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Research Paper

# Fate and Growth Kinetics of *Salmonella* and *Listeria monocytogenes* on Mangoes During Storage

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ABSTRACT

Imported mangoes have been linked to outbreaks of salmonellosis in the USA. The purpose of this research was to evaluate the persistence and growth kinetics of *Salmonella* and *Listeria monocytogenes* on the intact surface of whole 'Ataulfo', 'Kent', and 'Tommy Atkins' mangoes stored at three different temperatures. *L. monocytogenes* was also evaluated on fresh-cut 'Tommy Atkins' mangoes stored at 4, 12, 20 ± 2°C. Whole mangoes were spot inoculated with rifampicin-resistant pathogen cocktails (6 log CFU/mango) onto the midsection of whole fruit ($n$ = 6). Fruit was stored at 12, 20, or 30 ± 2°C and sampled for up to 28 days. The specific growth rates derived from DMFit models as a function of time were used to develop secondary models. On 'Kent' mangoes, *Salmonella* had a population increase from 0.3 to 1.1 log CFU/mango with a linear growth rate of ~0.004, 0.01, and 0.06 log CFU/mango/h at 12, 20, and 30°C, respectively. At 20 and 30°C, *Salmonella* growth rates were significantly higher than 12°C ($P$ < 0.05). No clear *Salmonella* growth trend was observed; populations decreased up to 1.6 log CFU/mango on 'Tommy Atkins' and 'Ataulfo' at 12°C. Populations of *L. monocytogenes* on whole and fresh-cut mangoes declined regardless of temperature and storage period. Food safety during storage should be the top priority for fresh-cut tropical fruit processors.

Five documented multistate *Salmonella* outbreaks in North America have been associated with imported mangoes, due to contamination with *Salmonella* serotypes Oranienburg, Newport, Saintpaul, and Braenderup and Worthington (Beatty et al., 2004; Deeks et al., 1998; CDC, 2012a; PHAC, 1998; Sivapalasingam et al., 2003). *Salmonella* is the only organism currently linked to any North American mango outbreak; however, concerns over *Listeria monocytogenes* exist due to recent outbreaks and recalls in other commodities including cantaloupes and prepackaged caramel apples (CDC, 2012b, 2015).

Contamination of mangoes with pathogenic bacteria may occur during production and postharvest processing (Beatty et al., 2004; Sivapalasingam et al., 2003). During commercial packing operations, mangoes can be exposed to washing procedures with commercial disinfectants to reduce possible pathogen populations (Mathew et al., 2018). Inadequate disinfectant concentration in wash water can be a contributing factor leading to cross-contamination when contaminated water is used or fruit are dumped into wash tank without sanitizers (Beatty et al., 2004; Mathew et al., 2018). *Salmonella* can infltrate into intact 'Tommy Atkins' mango flesh during postharvest heating and cooling treatments designed to control insect pests; all fresh mangoes imported to the USA and linked to salmonellosis outbreaks have undergone this treatment (Penteado et al., 2004; Bordini et al., 2007). Contaminated equipment, like knives, can transfer pathogens into mango flesh from the fruit surface (Penteado et al., 2014). The transfer of pathogens from the peel to flesh of melons and citrus has been documented during hand peeling and postharvest processing as a function of cutting method (Gagliardi et al., 2003; Jung et al., 2017; Shearer et al., 2016; Ukuku & Sapers, 2001); similar food safety risks can be assumed for mangoes.

On fresh and frozen-cut mangoes and in fresh mango pulp and juice, *Escherichia coli* O157:H7, *Salmonella*, and *L. monocytogenes* can grow at higher temperatures and survive at refrigerator and frozen temperatures (Hsin-Yi & Chou, 2001; Kroft et al., 2022; Leite et al., 2002; Luciano et al., 2022; Strawn & Danyluk, 2010). *E. coli* O157:H7 and *Salmonella* growth on fresh-cut mangoes is reported at ambient temperatures, as is extended survival at refrigerator temperatures (Strawn & Danyluk, 2010). Populations of *L. monocytogenes* increase on fresh-cut mangoes when held at 4°C (Kroft et al., 2022); *L. monocy-*

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*togenes* populations inoculated at low concentrations survived on mangoes regardless of the storage temperature for up to a week (Luciano et al., 2022).

Little research exists detailing the fate of *Salmonella* or other pathogens on the surface of whole mangoes. Understanding the survival of pathogens on contaminated whole mangoes is important to understand the potential risk for contamination of the edible flesh of mangoes. The objective of this research was to understand the fate and growth kinetics of *Salmonella* and *L. monocytogenes* on the surface of whole mangoes stored at 12, 20, and 30°C. To support previously published work (Strawn & Danyluk, 2010), the fate of *L. monocytogenes* on fresh-cut mangoes was also evaluated.

