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Antimicrobial Activity of Commercial Concrete Sealant Against *Salmonella* Spp: A Model for Poultry Processing Plants

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Abstract: *Salmonella* is an important foodborne pathogen often associated with poultry and highly prevalent in poultry processing plants. The objective of this study was to determine the efficacy of a commercial grade concrete sealant (BioSealed for Concrete™) to prevent bacterial attachment, colonization and antimicrobial effects against multiple strains of *Salmonella* (*S. enteritidis*, *S.* Kentucky, *S.* Typhimurium, *S.* Senftenberg and *S.* Heidelberg) on concrete blocks. Individual strains of *Salmonella* spp. were inoculated onto the concrete blocks and divided into 4 different treatment groups: (A) Bricks which were not treated with BioSealed for Concrete™ (B) Bricks which were treated with BioSealed for Concrete™ before inoculation (C) Bricks which were treated with BioSealed for Concrete™ after inoculation and (D) Bricks which were treated with BioSealed for Concrete™ before and after inoculation. External and internal surfaces of the treated concrete blocks were swabbed, serially diluted and plated onto XLD agar. Reductions of survival counts were enumerated and recorded as $\log_{10}$ CFU/cm^2. Significantly ($p<0.05$) lower viable counts were observed following treatments C and D as compared to treatments A and B. However, no significant differences ($p>0.05$) in the survival populations of *Salmonella* were observed between treatments A and B for all five strains tested and between treatments C and D for any of the strains tested. This indicates that BioSealed for Concrete™ proved to be a potent antimicrobial against multiple strains of *Salmonella* and can be used as an alternative method to control this pathogen in processing plant environments.

Key words: *Salmonella*, biofilm, antimicrobial, concrete sealant, poultry processing environment

INTRODUCTION

Salmonellae are small, Gram negative, non-spore forming rods. Every year, approximately 40,000 cases of salmonellosis are reported in the United States according to the Center for Disease Control and Prevention (CDC). Salmonellosis is an important public health problem in the United States with an estimated number of nontyphoidal *Salmonella* infections ranging from 800,000 to 4,000,000 annually (Voetsch *et al*., 2004). Although most outbreaks cause mild to moderate self limited illness, serious disease resulting in death does occur particularly in elderly and immunocompromised populations. The Centers for Disease Control and Prevention (2008) estimates that *Salmonella* infection causes approximately 1.4 million foodborne illnesses annually (Lynch *et al*., 2006). Accounting for medical costs and lost productivity the estimated costs associated with salmonellosis is approximately $2.3 billion (Frenzen *et al*., 1999). The CDC states that bacterial agents are the most common microorganisms associated with foodborne illnesses accounting for 55% of laboratory diagnosed foodborne illnesses and outbreaks. Among bacterial pathogens, *Salmonella enteritidis* accounted for the largest overall number of outbreaks and outbreak-related illnesses. Several foods including cereal, peanut butter, tomatoes, cantaloupe, beef, pork and poultry have been implicated in *Salmonella* related human illnesses. Recent *Salmonella* outbreaks were reported by the U.S. Department of Agricultures' Food Safety and Inspection Services (USDA-FSIS) involving fresh poultry and further processed poultry products such as chicken pot pies and raw frozen breaded and pre-browned stuffed chicken entrees.

Salmonella spp. has developed several strategies to survive in the environment and their ability to adhere to surfaces and form biofilms are among the most important ones. Extracellular structures contributing to bacterial adherence include curli fimbriae, cellulose, capsular polysaccharide and other polysaccharides such as Lipopolisaccharides (LPS) (Malcova *et al*., 2008). However, the mechanisms involving the adhesion of *Salmonella* spp. to inert surfaces are still unclear; different studies have shown that the bacterial attachment partially depends on bacterial characteristics and partially on surface properties (Joseph *et al*., 2001; Sinde and Carballo, 2000; Austin *et al*., 1998). A bacterial biofilm is formed in a number of distinct steps: initial reversible adsorption of cells onto a solid surface,

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production of surface polysaccharides or capsular material followed by formation of an extracellular polymeric matrix resulting in irreversible attachment, early development of biofilm architecture and maturation and dispersion of single cells from the biofilm (Kim and Wei, 2007).

