

Modeling the Fate of *Listeria monocytogenes* and *Salmonella enterica* on Fresh Whole and Chopped Wood Ear and Enoki Mushrooms



Megan L. Fay¹, Joelle K. Salazar¹, Josephina George², Nirali Chavda², Pravalika Lingareddygar¹, Gayatri R. Patil², David T. Ingram³

¹Center for Food Safety and Applied Nutrition, U. S. Food and Drug Administration, Bedford Park, IL, USA; ²Illinois Institute of Technology, Institute for Food Safety and Health, Bedford Park, IL, USA; ³Center for Food Safety and Applied Nutrition, U. S. Food and Drug Administration, College Park, MD, USA.

Abstract

Background: Recent listeriosis and salmonellosis outbreaks associated with imported specialty mushrooms in the U.S. have prompted research to understand how foodborne pathogens survive in these unique matrices.

Purpose: To evaluate the growth kinetics of *Listeria monocytogenes* and *Salmonella enterica* on whole and chopped wood ear and enoki mushrooms.

Methods: Fresh mushrooms were either chopped or kept whole and inoculated with a four-strain cocktail of either *L. monocytogenes* or *S. enterica* at 3 log CFU/g. Inoculated mushrooms were stored at 5, 10 or 25°C for up to 7 d. Populations were enumerated at 0, 1, 3, 5 and 7 d. Three independent trials with triplicate samples for each timepoint were conducted. Population data for each pathogen were fitted to the Baranyi model via DMFit to estimate growth rates. Population differences were statistically compared using ANOVA, whereas growth rates were compared using ANCOVA; $p < 0.05$ was considered significant.

Results: No proliferation was observed for either pathogen on whole or chopped wood ear or enoki mushrooms at 5°C. At 10°C, moderate growth was observed for both pathogens on enoki mushrooms (0.12-0.28 log CFU/g/d) and for *L. monocytogenes* on wood ear mushrooms (0.03-0.09 log CFU/g/d). Both pathogens proliferated at 25°C on both mushroom types and preparations. The growth rates ranged from 0.43 to 3.27 log CFU/g/d, resulting in 1 log CFU/g increases in only 0.31 d (7.44 h) to 2.32 d, with more rapid growth rates observed on enoki mushrooms.

Conclusion: The results of this study provide information on the growth of foodborne pathogens in specialty mushrooms and can inform discussions surrounding the safe time and temperature conditions for these food commodities.