## Materials and methods

### *Produce*

Three varieties of whole mangoes ('Ataulfo', 'Kent', and 'Tommy Atkins') were purchased from a local supermarket (Winter Haven, FL), stored at 4°C and brought to ambient temperature prior to starting experiments. For fresh-cut experiments, 'Tommy Atkins' mangoes were peeled and cut into 10 ± 1 g pieces using a sterile knife and cutting board as described by Strawn and Danyluk (2010).

### *Strain selection*

A five-strain *Salmonella* cocktail from produce-related outbreaks was used. *Salmonella* serovars and their sources included: Michigan (cantaloupe-related outbreak; Beuchat et al., 2001), Montevideo (tomato-related outbreak; CDC, 1993), Muenchen (orange juice-related outbreak; CDC, 1999), Newport (tomato-related outbreak; CDC, 2007), and Saintpaul (orange juice-related outbreak; Jain et al., 2009). The five strains of *L. monocytogenes* strain included: LIS0234 (raw diced onions associated with a recall of prepackaged diced yellow onions; USFDA, 2012), LIS0133 (a fresh-cut celery-related outbreak; Gaul et al., 2013), LIS0110 (whole cantaloupes-related outbreak; CDC, 2012b), LIS0087 (cantaloupe-related outbreak; CDC, 2012b), and LCD81-861 (raw cabbage-related outbreak; Schlech et al., 1983). All strains were adapted by following a stepwise procedure detailed in Parnell et al. (2005) and confirmed to grow in the presence of 80 μg/mL rifampicin (Thermo Fisher Scientific). All media used in this study were sourced from BD Difco (BD, Franklin Lakes, NJ) unless otherwise noted, and if supplemented with 80 μg/mL rifampicin as indicated by "R" following the media description.

### *Inoculum preparation*

Frozen stock cultures of each *Salmonella* serovar were streaked onto tryptic soy agar (TSAR), and *L. monocytogenes* strains onto brain heart infusion agar (BHIAR) and incubated at 35 ± 2°C for 24 h. A single colony from each strain was then transferred to 10 mL tryptic soy broth (TSBR, *Salmonella* spp.) or brain heart infusion broth (BHIR, *L. monocytogenes*) and incubated at 37°C for 24 h. Cultures were subcultured twice by transferring 0.1 mL of culture to fresh TSBR or BHIR and incubated at 37°C for 24 h. Each culture was pelleted by centrifuging at 0.6 × g for 10 min (Allegra X-12, Beckman Coulter). Cells were washed twice by removing the supernatant and suspending the cell pellet in 10 mL of 0.1% peptone. Washed cells were suspended in 5 mL of 0.1% peptone. Each bacterial strain or serovar was added in equal volume to produce its respective (*L. monocytogenes* or *Salmonella*) cocktail. Inoculum concentrations were confirmed on TSAR or BHIAR to confirm cell concentration.

### *Inoculation and Storage*

Whole 'Ataulfo', 'Kent', and 'Tommy Atkins' mangoes were inoculated by spotting 100 μL of the inoculum cocktail at 6 log CFU/mango onto a marked sample area on the smooth midsection of the fruits. Inoculated intact fruit were dried for 1 h at ambient temperature (ca. 23°C) on the bench top. Cut fruit (10 g) were placed in a petri dish and spot inoculated onto the flesh of the fruit with 10 μL resulting in 3 log CFU/g. Samples were held in a running biosafety cabinet for 20 min to allow the inoculum to dry. Following the drying period, whole fruit samples were placed into sterile bags (1.61 L, Thermo Fisher Scientific) and cut fruit into sterile filtered bags (207 mL, Nasco). Each bag was placed into a large plastic container with a temperature and relative humidity sensor (TempTale4, SensiTech). Bags were not sealed to allow air movement and to prevent the creation of an anaerobic environment due to fruit respiration. Whole mangoes were stored at 12, 20, and 30 ± 2°C and cut samples at 4, 12, and 20 ± 2°C. The average relative humidity during storage of whole 'Ataulfo', 'Kent', and 'Tommy Atkins' mangoes was 34.6 ± 2.5%, 33.1 ± 2.8%, and 31.2 ± 2.5% at 12°C; 22.6 ± 0.9 %, 26.6 ± 1.5 %, and 25.9 ± 1.2% at 20°C; and 28.5 ± 3.2%, 25.2 ± 2.1%, and 23.5 ± 2.6% at 30°C, respectively. The relative humidity during storage of fresh-cut 'Tommy Atkins' mangoes was 40.8 ± 2.1%, 33.1 ± 3.6%, and 21.8 ± 1.5% at 4, 12, and 20 ± 2°C, respectively. Three replications of each pathogen inoculation were performed, with duplicate samples in each replication. A separate mango was sampled at each timepoint.