Biofilms have developed into a significant issue for public health as they are less susceptible to antimicrobial treatments (Scher *et al*., 2005; Dunowska *et al*., 2005; Cloete, 2003; Joseph *et al*., 2001). This is especially important considering that biofilms have increased resistance towards the most common used biocides in the food industry such as iodine, chlorine, peroxygens and quaternary ammonium compounds (Cloete, 2003). Biofilms formed in food processing environments are important as they have the potential to act as a chronic source of microbial contamination that can eventually lead to food spoilage or transmission of diseases (Stepanovic *et al*., 2004). Biofilms lead to serious hygienic problems and economic losses due to food spoilage and potential recalls. Hence, the important aspects in controlling biofilm formation and minimizing biotransfer potential in food processing equipment and environments include proper cleaning and sanitation procedures. The control of biofilms represents one of the most persistent challenges within food and industrial environments where the microbial communities are problematic (Kumar and Anand, 1998). Removal of biofilms is a very difficult and demanding task and routine sanitation programs are usually not sufficient to remove biofilms. Therefore, food industry has been looking for cost efficient cleaning and sanitation alternatives to facilitate biofilms removal and to prevent new biofilm formation on inert surfaces. These new strategies usually include physical and chemical methods which interfere on bacterial colonization and biofilm development.

It has been reported that bacterial cells are more resistant to environmental stresses such as nutritional deprivation and oxidative stress when in a biofilm environment. In addition, when in a biofilm, the cells are more resistant to antimicrobial agents and antibiotics than free cells (Kim and Wei, 2007; Dunowska *et al*., 2005; Scher *et al*., 2005; Cloete, 2003; Hood and Zottola, 1997; Leriche and Carpenter, 1995). So far, very few studies have reported specific reasons for the increased resistance of biofilms. Concrete is widely used in the food industry especially in flooring, walls and ceilings. During processing, concrete receives a great amount of organic matter due to the usual processing steps such as bleeding, scalding, eviscerating and feather-picking. This organic matter has potential to serve as an initial source of nutrients to microorganisms allowing them to colonize on and/or in concrete. Concrete is a microporous and the pores in concrete are randomly sized, arranged and connected (Yang *et al*., 2004). These pores form capillary systems in concrete allowing water and other substances to traffic freely in concrete structures. When liquids flow freely on concrete, they may serve as carriers in the transport of microorganisms such as bacteria. Disintegration of concrete due to cycles of wetting, freezing, thawing, drying, chemicals and the propagation of the resulting cracks is a matter of great importance for the food industry (Nawy, 1996). The disintegration of concrete serves as an attachment site for bacteria to form niches that have the potential to work as permanent sources of contamination in food processing plants. Contamination of food may occur from direct contact of food to concrete surfaces or indirect contact (water splashes during sanitation, staff shoes and clothes). Therefore, the food industry has placed a great deal of effort on the reduction of bacterial niches and avoiding formation of biofilms.

There is no single action which will reduce or eliminate biofilms from industrial environments. Several actions must be taken collectively to prevent the formation of biofilms and eliminate these chronic sources of contamination. This study focuses on the attachment of *Salmonella spp*. on concrete and its potential to form biofilms. The objective of this study was to determine the efficiency of BioSealed for Concrete™; a hydrosilicate catalyst in a colloidal liquid base to prevent *Salmonella* spp. attachment on concrete surfaces.

MATERIALS AND METHODS

Bacterial cultures: *Salmonella* strains used in this study were chosen based on their incidence in the poultry industry report published by the United Stated Department of Agriculture (USDA-FSIS, 2008) and the Centers for Disease Control and Prevention (CDC). The five strains used in this study were *Salmonella* Typhimurium, *S.* Heidelberg, *S. enteritidis*, *S.* Senftenberg and *S.* Kentucky. All these strains were wild type isolates from poultry processing facilities. These strains were all independently cultured in Brain Heart Infusion (BHI) broth (Acumedia Manufacturers Inc., Lansing, MI) and incubated at 37°C for 24 h before being used to challenge the concrete bricks. The length of incubation and inoculation of the bacterial cultures were based on 24 h growth curves that were performed in the laboratory (data not shown). At the time of inoculation the average count of the inoculums varied based on the strain of *Salmonella* (Table 1).

Bricks preparation: Quikrete® (Quickrete, Georgia) powder mix was used to produce concrete bricks in commercial sized ice cube trays (total external surface area 40 cm^2), as per manufacturer's directions. Miniature bricks were made in ice cube trays in order to simulate concrete blocks to conduct laboratory experiments.

