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Review

Meta-analysis on the effect of interventions used in cattle processing plants to reduce *Escherichia coli* contamination

Samson Zhilyaev [a], Vasco Cadavez [b], Ursula Gonzales-Barron [b], Katherine Phetxumphou [a], Daniel Gallagher [a,*]

[a] *Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, United States*
[b] *CIMO Mountain Research Centre, School of Agriculture, Polytechnic Institute of Braganza, Braganza, Portugal*

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ABSTRACT

Cattle coming from feedlots to slaughter often harbor pathogenic *E. coli* that can contaminate final meat products. As a result, reducing pathogenic contamination during processing is a main priority. Unfortunately, food safety specialists face challenges when trying to determine optimal intervention strategies from published literature. Plant intervention literature results and methods vary significantly, making it difficult to implement interventions with any degree of certainty in their effectiveness. To create a more robust understanding of plant intervention effectiveness, a formal systematic literature review and meta-analysis was conducted on popular intervention methods. Effect size or intervention effectiveness was measured as raw log reduction, and modeled using study characteristics, such as intervention type, temperature of application, initial microbial concentration, etc. Least-squares means were calculated for intervention effectiveness separately on hide and on carcass surfaces. Heterogeneity between studies (I^2) was assessed and factors influencing intervention effectiveness were identified. Least-squares mean reductions (log CFU/cm^2) on carcass surfaces ($n = 249$) were 1.44 [95% CI: 0.73–2.15] for acetic acid, 2.07 [1.48–2.65] for lactic acid, 3.09 [2.46–3.73] for steam vacuum, and 1.90 [1.33–2.47] for water wash. On hide surfaces ($n = 47$), least-squares mean reductions were 2.21 [1.36–3.05] for acetic acid, 3.02 [2.16–3.88] for lactic acid, 3.66 [2.60–4.72] for sodium hydroxide, and 0.08 [−0.94–1.11] for water wash. Meta-regressions showed that initial microbial concentrations and timing of extra water washes were the most important predictors of intervention effectiveness. Unexplained variation remained high in carcass, hide, and lactic acid meta-regressions, suggesting that other significant moderators are yet to be identified. The results will allow plant managers and risk assessors to evaluate plant interventions, variation, and factors more effectively.

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* Corresponding author.
E-mail address: dang@vt.edu (D. Gallagher).

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1. Introduction

Shiga-toxin producing *Escherichia coli* (STEC) has been recognized as a serious source of illness since it was first identified in 1982 (CDC, 2015). Young children, the elderly, and immunocompromised individuals are especially susceptible to illness and death from STEC infections (CDC, 2015). An estimated 176,000 U.S. foodborne STEC infections occur annually, with approximately 63,000 due to *E. coli* O157:H7 and 113,000 from non-O157 STEC (Batz, Hoffmann, & Morris, 2012; Scallan et al., 2011). STEC is estimated to cause 1% of food borne illnesses in England and 3% in Scotland. O157 is the predominant STEC organism in both the U.S. and the U.K. Continental Europe generally has a lower outbreak rate than the U.S or U.K., but they are caused by a broader range of STEC organisms (Vanaja, Jandhyala, Mallick, Leong, & Balasubramanian, 2013). In the U.S., 39% of O157 infections and 30% of non-O157 STEC infections are linked to beef sources (Painter et al., 2013).

Consequently, reducing STEC concentration and prevalence in beef is a high priority (Sofos, 2008). Through the implementation of plant hazard analysis critical control point (HACCP) principles, sanitary conditions at cattle processing plants have improved (Ropkins & Beck, 2000; Sofos, 2008). The risk and impact of product contamination has significantly decreased through plant interventions (Antic et al., 2010; Arthur et al., 2004; Sheridan, 1998). However, current plant intervention literature provides conflicting results. Some authors, for instance, report very high reductions, such as 5.05 log CFU/cm^2 for a water wash spray, while others recorded increases in bacterial counts from water washes on cattle surfaces (Scanga et al., 2011; Yoder et al., 2010). These discrepancies among reported intervention effectiveness are found throughout the literature and make it difficult to determine optimal decontamination strategies. It is likely that variations in experimental design (i.e., temperature, surface type, indicator organism, etc.) contribute to these discrepancies.

