Survival of *Salmonella* on Dried Fruits and in Aqueous Dried Fruit Homogenates as Affected by Temperature

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ABSTRACT

A study was done to determine the ability of *Salmonella* to survive on dried cranberries, raisins, and strawberries in date paste, as affected by storage temperature. Acid-adapted *Salmonella*, initially at 6.57 to 7.01 log CFU/g, was recovered from mist-inoculated cranberries (water activity \(a_w\) 0.47) and raisins (\(a_w\) 0.46) stored at 25°C for 21 days but not 42 days, strawberries (\(a_w\) 0.21) for 42 days but not 84 days, and date paste (\(a_w\) 0.69) for 84 days but not 126 days. In contrast, the pathogen was detected in strawberries stored at 4°C for 182 days (6 months) but not 242 days (8 months) and in cranberries, date paste, and raisins stored for 242 days. Surface-grown cells survived longer than broth-grown cells in date paste. The order of rate of inactivation at 4°C was cranberry > strawberry > raisin > date paste. Initially at 2.18 to 3.35 log CFU/g, inactivation of *Salmonella* on dry (sand)–inoculated fruits followed trends similar to those for mist-inoculated fruits. Survival of *Salmonella* in aqueous homogenates of dried fruits as affected by fruit concentration and temperature was also studied. Growth was not observed in 10% (\(a_w\) 0.995 to 0.999) and 50% (\(a_w\) 0.955 to 0.962) homogenates of the four fruits held at 4°C, 50% homogenates at 25°C, and 10% cranberry and strawberry homogenates at 25°C. Growth of the pathogen in 10% date paste and raisin homogenates stored at 25°C was followed by rapid inactivation. Results of these studies suggest the need to subject dried fruits that may be contaminated with *Salmonella* to a lethal process and prevent postprocess contamination before they are eaten out-of-hand or used as ingredients in ready-to-eat foods. Observations showing that *Salmonella* can grow in aqueous homogenates of date paste and raisins emphasize the importance of minimizing contact of these fruits with high-moisture environments during handling and storage.

Several outbreaks of foodborne illness have been associated with or confirmed to have been caused by consumption of contaminated fresh fruits (1, 8, 25, 27). Tree nuts, defined by some as fresh dried fruits, have been implicated as vehicles of pathogens linked to outbreaks of salmonellosis and *Escherichia coli* O157:H7 infections (2, 13). With the exception of coconut (33, 37), dried fruits, which typically contain high amounts of sugars, have generally not been considered as likely vehicles of foodborne pathogens, although Scott et al. (28) do list low-moisture fruits and fruit products as *Salmonella*-sensitive ingredients.

Recent studies have provided information to better understand factors affecting survival and inactivation of foodborne pathogens on nuts, seeds, and cereals (13), but only a few reports describe the presence and conditions affecting the behavior of foodborne pathogens on dried fruits that may be eaten out-of-hand or used as ingredients in ready-to-eat products such as breakfast cereals, granola, trail mix, cold-pressed bars, and confections. Withuhn et al. (38) isolated *Salmonella* from commercial samples of raisins (water activity \(a_w\) 0.72) and prunes (\(a_w\) 0.81) 1 month after packaging and *Staphylococcus* (>20 CFU/g) from raisins (\(a_w\) 0.71) 8 months after packaging. *Salmonella* has been reported to survive on dried apples (9) and tomatoes (39) for at least 28 days at 25°C. Bontempo and Uesugi (4) reported that *Salmonella* can survive on 11 of 12 dried fruits stored for up to 3 months at 4 and 10°C. For most of these fruits stored at temperatures higher than 25°C, *Salmonella* decreased by 4 to 5 log CFU/g within 3 weeks. *Listeria monocytogenes* can survive on dried peaches stored at 25°C for at least 14 days (10).

Detection of foodborne pathogens in commercial dried raisins and prunes (38) and in seeds and high-sugar, seed-based products (2, 7, 24, 36) raises a public health concern. Halva, a low-\(a_w\), confectionery consisting largely of sesame seed paste and sucrose, has been linked to an outbreak of salmonellosis (6). *Salmonella* Enteritidis has been reported to survive in high-sugar products such as halva (50% sugar, \(a_w\) 0.18) for 8 months (18) and a peanut butter–flavored candy fondant (\(a_w\) 0.65 to 0.69) for 12 months (24). Tyssset and Durand (31), as cited by Snowdon and Cliver (29), reported that *Salmonella* Typhimurium and *Salmonella* Dublin survived for more than 28 months in honey stored at 10°C. These observations emphasize the need to better understand conditions affecting survival of *Salmonella* in high-sugar, low-\(a_w\) products such as dried fruits and dried fruit products.

