Factors Affecting *Salmonella* Inactivation on Apples During Hot Air Drying

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Abstract

Introduction: Previous research on *Enterococcus faecium,* a surrogate for *Salmonella*, inactivation on apple cubes showed a linear relationship with a_w during drying. However, data on other drying factors including temperature, airflow, and bed-depth affecting *Salmonella* inactivation is lacking.
Purpose: Evaluate the effects of temperature, airflow, and bed-depth on *Salmonella* inactivation during apple drying.
Methods: A six-strain *Salmonella* cocktail was harvested from lawns cultured on tryptic soy agar with 0.6% yeast extract (TSAYE) and inoculated onto Gala apple cubes (6.4 mm) at 9.41±0.21 log CFU/4 cubes. Inoculated apple cubes were dried at low (L), medium (M), and high (H) conditions for temperature (T; 88, 104, 120°C), bed-depth (B; 5.1, 8.9, 12.7 cm), and airflow (A; 25, 37.5, 50.0%) respectively utilizing a Box Behnken Design. *Salmonella*-inoculated apple cubes were collected at various time points (n=6) and enumerated on modified TSAYE.
Results: Linear (R^2 >0.78) relationships between *Salmonella* reduction and apple cube a_w were observed for all conditions. The lowest and highest *Salmonella* reduction when reaching the same apple a_w was estimated for LTMBLA and HTLBMA. On a_w 0.60 apple cubes, estimated *Salmonella* reduction was 2.34 ± 0.13 and 4.97 ± 0.26 log CFU/sample for LTMBLA and HTMBLA, respectively. On a_w 0.30 apple cubes, estimated *Salmonella* reduction was 4.18±0.21 and 8.93 ± 0.36 log CFU/sample for LTMBLA and MTLBHA, respectively. For apple cubes dried to the same a_w, higher *Salmonella* reduction was estimated for LTMBHA than LTMBLA, and for HTMBLA than LTMBLA (p<0.05), respectively.
Significance: Higher temperatures and airflow led to similar or higher *Salmonella* inactivation in apple cubes dried to the same a_w. The effect of temperature was more pronounced when using low airflow, and effect of airflow was more significant when using low temperature. Higher bed-depth delayed the inactivation but did not affect the inactivation achieved at target a_w.

Introduction

Hot air apple drying is a process where temperature increases as apple a_w decreases. Previous studies showed factors such as temperature, bed depth, and airflow affect microbial inactivation, but the interaction of the factors is unknown. A previous study (1) discovered that the *Enterococcus faecium* inactivation on apple cubes showed a linear relationship with the apple a_w during drying. Such a relationship regarding *Salmonella spp*. has not been investigated.

Objective

The objective is to investigate the inactivation of *Salmonella spp*. on apple cubes during hot air drying under various temperatures, drying bed depths, and airflow conditions and to study the correlation between *Salmonella* inactivation and the water activity of dried apple cubes.

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1. Liu X. Effect of Temperature and Airflow on Inactivation of *Enterococcus faecium* NRRL B-2354 in Apple Cubes During Hot Air Drying. IAFP Annual Meeting 2023; 2023 Jul 19; Toronto, Canada.

Materials and Methods

Sample inoculation

Salmonella spp. inoculum was harvested from plate grown cells, ~10-11 log CFU/mL, and colored red with Red 40.

Gala apples were peeled, cored, and cut into 6.4 mm cubes (~262 mm^3).

The red inoculum was mixed with fresh apple cubes in a ratio of 10mL inoculum per 160g apple cubes.

Hot air apple drying

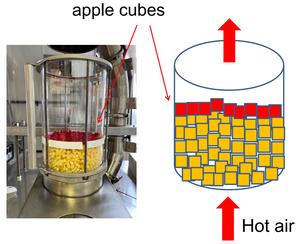

Table 1. Drying conditions.

Level/ Factor	Temperature (T)	Bed depth (B)	Air flow (A)
Low (L)	88°C	5.1 cm	25.0% (~2.10 m/s)
Medium (M)	104°C	8.9 cm	37.5% (~2.95 m/s)
High (H)	120°C	12.7 cm	50.0% (~3.82 m/s)

Un-inoculated and single-layer inoculated apple cubes were loaded into a round cylinder chamber with a mesh bottom, and one-directional hot air was used to dry the apple cubes. Conditions tested were LT-HB-MA, LT-LB-MA, LT-MB-HA, LT-MB-LA, MT-HB-HA, MT-HB-LA, MT-LB-HA, MT-LB-LA, MT-MB-MA, HT-HB-MA, HT-LB-MA, HT-MB-MA, and HT-MB-LA.

Sample collection & water activity measurement

At set time points (n=5), samples (n=3) containing 4 apple cubes were collected from the top. Samples were measured for a_w and then transferred to sterile sample bags. Three independent trials were completed for all 13 conditions.