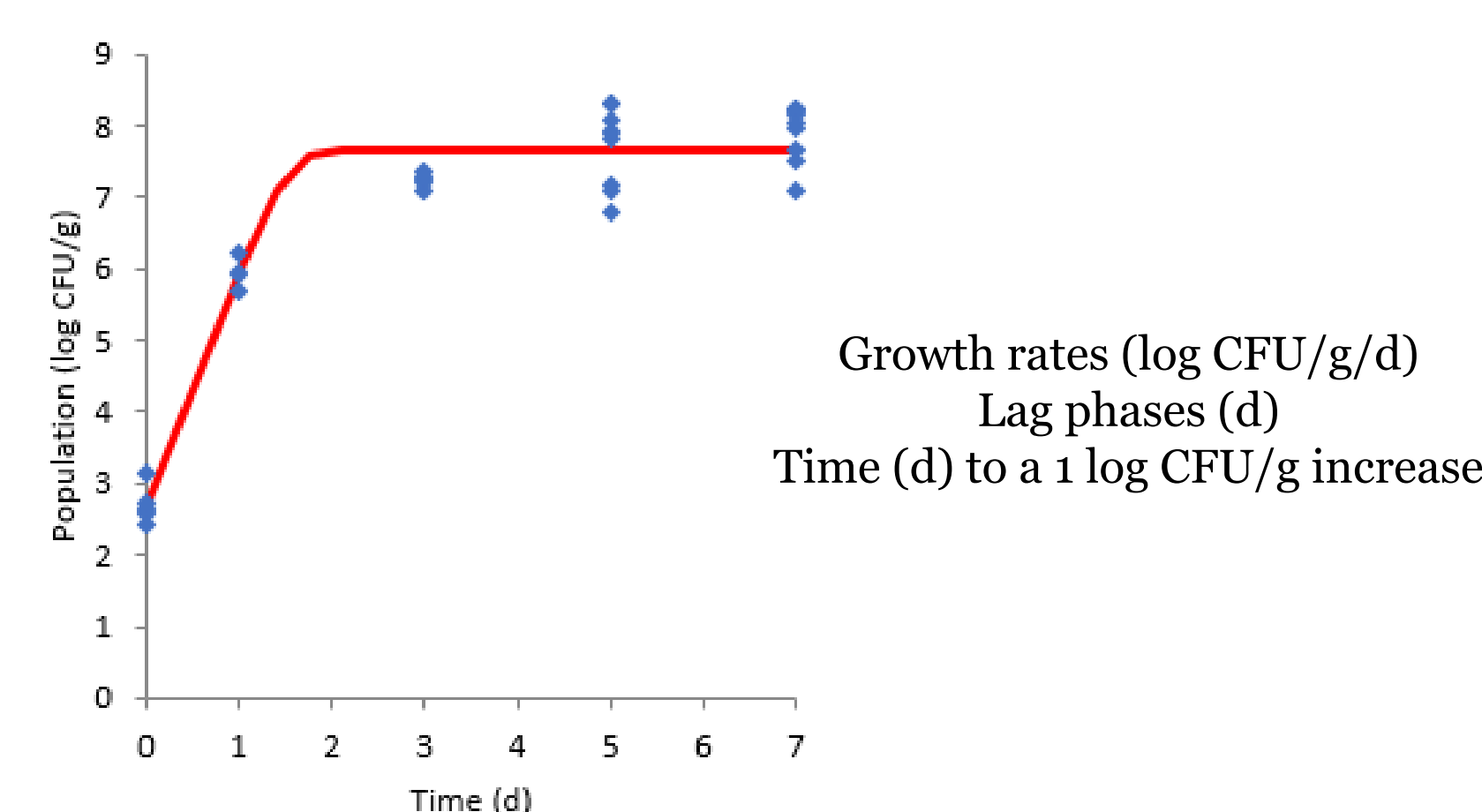
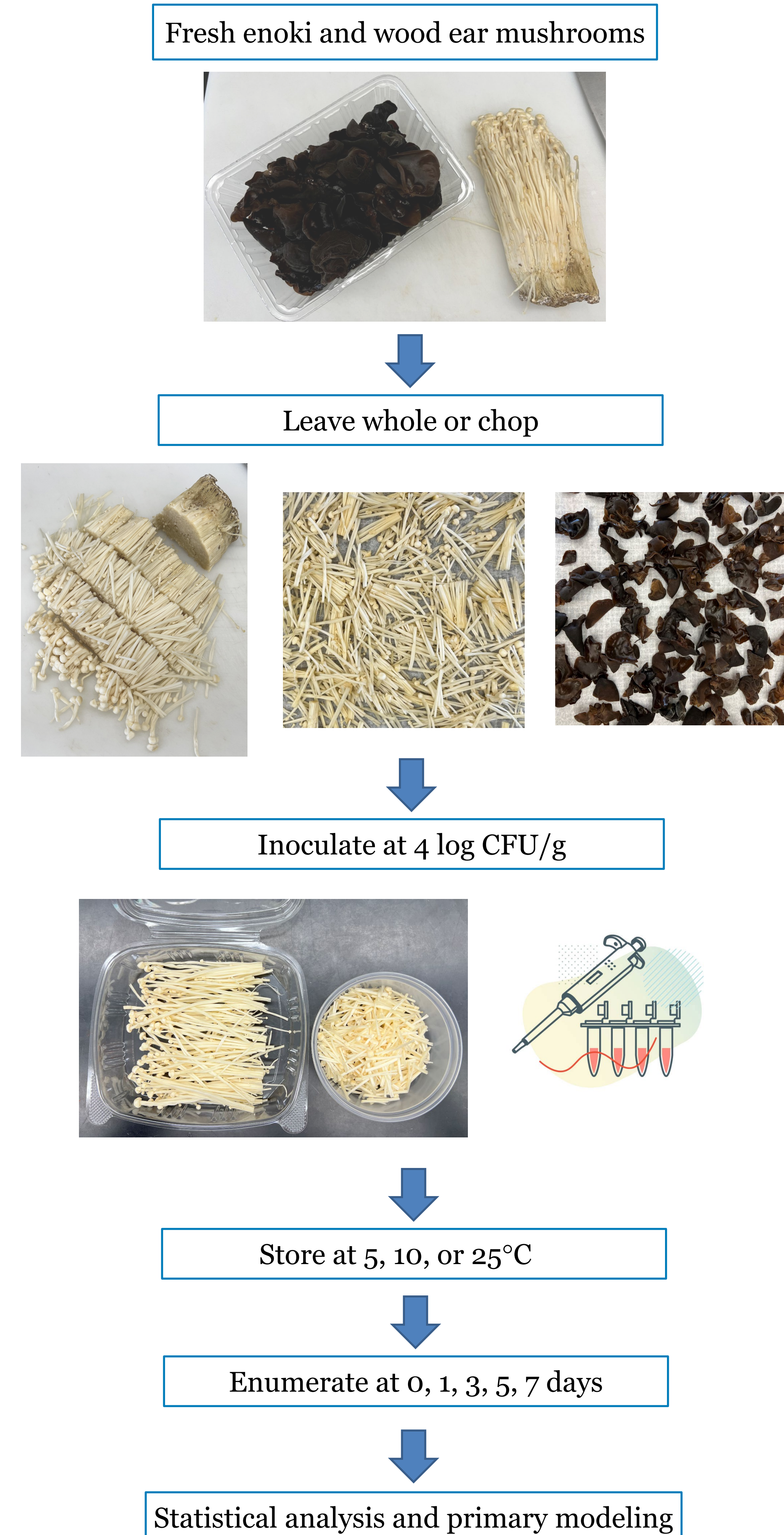
Plain language summary: The survival and growth of two foodborne pathogens, *Listeria monocytogenes* and *Salmonella enterica*, was evaluated on two outbreak-linked varieties of specialty mushrooms, enoki and wood ear. After inoculation with either pathogen, the mushrooms were stored for 7 days at three different temperatures. The populations of both pathogens were enumerated throughout the storage period.