### *Enumeration of pathogens*

Whole fruit were sampled at days 0, 1, 3, 5, 7, 10, 14, 21, and 28 at 12 ± 2°C; days 0, 1, 3, 7, 10, 14, and 21 at 20 ± 2°C; days 0, 1, 3, 5, 7, 10, and 14 at 30 ± 2°C. Fresh-cut fruit was sampled at days 0, 1, 3, 5, 7, 10, 14, 21, and 28 at 4 ± 2°C, and days 0, 1, 3, 5, and 7 at 12 ± 2 and 20 ± 2°C. At each whole fruit sampling, 10 mL of Dey/Engley neutralizing broth (DE; Thermo Scientific) was added and the sample bags were shaken (30 s), rubbed (30 s), and shaken (30 s). For fresh-cut samples, 10 mL of DE was added and the sample was macerated (Smasher, AES Lab) at high speed for 1 min. Serial dilutions in 0.1% peptone preceded surface plating in duplicate onto nonselective supplemented (TSAR, or BHIAR) and selective media supplemented (XLT4R, or modified oxford agar (MOXR). Plates were incubated at 35 ± 2°C, for 24 h (nonselective) or 48 h (selective). To increase the limit of detection, an additional 1 mL of the lowest dilution was plated onto four plates each (0.25 mL/plate) of nonselective media. After incubation, colonies were counted by hand and populations were expressed as log CFU/mango for whole fruit or log CFU/g for fresh-cut fruit. To determine the population of mesophile aerobic background microbiota of fresh-cut mangoes, samples were plated on TSA for 24–48 h incubation at 35 ± 2°C.

### *Model development*

Survivability parameters of *Salmonella* on all whole mango types were calculated using primary and secondary modeling, utilizing experimental data, following methods described by Danyluk et al. (2014) and Li et al. (2013). As counts on selective and nonselective media were generally in very close agreement, duplicate count from each medium were used in model fitting. To develop the primary model as a function of time, the Baranyi and Roberts equation (Baranyi & Roberts, 1994), commonly used to describe microbial mortality under different environmental stress conditions, was fitted using DMFit web edition (Institute of Food Research). The secondary model was developed using square root or Ratkowsky equation to describe pathogen growth/inactivation on all melon types and as a function of temperature:

$$\sqrt{Growthrate} = b * (T - T0)$$

where b is the regression coefficient, and $T_0$ represents the theoretical minimum growth temperature for the microorganism. The use of the ComBase models required assumptions regarding water activity and pH. A water activity of 0.99 was assumed for all predictions. Significant differences ($P < 0.05$) among growth rates were determined using the analysis of variance (ANOVA) using PROC GLM. All the analyses were performed using SAS v9.3 (SAS Inst. Inc., Cary, NC).

## Results

### *Fate of pathogens on whole mangoes*

Survival of *Salmonella* on all evaluated whole mango varieties and storage temperatures is shown in Figure 1. At 12°C, *Salmonella* populations initially decreased (up to 3.1 logs), on all mango varieties. Following the initial decline, populations of *Salmonella* increased gradually and reached those similar to the inoculation level through the 28 days of storage at 12°C on all varieties. When stored at 20°C, an initial *Salmonella* population decrease (of up to 1.1 log) was seen on 'Ataulfo' and 'Kent' mangoes. After 21 days of storage at 20°C, populations of *Salmonella* were between 5.5 and 6.7 log CFU/mango; slightly higher than the initial level of cells (5.3–5.7 log CFU/mango) on all mango varieties. *Salmonella* population levels increased up to 1.1 log and reached up to 7 log CFU/mango during 10 days of storage at 30°C on 'Kent' and 'Tommy Atkins' mangoes. On 'Ataulfo' mangoes, the population also initially increased, but then decreased again to 5 log CFU/mango by day 14 at 30°C.

Unlike the population declines initially noted for *Salmonella* at 12 and 20°C, no population decline was observed for *L. monocytogenes* at any temperature on whole 'Tommy Atkins' mangoes (Fig. 2). *L. monocytogenes* populations increased by up to 2.7 logs during the initial 3 days of storage, reaching up to 6.4 log CFU/mango; these increases are similar to what was observed *Salmonella*. However, following day 3, declines in *L. monocytogenes* populations were observed until the end of storage of 21 days at 20°C (4.7 log CFU/mango) and 14 days at 30°C (3.6 log CFU/mango).