The general hypothesis is that the osmotic, acidic, phenolic, and other naturally occurring antimicrobial...
stresses imposed by most dried fruits and dried fruit products will cause vegetative bacterial cells to rapidly die. However, cells that survive initial exposure to these stresses may remain viable for an extended time and exhibit increased tolerance to subsequent stresses. Gruzdev et al. (12) reported that desiccated *Salmonella* Typhimurium cells have increased resistance to sanitizers, sodium chloride, dry heat, and UV irradiation. Survival of salmonellae during desiccation can be enhanced by the presence of sucrose (14), and habituation to low aw results in increased heat resistance (22). Acid-adapted *Salmonella* Typhimurium has an increased tolerance to heat, sodium chloride, and organic acids (21, 30, 35) and shows enhanced survival in cheeses (20). Exposure of *Salmonella* cells to stress environments preceding contamination of dried fruits may protect the cells against otherwise lethal stresses imposed by the high-sugar, low-pH conditions typically present in these fruits.

Phenolic and other compounds naturally found in fresh berries (19, 23, 26), dried figs (15), and other dried fruits are known to be lethal to *Salmonella* and spoilage microorganisms. Phenolics and organic acids, particularly benzoic acid, in cranberries and other fruits are known to have antimicrobial activity against foodborne pathogens and spoilage microorganisms (19, 26). The inhibitory effects of raisins against *Salmonella* in a beef jerky formulation (5) and raisin extract against *Bacillus* and molds in bread (34) demonstrate the potential for food preservative applications of dried fruit constituents, but conditions affecting the antimicrobial activity of naturally occurring compounds in raisins and other low-aw fruits have not been described.

We undertook a study to determine the survival of *Salmonella* cells on the surface of dried cranberries, raisins, and strawberries and in date paste, as affected by method of culturing cells to prepare inocula, inoculation procedure, and storage temperature and time after inoculation. The survival of *Salmonella* in aqueous homogenates of dried fruits as affected by fruit concentration and storage temperature was also studied.

**MATERIALS AND METHODS**

**Dried fruits.** Sweetened dried cranberries (contains cranberries, sugar, citric acid, sunflower oil, and elderberry juice concentrate), date paste, freeze-dried strawberry slices, and seedless raisins were obtained from commercial sources. None of the fruits had been treated with sulfur dioxide. Products were stored at 5°C until they were used.

**Measurement of aw and pH.** The aw of dried fruits (3 g) and 10 to 90% (wt/vol; fruit:water) fruit homogenates was determined using a water activity meter (AquaLab CX-2, Decagon Devices, Inc., Pullman, WA). The pH was measured using a pH meter (Accumet AB15, Fisher Scientific, Ottawa, Ontario, Canada).

**Salmonellae used.** Inocula contained a mixture of five serotypes of *Salmonella enterica*: Agona, strain F5567, isolated from a dry cereal manufacturing plant; Enteritidis, strain 2415 (ATCC BAA-1045), from raw almonds; Montevideo, strain G4639, clinical isolate from patient in a tomato-associated outbreak of salmonellosis; Tennessee, strain K4643, clinical isolate from a patient in an outbreak of salmonellosis associated with consumption of peanut butter; and Typhimurium DT104 (source unknown). All strains were preserved at −20°C in tryptic soy broth (TSB; BD, Sparks, MD) supplemented with 15% glycerol.