Introduction

In 2020, the FDA responded to two multistate outbreaks associated with the consumption of specialty mushrooms, both representing a novel pathogen-commodity pairing. In the first outbreak, enoki (i.e., enokitake, golden needle) mushrooms were the implicated vector, resulting in 36 listeriosis cases, 31 hospitalizations, and four deaths (12 and six cases were also reported in Canada and Australia, respectively). In the second outbreak, wood ear mushrooms (i.e., kikurage, black fungus) were the implicated vector, resulting in 55 salmonellosis cases and six hospitalizations. The objective of this study was to evaluate the population dynamics of both *Listeria monocytogenes* and *Salmonella enterica* on fresh whole and chopped wood ear and enoki mushrooms.



Materials and Methods



Results

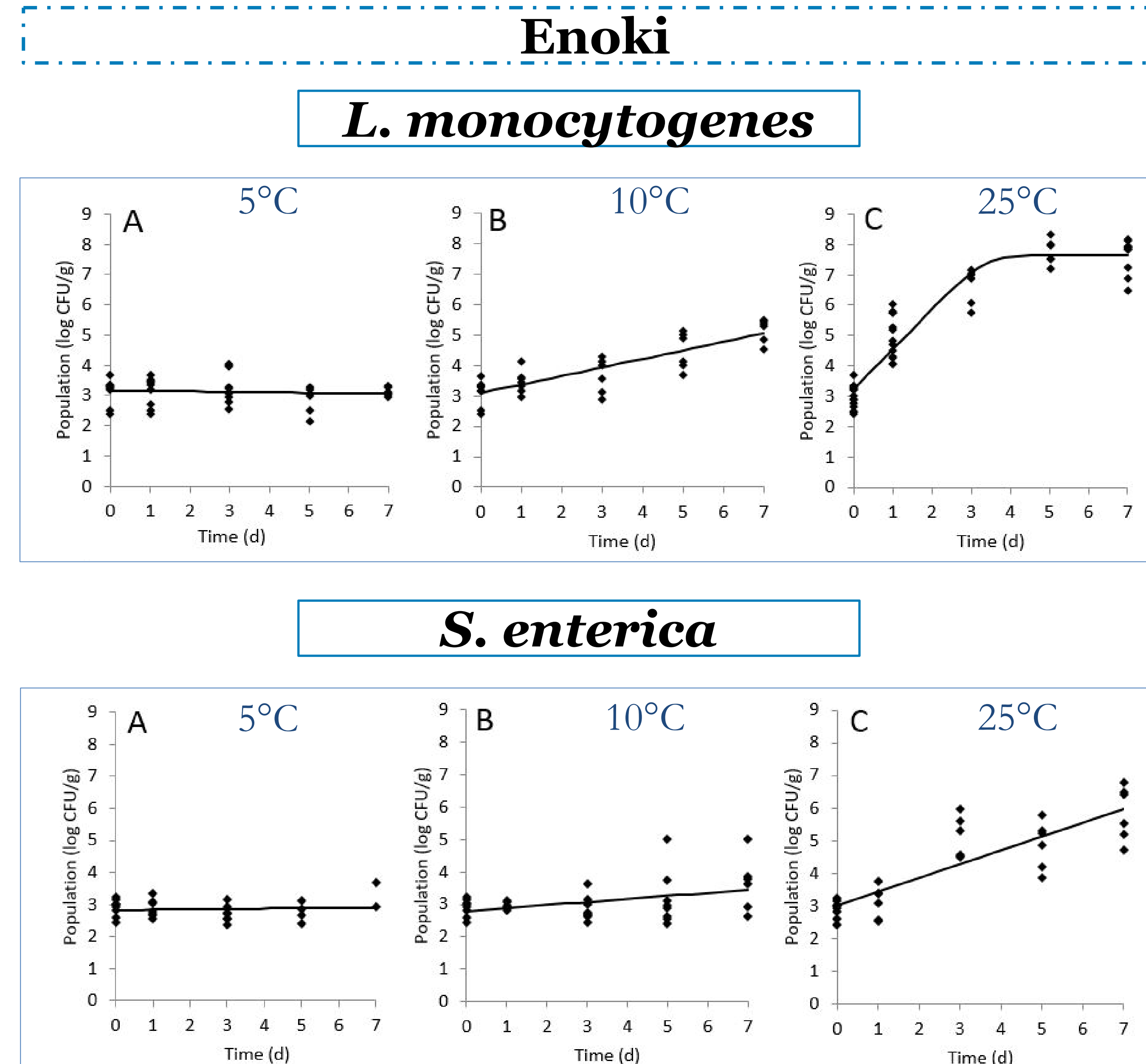


Figure 1: Population dynamics of *Listeria monocytogenes* and *Salmonella enterica* on whole enoki mushrooms during storage at A) 5°C, B) 10°C, or C) 25°C for 7 days. Diamonds indicate individual data points (log CFU/g) and black line indicates the fit of the population data to the Baranyi model.

Pathogen	Preparation	Storage temperature (°C)	Growth rate (log CFU/g per d ± SE)	Time (d) to 1 log CFU/g increase
<i>L. monocytogenes</i>	Whole	5	-0.02 ± 0.03 ^A	NA
		10	0.28 ± 0.03 ^B	3.57
		25	1.32 ± 0.12 ^C	0.76
	Chopped	5	-0.03 ± 0.02 ^A	NA
		10	0.23 ± 0.03 ^B	4.35
		25	1.70 ± 0.33 ^D	0.59
<i>S. enterica</i>	Whole	5	0.01 ± 0.02 ^A	100.00
		10	0.12 ± 0.03 ^B	8.33
		25	3.27 ± 0.29 ^F	0.31
	Chopped	5	-0.01 ± 0.02 ^A	NA
		10	0.13 ± 0.05 ^B	7.69
		25	2.40 ± 0.02 ^G	0.42

Table 1: Growth rates and calculated times for a 1 log CFU/g increase in *Listeria monocytogenes* and *Salmonella enterica* on whole and chopped enoki mushrooms during storage at 5, 10, or 25°C for 7 days. SE, standard error; NA, not applicable. Different uppercase letters indicate significance difference between growth rates.

