). If we let S_{1B} and I_{1B} denote the susceptible and contaminated densities of P1, then $I'_{1B} = \beta_{1B} S_{1B} I_{1B}$, where β_{1B} is the contamination rate. Adjusting this equation to account for the inflow and outflow of produce into the pre-wash stage and including the dynamics for S_{1B}, we have

$$S'_{1B} = -\beta_{1B} S_{1B} I_{1B} + \rho N_1 - b_1 S_{1B},$$
$$I'_{1B} = \beta_{1B} S_{1B} I_{1B} + (1-\rho) N_1 - b_1 I_{1B},$$

where $N_1 > 0$ is the incoming rate of P1, $0 < \rho < 1$ and $1/b_1 > 0$ is the average time the produce spends in pre-wash. Our assumption on ρ indicates that a portion of P1 comes into the B stage already contaminated. Finally, for simplicity we assume that P2 comes into the B stage clean and thus ignore any other contamination sources that may be involved (note that before pre-washing, cross-contamination could occur through cutting procedures, handling, etc., however, in our paper we do not consider these possibilities). See Fig. 1 for a schematic of the contamination dynamics in the B stage.

2.2. W stage

Following the pre-wash stage, both P1 and P2 move separately into the main wash stage, where the produce types are cleaned by an immersion produce washer (see Pao et al., 2012 for more details). While P1 and P2 follow distinct processing lines, we suppose that the wash water is re-circulated between these lines, which is a standard practice in the fresh produce industry (Bhagwat, 2006). Because of this, the wash water may become contaminated, leading to a cross-contamination event. The main point here is that contaminated produce can shed pathogens into the wash water, which can then spread to uncontaminated produce (thus our system allows for more than one "transmission pathway", see Tien and Earn, 2010, for a related model). Note that in the following development, we ignore produce-to-produce contact in the wash stage as well as the possibility that pathogens may be able to grow in the wash water.

Let W represent the pathogen concentration in the wash water which is shed from contaminated P1 at a rate $\alpha > 0$. Let $1/\mu$ be the mean pathogen lifetime in the water. This is regulated by the addition of a sanitizing agent to the water as we assume that $\mu > 0$ (a constant) depends on the concentration of sanitizer used to treat the wash water. If we define I_{1W} and S_{1W} as the contaminated and uncontaminated amounts of P1 in the produce washer, then the change of pathogen concentration in the wash water is given by the following equation:

$$W' = \alpha I_{1W} - \mu W.$$

Furthermore, as contaminated water can potentially spread pathogens to clean P1, we model the growth rate of contaminated P1 at this stage by $I'_{1W} = \beta_{1W} S_{1W} W$, where $\beta_{1W} > 0$ is the transmission rate from water to produce. Again, our incidence rate is based on the notion of mass action (which will be discussed in more detail when we derive a range for β_{1W} in Section 4). Including the flow of produce through the washer (i.e. let $1/c_1$ be the mean duration of the wash phase for P1, which will be

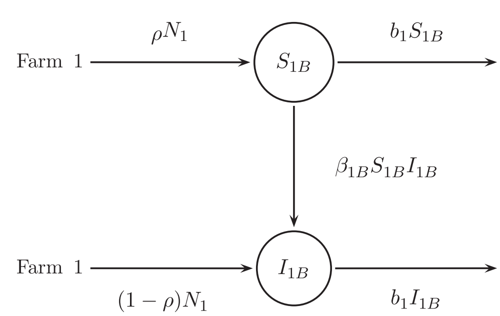

Fig. 1. I_{1B} is the contaminated amount of P1 in stage B. It increases via direct inflow from Farm 1 and via direct contact at rate β_{1B}. The average pre-wash time is $1/b_1$.

Download English Version:

https://daneshyari.com/en/article/4496484

Download Persian Version:

https://daneshyari.com/article/4496484

Daneshyari.com