A systematic literature review coupled with meta-analysis is one method used to address differences between experimental methods and results within a body of literature (O'Connor, Sargeant, & Wang, 2014; Sargeant, Rajic, Read, & Ohlsson, 2006). Reported results, as intervention effectiveness, can be aggregated to provide weighted averages, or summary effects, among similar trials. Summary effects draw from a larger pool of information and therefore, create a more robust estimate of an intervention's effectiveness. When heterogeneity between trials is high, other tools, such as meta-regressions, can be used to explain the differences in intervention effectiveness (O'Connor et al., 2014; Prado-Silva, Cadavez, Gonzales-Barron, Rezende, & Sant'Ana, 2015). Systematic reviews and meta-analysis are powerful tools that are currently being used in food safety to measure intervention effectiveness with reduced bias and increased transparency (Bucher et al., 2012; Greig et al., 2012; Sargeant et al., 2006). A recent report on abattoir-level plant intervention studies supported current industry practices as effective methods for the reduction of STEC (Greig et al., 2012). However, the report was only limited to abattoir-level studies and did not appear to account for substitution practices in the recorded data. Substitution practices refer to the replacement of a non-detection or zero count (i.e., either a true zero or a value below the limit of detection) by some fraction of the detection limit to calculate descriptive statistics. These substitution methods are an issue because they often lead to biased and inaccurate summary statistics.

This meta-analysis research had two objectives: (i) to determine the effectiveness of various plant interventions to mitigate Shiga-toxin producing *E. coli* using all published intervention data since 1990; and (ii) to apply meta-regressions to determine significant moderators, or covariates, (e.g., temperature of rinse, pressure of application) that could explain the variability observed across studies. It is expected that this research will help plant operators determine which combination of interventions and intervention parameters are optimal for the reduction of STEC.

2. Methods

2.1. Intervention selection and search design

The 2011 Food Safety Inspection Service report was used to compile the list of potential plant interventions (Alvares, Lim, & Green, 2008). Only primary interventions that were (a) continuously applied throughout the year and (b) applied at 5% or more of plants surveyed were included as potential candidates for this meta-analysis. This method was chosen because a meta-analysis on each intervention should include several studies, but the number of studies for uncommon interventions was expected to be low (Borenstein, Hedges, Higgins, & Rothstein, 2009). Nine interventions that met the above criteria were: rinsing with water, lactic acid, acetic acid, sodium hydroxide, peroxyacetic acid, steam vacuum, citric acid, hypochlorite, and acidified sodium chlorite.

In June 2015, a published systematic literature review process (Knobloch, Yoon, & Vogt, 2011; Moher, Liberati, Tetzlaff, & Altman, 2009) was followed in order to effectively search for preliminary interventions and identify potential explanatory variables that could influence the effectiveness of interventions. A full search of databases including Google Scholar, PubMed, Agricola, CAB, and Food Science and Technology Abstracts was completed in August of 2015. Journal articles within the previous 25 years were used. The general format of the searches was: *intervention type AND* (*beef OR carcass OR subprimal OR hide*) *AND* (“*Escherichia coli*” *OR O157 OR* “*non-O157*” *OR coliform OR* “*E. coli*”).

When these terms were too broad, restrictive terms against other products (e.g., poultry, produce, etc.) were added. A full list of search terms is available in Table 1, and a diagram of the systematic review procedure (Knobloch et al., 2011; Moher et al., 2009) is available in Fig. 1. All search results were screened for relevance, except for Google Scholar where only the first 40 results were screened. All the papers that passed the first round of screening were collected for further evaluation.

2.2. Screening and eligibility criteria

The screening criteria followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) method (Knobloch et al., 2011; Moher et al., 2009). Primary screening was purposefully broad; titles and abstracts from the initial searches were checked for any possible relevance to plant interventions. Papers were more rigorously screened in the second round by two independent reviewers.