Salmonella enumeration

Samples were serially diluted in BPW, plated on TSAYE + Ammonium Ion Citrate + Sodium Thiosulfate, incubated (37°C, 24 h), and then enumerated.

Results

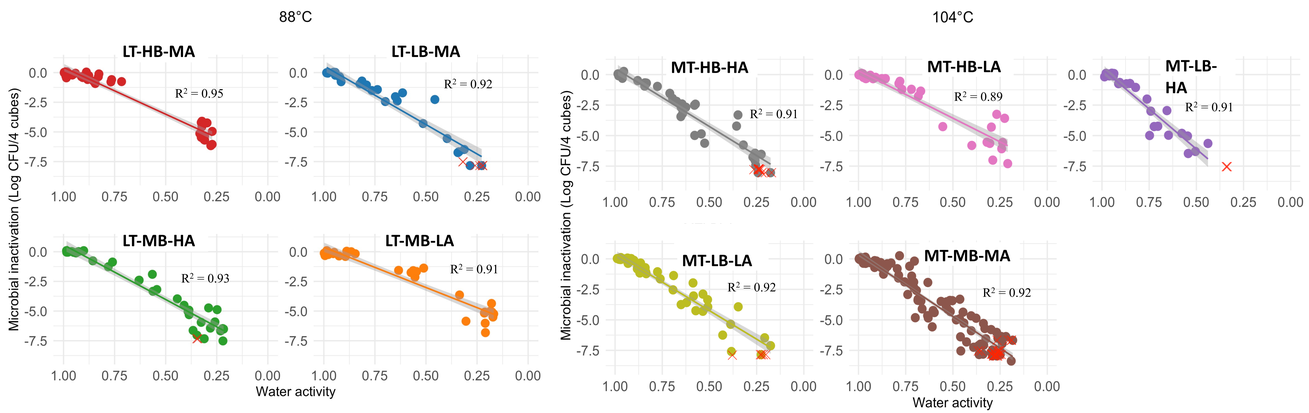

Figure 1. *Salmonella* inactivation in relation to apple cube water activity when drying under 88 and 104°C. ✕ represents data points with microbial population under the limit of detection (7.71 ± 0.29 log CFU/4 cubes). The colored lines represent linear regression trend lines. The grey bands represent 95% confidence intervals.

Results

120°C

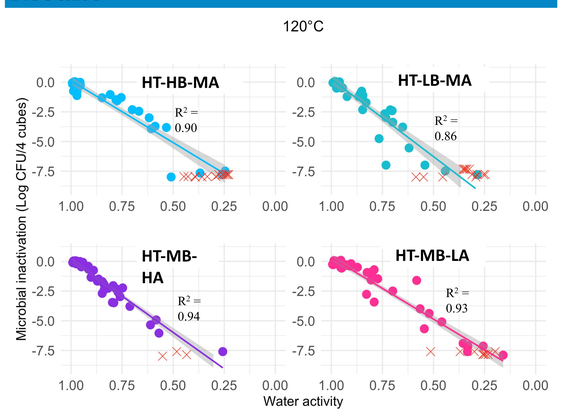

Figure 2. *Salmonella* inactivation in relation to apple cube water activity when drying under 120°C. ✕ represents data points with microbial population under the limit of detection (7.71 ± 0.29 log CFU/4 cubes). The colored lines represent linear regression trend lines. The grey bands represent 95% confidence intervals.

Discussion

- Linear relationships (R^2 >0.85) were observed in the *Salmonella* reduction and the water activity of apple cubes during hot air apple drying under all drying conditions.
- At a_w 0.60 the predicted *Salmonella* reduction ranged from 2.34 ± 0.13 (LT-MB-LA) to 4.97 ± 0.26 (HT-LB-MA) log CFU/4 cubes.
- At a_w 0.30 the predicted *Salmonella* reduction ranged from 4.37 ± 0.18 (LT-MB-LA) to 8.88 ± 0.51 (HT-LB-MA) log CFU/4 cubes.
- Response surface model fitting suggested that higher temperature, higher airflow, and lower bed depths all led to increased *Salmonella* reduction (p<0.05). The bed depth and airflow had a significant (p<0.05) interactive effect on *Salmonella* reduction.

Significance

- The water activity of the apple cubes during drying could be used as a predictor for *Salmonella* inactivation under tested drying conditions.
- **5-log *Salmonella* reduction was not achieved** in any tested conditions on **intermediate moisture (0.6 a_w) apple cubes**.
- Drying apples with higher temperatures, higher airflow, and lower bed depth could lead to higher *Salmonella* inactivation under the conditions tested.
- A beneficial effect of decreasing bed depth on microbial inactivation is more pronounced at certain airflow rates. Optimizing these two factors together could improve *Salmonella* inactivation efficiency.

Next step

- Identify the optimized drying condition for achieving the highest *Salmonella* reduction.
- Utilize whole genome sequencing to identify the relative abundance of the six *Salmonella* strains under different drying conditions.

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