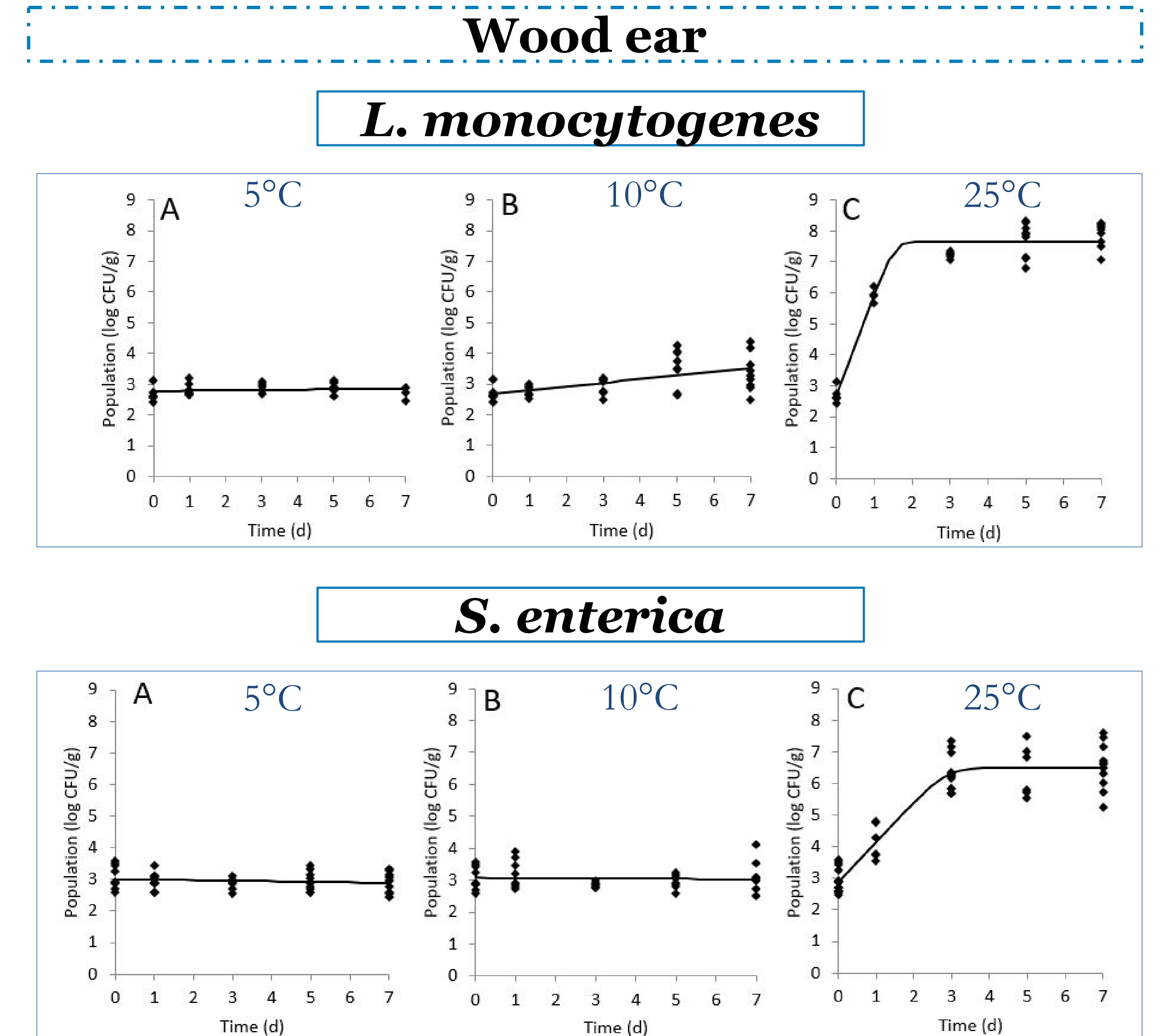


Figure 2: Population dynamics of *Listeria monocytogenes* and *Salmonella enterica* on whole wood ear mushrooms during storage at A) 5°C, B) 10°C, or C) 25°C for 7 days. Diamonds indicate individual data points (log CFU/g) and black line indicates the fit of the population data to the Baranyi model.

Pathogen	Preparation	Storage temperature (°C)	Growth rate (log CFU/g per d ± SE)	Time (d) to 1 log CFU/g increase
<i>L. monocytogenes</i>	Whole	5	0.01 ± 0.03 ^{AE}	100.00
		10	0.09 ± 0.04 ^A	11.11
		25	0.43 ± 0.48 ^B	2.33
	Chopped	5	-0.02 ± 0.03 ^{AE}	NA
		10	0.03 ± 0.02 ^{AE}	33.33
		25	0.55 ± 0.13 ^B	1.82
<i>S. enterica</i>	Whole	5	-0.02 ± 0.02 ^{AE}	NA
		10	-0.01 ± 0.02 ^{AE}	NA
		25	1.25 ± 0.15 ^C	0.80
	Chopped	5	-0.25 ± 0.13 ^D	NA
		10	-0.04 ± 0.02 ^E	NA
		25	0.48 ± 0.05 ^B	2.08

Table 2: Growth rates and calculated times for a 1 log CFU/g increase in *Listeria monocytogenes* and *Salmonella enterica* on whole and chopped wood ear mushrooms during storage at 5, 10, or 25°C for 7 days. SE, standard error; NA, not applicable. Different uppercase letters indicate significance difference between growth rates.

Conclusions

- *L. monocytogenes* and *S. enterica* survived on enoki and wood ear mushrooms.
- No proliferation was observed on either mushroom type during storage at 5°C.
- The highest growth rates of both pathogens were observed when stored at 25°C.
- Growth rates on enoki were higher than on wood ear mushrooms at 25°C.
- Growth rates of *L. monocytogenes* were higher at 25°C on chopped mushrooms compared to whole, whereas the reverse was true for *S. enterica*.

Acknowledgements

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