Table 1: Average counts of *Salmonella* inoculum (log_{10} CFU/ml) used throughout the trial

Strains	*S.* Typhimurium	*S.* Heidelberg	*S. enteritidis*	*S.* Senftenberg	*S.* Kentucky
Inoculum A[1]	9.64	9.87	9.28	9.37	11.51
Inoculum B	10.07	10.40	9.43	9.94	9.98
Inoculum C	8.81	9.58	8.99	9.32	9.92
Inoculum D	8.53	8.75	8.15	8.77	10.24

[1]A = Initial inoculums before introducing cement blocks; B = Inoculums at removal time without any cement blocks; C = Inoculums at removal time containing cement blocks with no BioSealed for Concrete™; D = Inoculums at removal time containing cement blocks with BioSealed for Concrete™

Sampling: Concrete bricks were divided into four groups: (A) bricks which were not treated with BioSealed for Concrete™ [positive control] (B) bricks which were treated with BioSealed for Concrete™ before inoculation (C) bricks which were treated with BioSealed for Concrete™ after inoculation and (D) bricks which were treated with BioSealed for Concrete™ before and after inoculation. The inoculums were split in two equal parts: (1) The first half were considered the control and contained bricks from groups A and C (bricks untreated before inoculation) and (2) the second half of the inoculum was named the "inoculums treated" which contained bricks from groups B and D (bricks which were treated before inoculation). Following manufacturer's directions, BioSealed for Concrete™ was sprayed on the surface of the bricks using a paint spray (Wagner 5.4 GPH, Wagner Spray Tech Corporation, Plymouth, MN). Samples of the inoculums were spread plated onto Xylose Lysine Desoxycholate (XLD) agar (Neogen, Lansing, MI) for enumeration at inoculation time and at the time of removal of the samples. Treated and non-treated bricks were plated onto Tryptic soy agar (TSA; Neogen, Lansing, MI) and XLD without being challenged with any strain of *Salmonella* to ensure no background microflora.

Bricks were submerged in the inoculums for 24 h at 37°C. After 24 h the bricks were removed from inoculums and held for 30 min. in a sterile laminar flow cabinet (Nuaire Inc., Plymouth, MN) to allow drying of excess inoculum from the brick surface. Swabs were then used to sample the entire surface of each brick. The swabs were then placed in 10 mL of 0.1% sterile peptone water (Acumedia Manufacturers Inc., Lansing, MI) tubes and vortexed for 30 sec. Serial dilutions were made from these initial tubes. After swabbing the surface, bricks were broken in half and the inner surfaces of both halves were swabbed. The swab was then placed in 10 mL autoclaved peptone water tubes and vortexed for 30 sec. Serial dilutions were made from these initial tubes and 0.1 mL of the sample was spread plated onto XLD agar. Plates were incubated for 24 h at 37°C and the results were recorded as log_{10} CFU/cm^2 with the exception of inoculum samples, which were recorded as log_{10} CFU/mL.

Statistical analysis: Completely randomized design was used to assign concrete blocks to the four treatment groups. Three replications of this experiment (3 bricks per treatment) were performed and the averages of the survival populations (log_{10} CFU/cm^2) of various strains of *Salmonella* were analyzed using analysis of variance (ANOVA) with SAS PROC GLM procedures (2002-03 SAS Institute, Gary, NC). Statistical significance was reported at a p-value of less than or equal to 0.05 ($p<0.05$).

RESULTS AND DISCUSSION

Scanning Electron Microscopy (SEM) demonstrated the development of biofilms by all five *Salmonella* strains tested in this study but was not useful in concluding statistical differences between the treatments (data not shown). Biofilm contents and architecture are highly heterogeneous and variable and they depend not only on the bacterial strains that form the biofilm but also on the material of the surface and on the growth and environmental conditions (Scher *et al*., 2005; Joseph *et al*., 2001). In this study several antimicrobial characteristics of BioSealed for Concrete™ were evaluated such as bactericidal effects, prevention of bacterial attachment and prevention of biofilm formation and removal. Group A was the positive control and served as a base for comparison to all other treatments. In group B treatment was applied to evaluate the residual effects of the product and determine if the residual effects of the product were able to prevent biofilms formation, whereas in groups C and D, treatments simulated situations of most present day food processing plants i.e. never had this type of product applied before. Treatment D allowed us to evaluate if previous treatment would have any residual effect from first time applications of this product.

