Innovative hurdle strategies for *Listeria* control on food-contact surfaces: A peroxyacetic acid-steam approach

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Introduction

Listeria monocytogenes contaminated food-contact surfaces have been recognized as the main reason for listeriosis outbreaks implicated in caramel apples [1], emphasizing the need to effectively clean and sanitize surfaces directly in contact with fresh produce. Chlorine is a traditional sanitizer for surface disinfection, whereas its reaction with organic matter could produce harmful by-products [2], suggesting alternative approaches for surface decontamination. Peroxyacetic acid (PAA) is a safe choice for surface disinfection, and it has been proven to be the most effective sanitizer among the others in disinfecting *L. monocytogenes* biofilms [3]. However, the efficacies of PAA were negatively impacted by surface defects and/or organic soils [4]. In addition, saturated steam has exerted fast-killing efficacy against 7-day-old *Listeria* biofilms, only a 6-s exposure to steam resulted in a 3.1 log reduction on stainless steel [5]. Meanwhile, the efficacy of steam decreased at prolonged steam treatment times. Hurdle treatment combining the sanitizer with thermal interventions has been used to eradicate *Listeria* biofilms. Yet the efficacy of PAA in combination with saturated steam against *Listeria* biofilms on surfaces used in fresh apple packing lines has not been tested. Also, there is limited information on the impact of surface defects and organic matter on the efficacy of PAA-steam hurdle treatments.

Materials and Methods

- Three-strain *L. innocua* cocktail was prepared at a concentration of ~ 10^8 CFU/ml.
- Stainless steel (SS), polyester (PET), and rubber coupons (2.25 cm^2) were prepared with and without surface defects and organic soiling (1:10 diluted apple juice).
- All coupons were inoculated with *L. innocua* suspension and incubated at room temperature for 7 days to form biofilms.
- Biofilms were treated with 40-80 ppm PAA for 1 min, with and without a 6-s steam exposure (Fig. 1).
- After each treatment, the surviving *L. innocua* cells were detached from each coupon and enumerated.

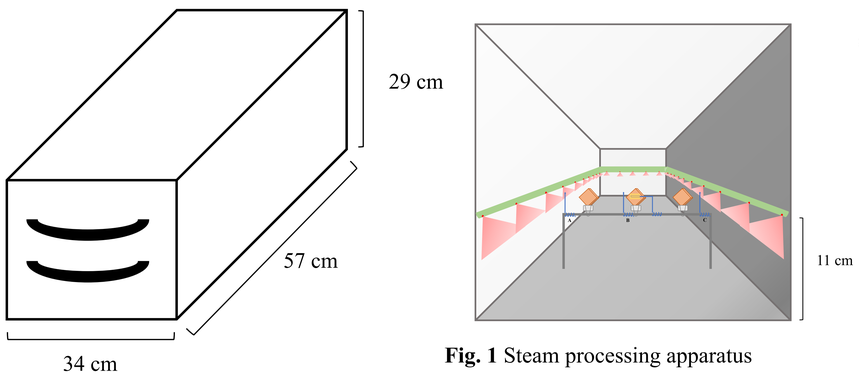

Fig. 1 Steam processing apparatus

Acknowledgement

This study was supported by the Washington Tree Fruit Research Commission. We thank Pace International Inc. for their generous donations of Bioside™ HS 15%.

Results

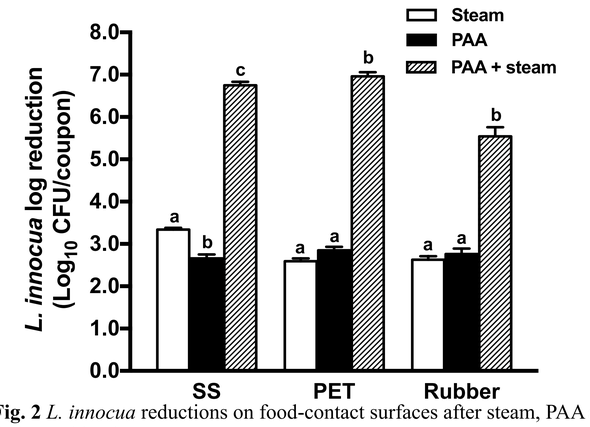

Fig. 2 *L. innocua* reductions on food-contact surfaces after steam, PAA and their combination. Mean ± SEM, n=3.

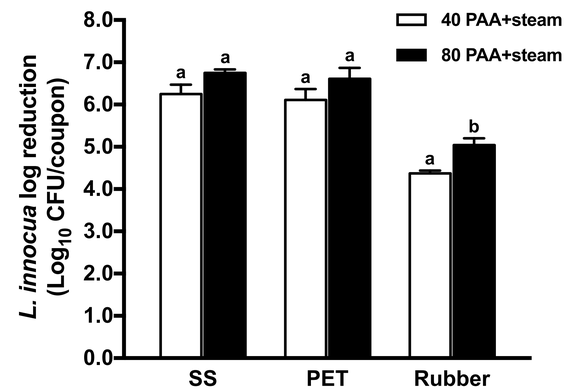

Fig. 3 Efficacies of saturated steam with different PAA concentrations against *L. innocua* biofilms on food-contact surface. Mean ± SEM, n=3.

