Electrostatic application of antimicrobial sprays to sanitize food handling and processing surfaces for enhanced food safety

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Abstract. Human illnesses and deaths caused by foodborne pathogens (e.g., Salmonella enterica, Listeria monocytogenes, Escherichia coli O157:H7, etc.) are of increasing concern globally in maintaining safe food supplies. At various stages of the food production, processing and supply chain antimicrobial agents are required to sanitize contact surfaces. Additionally, during outbreaks of contagious pathogenic microorganisms (e.g., H1N1 influenza), public health requires timely decontamination of extensive surfaces within public schools, mass transit systems, etc. Prior publications verify effectiveness of air-assisted, induction-charged (AAIC) electrostatic spraying of various chemical and biological agents to protect on-farm production of food crops...typically doubling droplet deposition efficiency with concomitant increases in biological control efficacy. Within a biosafety facility this present work evaluated the AAIC electrostatic-spraying process for application of antimicrobial liquids onto various pathogen-inoculated food processing and handling surfaces as a food safety intervention strategy. Fluoroanalysis of AAIC electrostatic sprays (-7.2 mC/kg charge-to-mass ratio) showed significantly greater (p<0.05) mass of tracer active ingredient (A.I.) deposited onto target surfaces at various orientations as compared both to a similar uncharged spray nozzle (0 mC/kg) and to a conventional hydraulic-atomizing nozzle. Per unit mass of A.I. dispensed toward targets, for example, A.I. mass deposited by AAIC electrostatic sprays onto difficult to coat backsides was 6.1-times greater than for similar uncharged sprays and 29.0-times greater than for conventional hydraulic-nozzle sprays. Even at the 56% reduction in peracetic acid sanitizer A.I. dispensed by AAIC electrostatic spray applications, they achieved equal or greater CFU population reductions of Salmonella on most target orientations and materials as compared to uncharged sprays and conventional full-rate hydraulic-nozzle sprays.

1. Introduction

Foodborne pathogenic microorganisms in the USA annually cause ~7.6 million acute illnesses, ~5 thousand deaths, and an associated US$152 billion cost in healthcare, workplace losses, etc.; nearly 25% of this public-health problem is attributable to unprocessed fresh fruits and vegetables [1]. Decontamination of food-contact surfaces and equipment in food handling and processing facilities presents challenges due in part to lack of effective cleaning and sanitizing options. Inefficient
application of antimicrobial chemicals by conventional high-volume sprays often does not evenly cover and protect all surfaces...especially the hard to reach and hidden target areas. Additionally, high liquid volumes are logistically problematic and tend to detrimentally soak cardboard packing cartons carrying the food product. As hypothesized based upon prior work [2], a promising alternative is offered by the air-assisted, induction-charged (AAIC) electrostatic-spraying process in which a reduced liquid-carrier volume of finely atomized, highly charged droplets is aerodynamically propelled (AA..) into the target vicinity where electric forces of attraction efficiently deposit the charged droplets uniformly onto all target surfaces, both directly exposed and obscured. Especially appropriate here is droplet charging by electrostatic induction (..IC) within the nozzle because it accommodates the wide range of target materials and resistances to earth encountered in food handling/processing operations, in contrast to industrial coating by the ionized-field “corona” droplet charging process which demands electric current flow to earth through well grounded targets.

Both increased mass-transfer efficiency and improved biological-control efficacy are reported for AAIC electrostatic spraying of conductive liquids [3, 4]. The highly charged droplets (e.g., 30 µm dia. @ 5-10 mC/kg) are strongly attracted to opposite polarity charge naturally induced into the target and provide uniform coverage of its surface including wrap-around onto backsides [5, 6]. AAIC electrostatic-spraying has been documented successful for applying both biological and chemical pesticides to crops [7, 8]; antifungal preservatives to fresh produce (viz., bananas) [9]; and decontaminant and tanning agents to human skin [10]. The electrostatic deposition benefit for these chemical and biological control agents was increased typically 2-5 fold while using much lower volumes of carrier liquid. Consequently, effective pest and pathogen control can be maintained while dispensing reduced amounts of active ingredient from the nozzle.

The objective of this present food-safety work was to experimentally evaluate the mass-transfer efficiency and antimicrobial efficacy of the AAIC electrostatic-spraying process for applying sanitizer liquids to various surface orientations and compositions commonly encountered in food handling and processing operations...specifically investigating whether the lower volume of spray-carrier liquid (with higher concentration of sanitizer active ingredient) deposited on the target surface would provide sufficient contact time for microbial cell death, as well as determining adequacy of target charge-transfer for various electrically insulating vs. conductive food-contact materials.