External brick surfaces: Analysis of Variance (ANOVA) of survival populations of *Salmonella* (log_{10} CFU/cm^2) did not show any significant difference ($p>0.05$) between groups A and B suggesting that there is no evidence of residual effect of the product that could prevent the attachment of bacteria and potential biofilm formation for all the strains of *Salmonella* tested in this study except for *S.* Kentucky. When comparing the survival populations of *Salmonella* Typhimurium on the external surface no significant differences ($p>0.05$) between groups A and B; or groups C and D were observed (Table 2). Treatment in group C resulted in a significant reduction of the *S.* Typhimurium population ($p<0.05$; ca. 3.78 log_{10} CFU/cm^2) as compared to those in group A,

Table 2: Survival populations@ (Log_{10} CFU/cm^2) of *Salmonella* strains on the external surfaces of brick blocks

	Strains of *Salmonella*				
Treatments	Typhimurium	Heidelberg	*enteritidis*	Senftenberg	Kentucky
A[1]	4.45(0.65)^X	5.49(0.79)^X	4.69(0.89)^X	3.86(0.85)^X	5.22(0.57)^X
B	4.29(0.65)^X	4.09(0.79)^X	5.02(0.89)^X	4.29(0.85)^X	3.43(0.57)^{X,Y}
C	0.67(0.65)^Y	1.27(0.79)^Y	1.73(0.89)^Y	0.68(0.85)^Y	1.66(0.57)^{Y,Z}
D	1.39(0.65)^Y	0.64(0.79)^Y	1.25(0.89)^Y	0.80(0.85)^Y	1.03(0.57)^Z
p-value	0.0220	0.0077	0.0347	0.0286	0.0196

@Least square means (standard error), [1]A = No BioSealed for Concrete™ application; B = BioSealed for Concrete™ applied before bacterial inoculation; C = BioSealed for Concrete™ applied after bacterial inoculation; D = BioSealed for Concrete™ applied before and after bacterial inoculation. Superscripts (x and y) indicate significant difference ($p<0.05$) within a column

whereas treatment in group D resulted in significant reduction ($p<0.05$; ca. 2.9 log_{10} CFU/cm^2) of the *S.* Typhimurium populations when compared to those in group B. *S.* Heidelberg showed similar results on the external surface of the bricks as *S.* Typhimurium (Table 2). Results showed a significant reduction ($p<0.05$; ca. 4.22 log_{10} CFU/cm^2) in the *S.* Heidelberg populations following treatment in group C as compared to those in group A while treatment in group D resulted in significantly reducing ($p<0.05$; ca. 3.45 log_{10} CFU/cm^2) the populations of *S.* Heidelberg as compared to those in group B. Similar to *S.* Typhimurium and *S.* Heidelberg, results indicated that Bioseal for Concrete™ has potent antimicrobial effect on *S.* Senftenberg and *S. enteritidis*. A 2.96 log_{10} CFU/cm^2 reduction was observed when comparing treatments A and C and a 3.77 log_{10} CFU/cm^2 reduction was observed when comparing treatments B and D for *S. enteritidis* trial. Reduction in the survival populations of *S.* Senftenberg were observed to be greater than *S.* enteriditis; 3.18 log_{10} CFU/cm^2 reduction when comparing groups A and C and a 3.49 log_{10} CFU/cm^2 reduction when comparing groups B and D.