Table 1 The impact of treatment order on the effectiveness of hurdle treatments against *L. innocua* biofilms on new food-contact surfaces (Mean ± SEM, n=3)

Surface	PAA conc. (ppm)	Reduction (Log_{10} CFU/coupon)	
		PAA + steam	steam + PAA
SS	40	6.25 ± 0.22^{aA}	6.31 ± 0.25^{aA}
	80	$>6.53^{aA}$	$>6.53^{aA}$
PET	40	6.11 ± 0.26^{aA}	6.27 ± 0.30^{aA}
	80	6.61 ± 0.26^{aA}	6.26 ± 0.28^{aA}
Rubber	40	4.37 ± 0.07^{aA}	4.61 ± 0.22^{aA}
	80	5.04 ± 0.16^{bA}	4.84 ± 0.15^{aA}

Table 2 The impact of organic matter on the efficacy of saturated steam with or without 40 ppm PAA against *L. innocua* biofilms on new food-contact surfaces (Mean ± SEM, n=3)

Surface	Conditions	Initial levels	Reduction (Log_{10} CFU/coupon)	
			Steam	PAA + steam
SS	Clean	6.83 ± 0.05	3.34 ± 0.04^{aA}	6.25 ± 0.22^{aB}
	Soiled	7.17 ± 0.08	3.56 ± 0.05^{aA}	5.56 ± 0.18^{bB}
PET	Clean	7.13 ± 0.09	2.59 ± 0.07^{aA}	6.11 ± 0.26^{aB}
	Soiled	7.32 ± 0.06	2.72 ± 0.07^{aA}	5.76 ± 0.21^{bB}
Rubber	Clean	7.03 ± 0.09	2.65 ± 0.09^{aA}	4.37 ± 0.07^{aB}
	Soiled	7.32 ± 0.08	2.64 ± 0.07^{aA}	4.17 ± 0.04^{aB}

Table 3 Impact of surface condition on the efficacy of saturated steam with or without 40 ppm PAA against *L. innocua* biofilms on food-contact surfaces (Mean ± SEM, n=3)

Surface	Conditions	Initial levels	Reduction (Log_{10} CFU/coupon)	
			Steam	PAA + steam
SS	New, clean	6.83 ± 0.05^{a}	3.34 ± 0.04^{aA}	$>6.53^{aB}$
	Worn, clean	7.22 ± 0.04^{a}	2.56 ± 0.04^{bA}	5.91 ± 0.27^{bB}
	Worn, soiled	7.15 ± 0.06^{a}	2.70 ± 0.12^{bA}	5.08 ± 0.12^{cB}
PET	New, clean	7.13 ± 0.09^{a}	2.59 ± 0.07^{aA}	6.61 ± 0.26^{aB}
	Worn, clean	8.28 ± 0.07^{b}	3.50 ± 0.07^{bA}	5.69 ± 0.22^{bB}
	Worn, soiled	8.18 ± 0.07^{b}	3.33 ± 0.05^{bA}	5.18 ± 0.08^{cB}
Rubber	New, clean	7.03 ± 0.09^{a}	2.65 ± 0.09^{aA}	4.37 ± 0.07^{aB}
	Worn, clean	8.00 ± 0.05^{b}	3.23 ± 0.10^{bA}	4.84 ± 0.04^{bB}
	Worn, soiled	7.97 ± 0.07^{b}	2.79 ± 0.13^{aA}	4.49 ± 0.04^{cB}

Conclusions

- Hurdle treatment combining PAA and saturated steam was more effective ($P < 0.05$) than their single treatments (Fig. 2).
- Decreasing PAA levels from 80 ppm to 40 ppm did not reduce ($P > 0.05$) the efficacy of hurdle treatment on SS and PET surfaces, while efficacy was lowered ($P < 0.05$) on rubber (Fig. 3).
- The treatment order had little impact on the efficacy of PAA-steam hurdle treatment, regardless of concentration and surfaces (Table 1).
- The efficacy of PAA-steam hurdle treatment was decreased ($P < 0.05$) on soiled surfaces, which still resulted in > 4 log reduction (Table 2).
- The efficacy of PAA-steam hurdle treatment was reduced ($P < 0.05$) on all worn surfaces, especially when organic matter was present.
- PAA (40 ppm, 1 min) followed by steam (100°C, 6 s) caused ≥ 4.5 log reduction of *Listeria* under the worst-case situation.

References

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