2. Experimental methods and materials
Within an air-exhausted metal biosafety chamber (1.5 m high x 1 m wide x 1 m deep) an AAIC electrostatic-spraying nozzle [3], commercially provided by Electrostatic Spraying Systems, Inc. www.maxcharge.com and herein designated ESS, was operated with charging ON (-7.2 mC/kg @ 1.2 kV, 207 kPa atomizing air) and charging OFF (0 mC/kg @ 0 kV, 207 kPa) and compared to a conventional hydraulic-atomizing nozzle (TeeJet® #TP40015E @ 295 kPa liquid pressure) to determine mass transfer of active ingredient (A.I.) deposited onto target coupons (23 mm x 90 mm x 1 mm thick). These three spray-nozzle treatments were similarly evaluated for antimicrobial efficacy of sanitizer (peracetic acid C2H4O3) they achieved on stainless steel, PVC conveyor belting, and waxed cardboard expressed as reduction in the population of colony forming units (CFU) of Salmonella enterica previously inoculated onto these target materials – all assessed to a detection limit of 80 CFU/coupon face using standard microbiological practices. Fluorometric analysis detailed previously [11] was used to quantify mass transfer of an aqueous suspension of fluorescent tracer powder (tracer analogous to mass of A.I.) deposited by each spray-nozzle treatment onto target coupons having surfaces positioned in two orientations with respect to the incoming spray vector: surface perpendicular (frontside, backside) vs. parallel. A bactericidal equivalence point was experimentally determined for peracetic acid sanitizer at which this lower than conventionally recommended full-rate mass of A.I. when dispensed from a charged electrostatic nozzle achieved the same population reduction of Salmonella as did the full-rate when dispensed from the conventional hydraulic nozzle onto stainless steel frontside surfaces. The equivalence point mass of A.I. was then used to determine population log10 reduction on the three target-material types in the two orientations.
Because the hydraulic nozzle dispensed 6-times more carrier-liquid volume than did the electrostatic nozzle (Hydr.@ 600 ml/min vs. ESS @ 100 ml/min), an unbiased comparison having equal mass of A.I. dispensed toward the targets by all nozzle treatments required the A.I. concentration of liquid sprayed from the ESS nozzle to be 6-times that from the hydraulic nozzle. Furthermore, nozzle-to-target spacing (Hydr. @ 42 cm vs. ESS @ 70 cm) provided equal width spray swaths (30.5 cm) traversing the target coupons ensuring an identical incoming mass-flux density of A.I. (mg cm⁻² s⁻¹) for all spray-nozzle treatments as a robotic-arm apparatus [7, 12] accurately replicated a back and forth dual traverse at 76 cm/s (±1%) along the target arc holding four coupons.

3. Results and discussion

3.1. Mass-transfer efficiency
Figure 1 plots the fluorometrically determined treatment mean values for amount of active ingredient tracer deposited (ng/cm²) by spray applications using the conventional hydraulic-atomizing nozzle compared with the ESS ON (Ch.) and ESS OFF (Unch.) electrostatic nozzle. Statistical analysis (ANOVA) by Tukey’s multiple comparison method indicates spray-nozzle treatment mean values within any plotted grouping-of-three differ significantly (p<0.05).

As seen where air-assist velocity was strongest onto perpendicular target front sides, charged spray increased deposition of A.I. to a value 1.2-times greater than uncharged spray and 9.1-times greater than hydraulic-nozzle spray; for back sides, the charged-spray increases were respectively 6.1-times and 29.0-times. For target surface parallel to the spray vector’s air-assist velocity, the electrostatic-deposition benefit was 2.9-times vs. uncharged and 6.1-times vs. hydraulic sprays.

3.2. Antimicrobial efficacy
For the 0.44 dosage equivalency point experimentally determined for peracetic acid sanitizer (Oxonia Active® by EcoLab), Figure 2 plots results of subsequent surface-sanitizing efficacy achieved on the indicated target materials and orientations when dispensing manufacturer’s recommended full-rate active ingredient by the hydraulic-nozzle spray vs. 0.44-rate by the ESS ON (Ch.) and ESS OFF (Unch.) electrostatic nozzle. On logarithmic scales, the treatment mean values (n = 3 reps., standard error bars) document the population reductions of Salmonella expressed as log₁₀ CFU/coupon face.

Figure 1. Mean values of areal density of active ingredient (i.e., fluorescent tracer) deposited by the three spray-nozzle treatments onto stainless steel target coupons for the indicated target orientations (n = 3 reps.; all nozzles dispensed equal mass of A.I. toward targets).
As seen in Figure 2 even at its 0.44-rate of sanitizer A.I. dispensed, the air-assisted charged spray provided equal or greater population reduction of *Salmonella enterica* on all target materials and orientations...except for the vertical frontside waxed cardboard which exhibited hydrophobicity impeding the filming of the reduced-volume spray applications.

3. Conclusion
This study showed significant (p<0.05) increases in both spray-deposition efficiency and surface-sanitizing efficacy were provided by reduced carrier volumes of finely atomized, air-assisted, induction-charged (-7.2 mC/kg) antimicrobial spray as compared to similar uncharged spray and to conventional high-volume, hydraulic-atomized spray. Electrostatic deposition benefit up to 29-times A.I. was measured on backside surfaces. For most target materials and orientations tested, 44%-rate A.I. peracetic acid sanitizer dispensed in 1/6th the spray volume achieved equal or greater population reductions of *Salmonella enterica* as did full-rate A.I. applied by conventional hydraulic-nozzle spray.

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