Although, the antimicrobial effects of Bioseal for Concrete™ on *S.* Heidelberg and *S.* Typhimurium were similar to those on *S. enteritidis* and *S.* Senftenberg, treatment B resulted in slightly greater average survival populations of the bacteria than treatment A for the later two strains of *Salmonella*. Although the difference is not significantly different ($p>0.05$), higher recovery of the pathogen from the surface of concrete blocks as a result of prior application of Bioseal for Concrete™ might suggest loose attachment and/or the lack of bacterial attachment hence making it more susceptible to standard sanitation procedures and leading to more effective sanitation in the processing plants. Survival population (log_{10} CFU/cm^2) of *S.* Kentucky was different from the other strains of *Salmonella*. Bioseal for Concrete™ was an effective ($p<0.05$) antimicrobial against *S.* Kentucky and a 3.56 log_{10} CFU/cm^2 reduction was observed when comparing treatments A and C and a 2.4 log_{10} CFU/cm^2 reduction was observed when comparing treatments B and D. Throughout the study treatments A and B showed similar results and no significant difference ($p>0.05$) was observed between these two groups on *S.* Kentucky. The difference observed between *S.* Kentucky and all the other strains tested was that the survival populations (log_{10} CFU/cm^2) in groups B and C were not significantly different ($p>0.05$) indicating that treating concrete with Bioseal for Concrete™ prior to or post bacterial challenge does not change bacterial colonization. These results suggested that there was no residual effects of Bioseal for Concrete™ on *S.* Kentucky as there was no significant difference ($p<0.05$) between treatments A and B. Significant differences ($p<0.05$) in the survival populations of *S.* Kentucky between treatment B and D indicate a cumulative bactericidal effect on the concrete blocks. These results indicate that Bioseal for Concrete™ does not necessarily need to be applied on newly built facilities thus being effective under existing conditions in processing plants.

Internal brick surfaces: Analysis of variance (ANOVA) of the survival populations (log_{10} CFU/cm^2) of *Salmonella* spp. from the internal surfaces of concrete blocks varied greatly among strains (Table 3). The detection level for this study was less than 5 CFU/cm^2 (ca. 0.7 log_{10} CFU/cm^2). Following treatments C and D the survival populations (log_{10} CFU/cm^2) of *Salmonella* Typhimurium, *S.* Heidelberg and *S. enteritidis* were below detection limit (< 0.7 log_{10} CFU/cm^2), whereas no recoverable populations of *S.* Senftenberg were observed as a result of treatment D. Due to the lack of recovery of any survival populations of *S. enteritidis* and Senftenberg the data for these two strains is not shown in this paper. The lack of recoverable populations of these strains of *Salmonella* could be possible due to the low initial levels of inoculum on the interior surface of the concrete blocks. The survival populations (log_{10} CFU/cm^2) of *S.* Heidelberg and *S.* Typhimurium were significantly lower ($p<0.05$) when comparing treatment A to treatments C and D, but the actual levels of reductions could not be enumerated due to the low initial counts of bacteria on the interior surfaces. This indicates that although Bioseal for Concrete™ does show antimicrobial characteristics the true extent of this could not be well evaluated because of the lack of penetration of *Salmonella* into the concrete blocks. No significant

Table 3: Survival populations@ (Log_{10} CFU/cm)[2] of *Salmonella* strains on the internal surfaces of brick blocks

	Strains of *Salmonella*		
Treatments	Typhimurium	Heidelberg	Kentucky
A[1]	1.20(0.31)^{x}	0.96(0.27)^{x}	1.56(0.25)^{x}
B	0.79(0.31)^{xy}	0.70(0.27)^{xy}	0.70(0.25)^{y}
C	ND(0.31)[2y]	ND(0.27)^{y}	ND(0.25)^{y}
D	ND(0.31)^{y}	ND(0.27)^{y}	ND(0.25)^{y}
p-value	0.0923	0.1363	0.0685

@Least square means (standard error)

[1]A = No BioSealed for Concrete™ application; B = BioSealed for Concrete™ applied before bacterial inoculation; C = BioSealed for Concrete™ applied after bacterial inoculation; D = BioSealed for Concrete™ applied before and after bacterial inoculation.

[2]ND = Non detectable; detection limit is less than log_{10} 0.69 CFU/cm^2. Superscripts (x and y) indicate significant difference ($p<0.05$) within a column

differences ($p>0.05$) were observed in the survival populations of all the strains of *Salmonella* when comparing treatment B to groups C and D. The lack of any antimicrobial effects on the internal surface of the concrete blocks could be attributed either to the inability of Bioseal for Concrete™ to penetrate into the concrete pores or due to the lower populations of viable *Salmonella* on the internal surfaces of cement blocks to evaluate the magnitude of reduction. *S.* Kentucky was the only strain which presented significant difference ($p<0.05$) between treatment A and all other treatments. The significantly lower ($p<0.05$) populations of *S.* Kentucky as a result of the application of Bioseal for Concrete™ (treatment C and D) suggest that this strain is probably more susceptible than the other strains tested even in the presence of lower concentrations of the product. The lack of antimicrobial activity on the interior of the concrete blocks could also have been due to the slow migration rate of Bioseal for Concrete™ from the exterior to the inside of the blocks.