### *Fate of pathogens on fresh-cut mangoes*

On fresh-cut 'Tommy Atkins' mangoes, *L. monocytogenes* populations remained stable over 14 days with a slight decline (up to 1.1

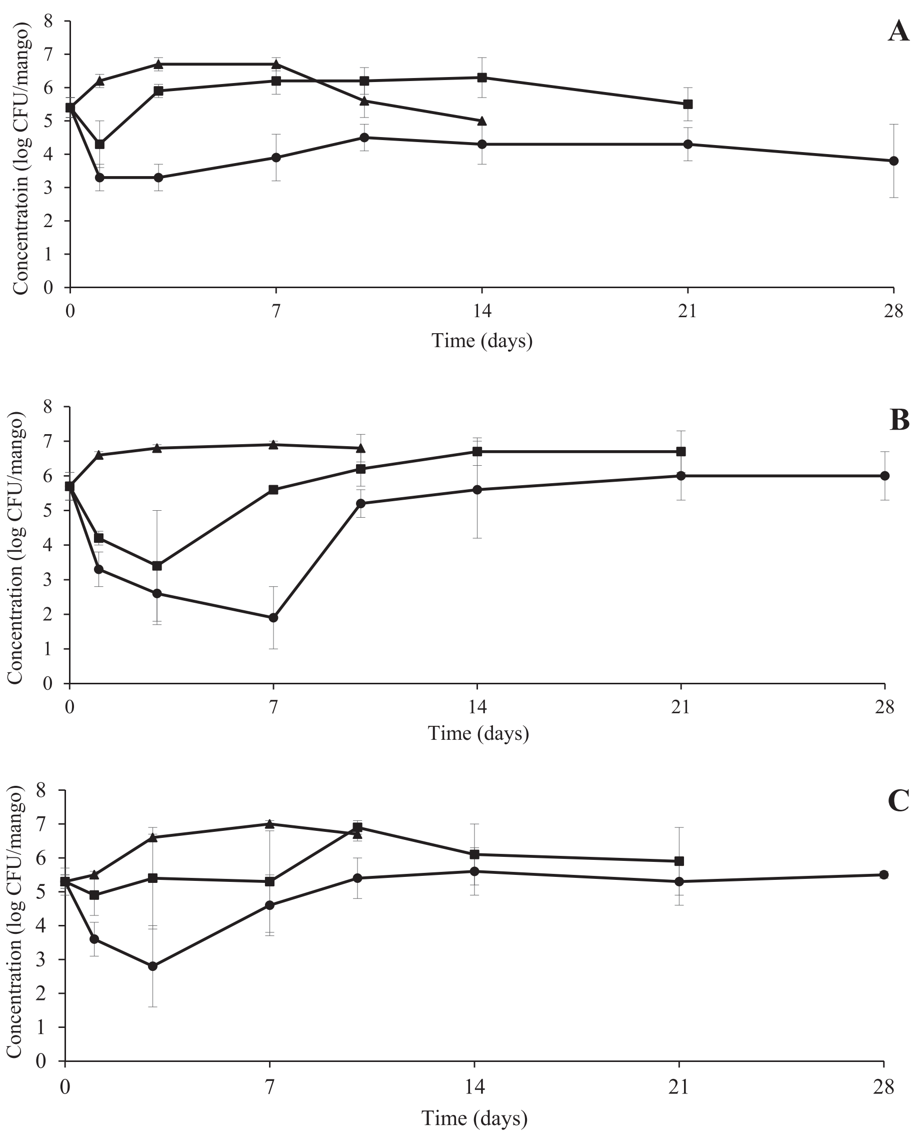



**Figure 1.** Fate of a five-strain cocktail of *Salmonella* spp. on the surface of whole (A) 'Ataulfo', (B) 'Kent' mangoes, and (C) 'Tommy Atkins' stored at 12 ± 2°C (●) for 28 days; 20 ± 2°C (■) for 21 days; and 30 ± 2°C (Δ) for 14 days. Inoculated mangoes held at 30°C were discontinued on Day 14 due to spoilage of the fruit ($n = 6$).