In this study the effectiveness of Bioseal for Concrete™ to reduce populations of different strains of *Salmonella* from the external surfaces of concrete blocks ranged from 3.06-4.22 log_{10} CFU/cm^2. This is comparable to other studies where quaternary ammonium compounds were shown to be effective against *Salmonella* attachment on stainless steel (type 304), rubber (type 7S15) and plastic (polytetrafluorethylene) (Sinde and Carballo, 2000). Results from the present study showing effectiveness in reducing *Salmonella* populations on the external and internal surfaces of concrete blocks are in concurrence with results reported by Joseph *et al.* (2001) and Ramesh *et al.* (2002). Joseph *et al.* (2001) in their research reported complete inactivation of *Salmonella* biofilm cells (6 log reduction) on cement after iodophor (50 ppm-25 min) exposure. Ramesh *et al.* (2002) evaluated different groups of sanitizers in reducing viable counts of *Salmonella* cells from biofilms attached on galvanized steel and found averages of 7.63-log reduction for chlorinated compounds (500 ppm -2 min) in the absence of organic matter, however, reported only a 2 log reduction when organic matter was present. In the same study, iodine compounds evaluated resulted in an average of 7.3-log reduction in the absence of organic matter and a 2.14-log reduction in the presence of organic matter. Leyer and Johnson (1997) reported a 5-log reduction of an original 7-log population when using iodine as a sanitizer in planktonic cells of *S.* Typhimurium. The variation in the reduction levels of different strains of *Salmonella* to Bioseal for Concrete™ is an indication of differences in the susceptibility of the different strains as suggested by Joseph *et al.* (2001). In their study Joseph *et al.* (2001) found great variation among the *Salmonella* cultures susceptibility to hypochorites. At identical concentrations (100 ppm) the researchers reported a 5 log reduction for *Salmonella weltevreden* after cement was exposed to hypochlorite for 15 min whereas no cells were detected for *Salmonella* FCM 40. Korber *et al.* (1997) when evaluating the susceptibility of *Salmonella enteritidis* to disinfectants in glass biofilms found that 10% trisodium phosphate was able to inactivate all the cells from *Salmonella* biofilms after 15 sec while Wang *et al.* (1997) reported a 2-log reduction of *Salmonella* Typhimurium using same concentrations of trisodium phosphate on chicken skin.

Peroxygens are another group of disinfectants largely used in the food industry and have been reported to reduce *Salmonella* Typhimurium biofilms by 2.96 log on cement by fogging the room (Dunowska *et al.*, 2005). Results from our study indicating up to 4.22 log_{10} CFU/cm^2 reduction suggest a higher effectiveness of BioSealed for Concrete™ on *Salmonella* when comparing it to results from the study conducted by Dunowska *et al.* (2005). It is well documented that acid adapted bacteria are more resistant to antimicrobials than non-adapted cells (Leyer and Johnson, 1997; 1993). Variation in the results from multiple studies that have evaluated various disinfectants and multiple strains of *Salmonella* indicate that the effectiveness depends on several factors including the type of surface, contact time of the disinfectants with the surface, concentration of the disinfectant, temperature and the type of strains of the pathogen. Results from the current study indicate that populations of multiple strains of *Salmonella* were reduced after application of BioSealed for Concrete™ suggesting that this product can be used in poultry processing plants where the issue of contaminated concrete previously exists. Although application of BioSealed for Concrete™ prior to contamination of *Salmonella* did not effectively reduce the population of the bacteria, multiple factors such as contact time and concentration of the disinfectant need to be further studies. From this point of view further

studies need to be conducted to establish application parameters to clarify the antimicrobial properties of BioSealed for Concrete™ against biofilms.

Conclusion: BioSealed for Concrete™ had immediate bactericidal effects and results from this study indicate that BioSealed for Concrete™ can be used as an alternative in food processing plants which have persistent and recurrent *Salmonella* spp. issues on non-food contact surfaces. Although antimicrobial capabilities of BioSealed for Concrete™ are shown in this study, its use should not be substituted for good manufacturing practices and/or efficient cleaning and sanitizing procedures. In sight of the current industry efforts to control biofilms in the poultry processing environment and results from this study demonstrating bactericidal effects of BioSealed for Concrete™, further research needs to be conducted to determine the mode of action, concentration and time of contact of this concrete sealant to be effective against bacterial biofilms.

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