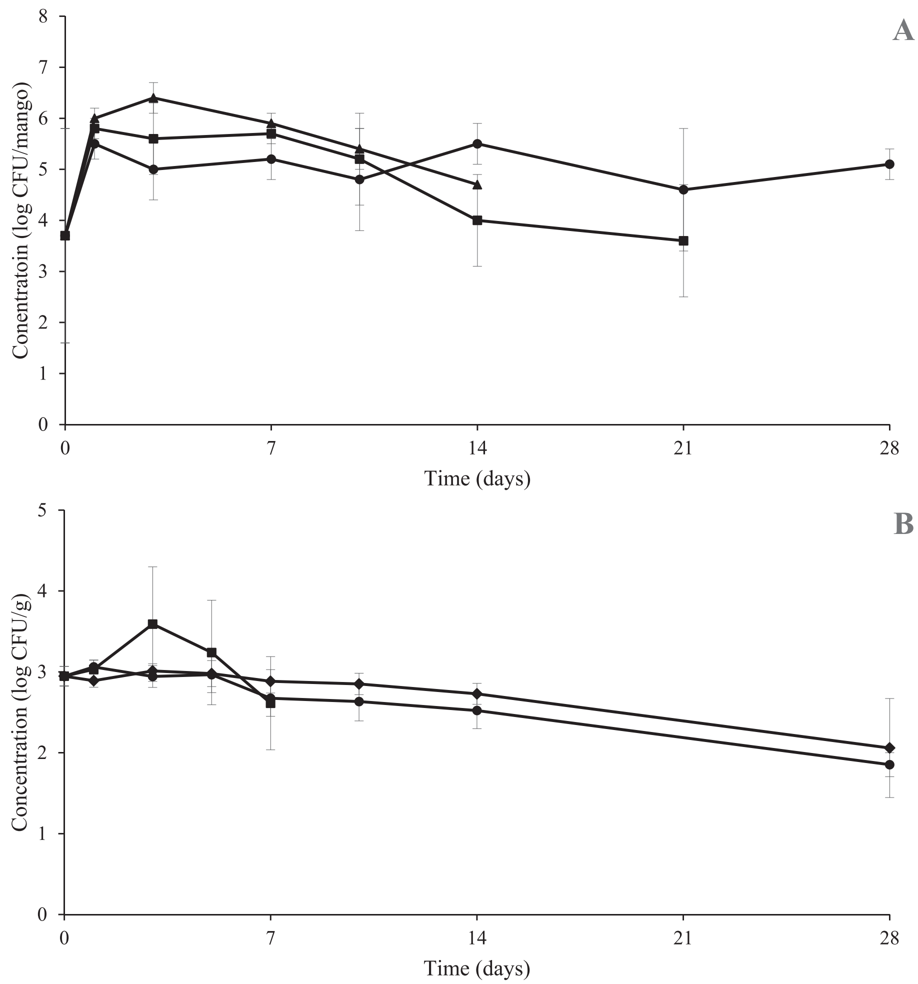



**Figure 2.** Fate of a five-strain cocktail of *Listeria monocytogenes* on the surface of (A) whole and (B) fresh-cut 'Tommy Atkins' mangoes stored at 4 ± 2°C (◆) for 28 days; 12 ± 2°C (●) for 28 days; 20 ± 2°C (■) for 21 days; and 30 ± 2°C (Δ) for 14 days. Inoculated whole mangoes held at 30°C and fresh-cut mangoes stored at 20°C were discontinued at Day 14 and Day 7 respectively due to spoilage of the fruit ($n$ = 6).

log CFU/g) on day 28 at 4 and 12°C (Fig. 2B). When stored at 20°C, *L. monocytogenes* populations increased to 3.6 log CFU/g at day 3 (up to 0.6 log CFU/g increase) and then declined throughout the 7 days of storage (Fig. 2B).

The total mesophilic aerobic bacteria background microbiota population on fresh-cut mango samples increased between 1.5 and 2.4 log CFU/g for the first 3 days at all tested temperatures (Fig. 3). The highest mesophilic aerobic bacteria population reached up to 6.3 log CFU/g at 4°C and 7.8 log CFU/g at 12°C after 10 days of storage. Then, the population of mesophilic aerobic bacteria declined to 4.1 log CFU/g at 4°C and 7.1 log CFU/g at 12°C on fresh-cut mangoes until the last sampling day of 28.

*Growth kinetics of pathogens on whole mangoes*

The growth rates of *Salmonella* on the surface of the whole mangoes 'Ataulfo', 'Kent', and 'Tommy Atkins' under various postharvest storage conditions calculated by DMFit are presented in Table 1. Linear and Baranyi models included in the DMFit were successful in describing the growth rates for all the pathogens (Supplemental Fig. S1A-B, S2A-C, S3A-C). DMFit usually indicated no lag times in pathogen growth except in one instance where a lag time of 84 h was observed.

Figures 4A and B have the square root of growth rate versus storage temperature plotted and fitted to the Ratkowsky equation. The y-axis shows the square root of the growth rate in log CFU/mango/h, and the $x$-axis the temperature in °C. Square root growth model for *Salmonella* on 'Kent' and 'Tommy Atkins' is given by:

$$\sqrt{Growth\,rate}\,(logCFU/h)\,of\,Salmonella\,on\,'\mathrm{Kent}' = 0.0103\,\mathrm{T} - 0.0763.$$

and $\sqrt{Growth\,rate}\,(logCFU/h)\,of\,Salmonella\,on\,'\mathrm{Tommy\ Atkins}'$
$$= 0.005\mathrm{T} + 0.0034$$

Square root growth model indicated populations of *Salmonella* on 'Kent' and 'Tommy Atkins' increased linearly with temperature.

On 'Ataulfo' mangoes, growth rates increased from 12°C (no/low growth) to 20°C (0.012 log CFU/mango/h) and decreased at 30°C (0.006 log CFU/mango/h). On 'Kent' mangoes, *Salmonella* growth rate increased linearly as the storage temperature increased; ~0.004, 0.01, and 0.06 log CFU/mango/h at 12, 20, and 30°C, respectively. At 20 and 30°C, growth rates were significantly higher than 12°C ($P < 0.05$). On 'Tommy Atkins' mangoes, at 12 and 20°C, no difference in the growth rates of *Salmonella* (0.006 log CFU/mango/h) was observed. However, the growth rate increased to 0.027 log CFU/mango/h when the temperature increased to 30°C.

No growth of *L. monocytogenes* was observed over time at all temperatures on fresh-cut and whole 'Tommy Atkins'.

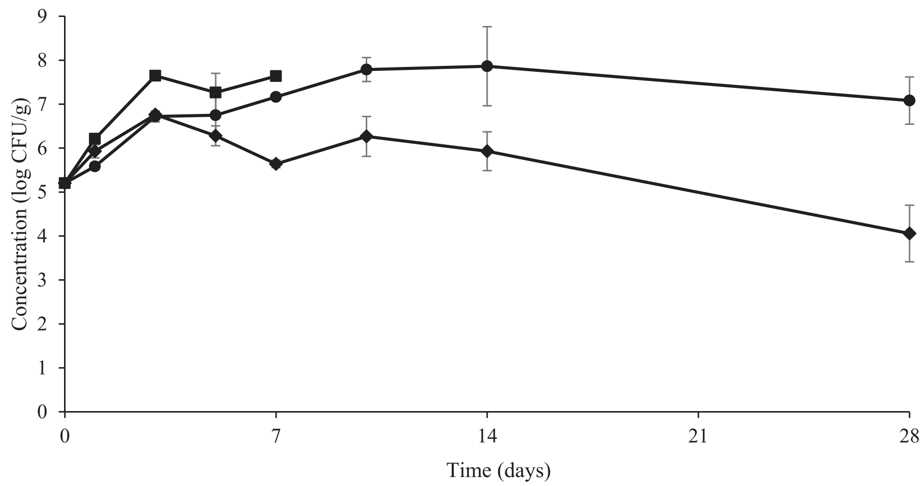



**Figure 3.** Fate of aerobic mesophile bacteria on fresh-cut 'Tommy Atkins' mangoes stored at 4 ± 2°C (◆) for 28 days, 12 ± 2°C (●) for 28 days, 20 ± 2°C (■) for 21 days ($n$ = 3).

**Table 1**
Calculated rates of growth or pathogens on inoculated whole mangoes during storage

| Pathogen cocktail | Mango | Storage temp. (°C) | Storage time (days) | DMFit Models* | Rate of change (log CFU/mango/h) | $R^2$ | RMSE[a] |
|---|---|---|---|---|---|---|---|
| *Salmonella* | 'Ataulfo' | 12 | 28 | – | No/Low Growth | – | – |
| | | 20 | 14 | Baryani | 0.012 | 0.60 | 0.07 |
| | | 30 | 10 | Baryani | 0.0006 | 0.60 | 0.81 |
| | 'Kent' | 12 | 28 | Linear | 0.004 | 0.30 | 1.44 |
| | | 20 | 21 | Baranyi-L | 0.01 | 0.52 | 0.95 |
| | | 30 | 10 | Baranyi | 0.06 | 0.70 | 0.40 |
| | 'Tommy Atkins' | 12 | 28 | Baranyi | 0.006 | 0.32 | 1.17 |
| | | 20 | 21 | Baranyi | 0.006 | 0.20 | 1.02 |
| | | 30 | 10 | Baranyi | 0.027 | 0.40 | 0.89 |
| *L. monocytogenes* | 'Tommy Atkins' | 12 | 28 | – | No Growth | – | – |
| | | 20 | 21 | – | No Growth | – | – |
| | | 30 | 14 | – | No Growth | – | – |

[a] RMSE: Root Mean Square Error.

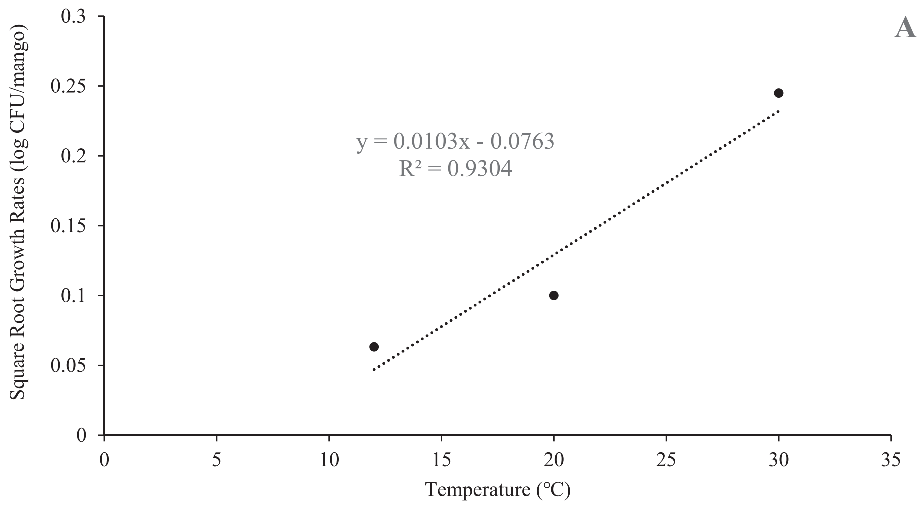
## Discussion

Fresh-cut fruits, including mangoes, can be washed, rinsed, sanitized, peeled, and cut prior to consumption (Luciano et al., 2022). When pathogens are present on the surface of whole mangoes, the potential for flesh contamination during preparation cannot be ignored; similar transfer from the peel to flesh of melons and citrus has been (Gagliardi et al., 2003; Jung et al., 2017; Shearer et al., 2016; Ukuku & Sapers, 2001). Contamination of fruit flesh may occur due to contaminated equipment in addition to poor hygiene practices and food handlers. Penteado et al. (2014) described the potential for *Salmonella* and *L. monocytogenes* cross-contamination from contaminated equipment, including knives during processing or at home onto mangoes. *S.* Enteritidis ($10^6$, $10^{5,}$ and $10^4$ CFU/mL) and *L. monocytogenes* ($10^6$ and $10^5$ CFU/mL) on knives were recovered from up to 3.8% from the knives and contaminated knives resulted in a transfer of 1 to <3 log CFU/mL (up to 0.04%) on fresh-cut mangoes because of cross-contamination during cutting. (Penteado et al., 2014). If contaminated, *E. coli* O157:H7, *Salmonella*, and *L. monocytogenes* can survive or grow on/in fresh-cut mangoes, mango juice, and foods produced from fresh mangoes can harbor the pathogens until consumption even at refrigerator and frozen temperature (Hsin-Yi & Chou, 2001; Leite et al., 2002; Penteado, et al., 2014).

On fresh-cut mangoes, the population of pathogens remain stable or increases proportional to the storage temperature (Kroft et al., 2022; Luciano et al., 2022; Ukuku & Fett, 2002). In this study, *L. monocytogenes* survived on the fresh-cut 'Tommy Atkins' mangoes at 4, 12, and 20°C similar to previous studies evaluating *L. monocytogenes*, *E. coli* O157:H7, and *Salmonella* on fresh-cut mangoes. Luciano et al. (2022) calculated the difference between *L. monocytogenes* counts (log CFU/g) at the end of 10 days of storage and inoculation day on fresh-cut mangoes as −0.34 at 4°C similar to results of −0.10 in this study. *Salmonella* grew at 23 and 12°C and survived long term at 4 and −20°C; *E. coli* O157:H7 grew at 23°C, and survived at 12, 4, and −20°C on fresh-cut mangoes (Strawn & Danyluk, 2010). Initial increase in *L. monocytogenes* in 24 h followed by a slight decrease during rest of the storage in this study is similar to the survival trend of *E. coli* O157:H7 and *Salmonella* at refrigerator temperature (Strawn & Danyluk, 2010).

Inoculum concentration has been reported as an important factor on the survival of pathogens on produce (Flessa et al., 2005). On fresh-cut mangoes, increases in *L. monocytogenes* population stored at 4°C for a week were less than 1 log CFU/g from the initial concentration of 3.17 log CFU/g to 4.59 log CFU/g (Kroft et al., 2022). Even on low-population inoculated (1–4 cells) mangoes, *L. monocytogenes* population increased between 1 log CFU/g when stored at 4 and 8°C and up to 5 log at the storage temperatures of 12 and 16°C in a week (Luciano et al., 2022). An initial increase in the pathogen population followed by a slight decrease has also been observed in fresh-cut mangoes and similar fruits including fresh-cut papayas as seen in this study (Strawn & Danyluk, 2010).

The temperatures used to evaluate the persistence of *Salmonella* and *L. monocytogenes* cocktails on whole mangoes were based on the lowest safe temperature for long-term exposure of mangoes (12°C),



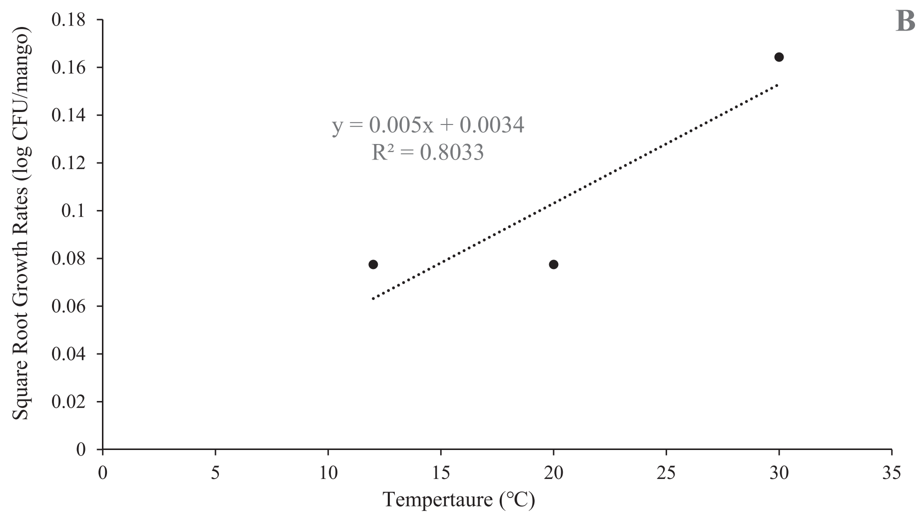




**Figure 4.** Growth curves for *Salmonella* on whole 'Kent' (A) and 'Tommy Atkins' (B) under environmental conditions.

the minimum forced-air cooling temperature (10°C), the recommended storage room, marine container, or truck trailer temperatures for shipping (10–12°C), the temperature for storage following ripening (10–13°C), the temperature mangoes are cooled to in the hydrocooler (21–22°C), the optimum temperature for ripening mangoes (20–22°C), the approximate ambient temperature of retail display (ca. 20°C), and the highest temperature for exposure to prevent poor ripening and flavor (30°C) temperatures mangoes may experience between being unloaded at a packinghouse and being processed (Brecht, 2014).

*Salmonella* populations slightly decreased or increased on the whole mango varieties evaluated, different to what has previously been reported for *Salmonella* on fresh-cut mangoes (Strawn & Danyluk, 2010). Similar to results reported in here, no significant increase or decrease in the population of *Salmonella* was observed on whole 'Ataulfo' and 'Tommy Atkins' mangoes stored at ambient (29–32°C and RH 85–95%, for 48 h), ripening (20–22°C and RH 90–95% for 9 days), or refrigerated storage (10–15°C and 85–95% for 24–48 h) conditions (Mathew et al., 2018). *L. monocytogenes* populations declined on whole mangoes over time at all the temperatures tested. *Salmonella* populations at 12 and 20°C grew significantly more ($P \leq 0.05$) than *L. monocytogenes* on whole mangoes in this study. Recently, conflicting results have been reported about the survival of *L. monocytogenes* on whole mangoes compared to slight decline in this study. *L. monocytogenes* with an initial concentration of 5.61 log CFU/sample was recovered at the population level below 1.0 log CFU/sample from whole mangoes stored for 16 days at 12°C to simulate distribution, followed by up to 6 days at 20–22°C to simulate ensuing ripening and retail display conditions (Kroft et al., 2022). On other fruits, such as cantaloupe (Ukuku & Fett, 2002), *L. monocytogenes* population decreased slightly during storage at 4 and 20°C. Girbal et al. (2021) evaluated the fate of L. monocytogenes on 10 whole intact raw fruits and vegetables, not including mangoes, at 2, 12, 22, 30, and 35°C, up to 28 days; initial population increases of *L. monocytogenes,* seen on all commodities except carrots, was followed by decreases in concentration.

Safety, sanitation, and temperature control should be a priority for fresh-cut mango processors. *L. monocytogenes* did not grow substantially at any three storage temperatures but has the potential to survive for the shelf life of fresh-cut mangoes. The surface of whole mangoes ('Ataulfo', 'Kent', and 'Tommy Atkins') is more susceptible to potential *Salmonella* growth than to *L. monocytogenes* growth. No meaningful reductions of *Salmonella* were observed on the surface of whole mangoes. Pre- and postharvest measures to prevent the contamination of whole mangoes are of the utmost importance. The generated model may provide a faster way to validate the efficacy of storage temperature on pathogen behavior on the surface of mangoes and can also be used in validating food safety plans.

## Author contributions

Conceptualization was designed by Michelle D. Danyluk. Data curation and methodology were performed by Loretta M. Friedrich (whole mangoes) and Vijendra Sharma (fresh-cut mangoes). Formal analysis and writing – original draft was completed by Joyjit Saha and Zeynal Topalcengiz. Funding acquisition, project administration, resources, software, supervision, writing – review and editing were organized by Michelle D. Danyluk.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jfp.2023.100151.

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