**Preparation of inocula for dried fruits.** Dried fruits were inoculated using two methods: misting (atomizing) with an aqueous suspension of a five-serotype mixture of *Salmonella* and mixing with sand on which a five-serotype mixture had been dried. These methods mimic contamination of the fruits resulting from contact with water containing *Salmonella* or cross-contamination by contact with soil, dust, or dry surfaces, respectively. For acid adaptation, each serotype was grown in 10 ml of TSB supplemented with 1% glucose (TSBG, initial pH 7.3) for 22 to 24 h at 37°C. After two consecutive 24-h transfers of each serotype, two tubes of each 24-h culture (pH 4.67 to 4.76) were combined to give 100 ml of a five-serotype mixture. The mixture was centrifuged at 3,000 × g for 10 min, and cells were resuspended in 50 ml of sterile deionized water. Dried fruits were misted with the inoculum within 1 h after preparation. A second type of inoculum was prepared by drying cells on sand (40 to 400 mesh; Argos Organics, Geel, Belgium). Fifty milliliters of a five-serotype cell suspension prepared as described above were combined with 250 g of sterile sand at 21°C, mixed, and held for 15 min. To separate sand from the suspension, it was drained, spread in a thin layer (ca. 0.5 cm deep) in a shallow pan, and dried to aw 0.16 at 21°C in a biosafety cabinet for 29 ± 2 h. The sand inoculum was sealed in a glass jar and was stored at 4°C for 7 to 14 days before use.

In a second study, mist inoculum was prepared using *Salmonella* grown in TSBG and on tryptic soy agar (TSA; BD) supplemented with 1% glucose (TSAG). The purpose of this study was to determine whether cells grown on a solid medium exhibit a different survival pattern compared to cells grown in broth culture, as described above. Each serotype was grown in TSBG for 22 to 24 h at 37°C. Culture (1 ml) of each serotype was spread on the surface of TSAG in three large petri dishes (150 by 15 mm) and was incubated at 37°C for 24 h. To harvest cells, 5 ml of sterile 0.1% peptone water was deposited on the lawn that had developed on the surface of each TSAG plate, and cells were suspended by gently rubbing the lawn with a sterile glass rod. Cell suspensions were pooled to give approximately 15 ml of each serotype; 10-ml aliquots of suspension of each serotype were combined to give 50 ml of a five-serotype suspension. Five milliliters of this suspension was combined with 100 ml of sterile deionized water. This suspension, along with a suspension of TSBG-grown cells, was used for mist inoculation of date paste. Dried cranberries, raisins, and strawberries were not included in experiments using inoculum prepared from cells grown on TSAG.

**Inoculation and incubation of dried fruits.** Dried cranberries, raisins, and strawberries (1,500 g) were spread in single layers on a sterile screen elevated ca. 18 cm above the work surface of a biosafety cabinet. Date paste (1,500 g) was spread in a 2-cm layer on a sterile stainless steel tray. Inoculum (15 ml) prepared from cells grown in TSBG or on TSAG was applied to the surface of the dried fruits using a mist (Misty 2.5 Personal Mister 10025; www.mistymate.com). Inoculated fruits were allowed to dry 60 ± 10 min to reduce the aw to values (±0.02) of those of uninoculated fruits and then they were thoroughly mixed and deposited (25-g samples) in Stomacher 400 bags. Samples of the four fruits inoculated with cells grown in TSBG were placed in plastic tubes (60 by 43 by 15 cm), sealed, and stored at 4 and 25°C for up to 242 days (ca. 8 months) before analysis for the presence (by enrichment) and number of surviving *Salmonella*. Date paste...
inoculated with *Salmonella* grown on TSAG was also stored at 4 and 25°C for up to 242 days before analysis for survivors. The procedure for inoculating dried fruits using sand on which TSBG-grown *Salmonella* had been dried was the same as that used for mist inoculation, except fruits (1,500 g) were placed in sterile trays rather than on screens before application of 15 g of the dry inoculum.

**Preparation of fruit homogenates.** Fruit homogenates were prepared by combining dried fruits and sterile deionized water at ratios of 1:9 to 9:1 (wt/vol, fruit/water) in Stomacher 400 bags. The mixtures were pummeled in a stomacher (Seward Medical, Ltd., London, UK) for 2 min at normal speed.

**Preparation of inoculum for fruit homogenates.** *Salmonella* serotypes were separately grown in 10 ml of TSBG supplemented with nalidixic acid (50 μg/ml) for 22 to 24 h at 37°C. After two consecutive transfers at 24-h intervals, one tube of each culture was combined to give 50 ml of a five-serotype mixture. The suspension was diluted in sterile deionized water to give desired populations for inoculating fruit homogenates.

**Inoculation and incubation of fruit homogenates.** One milliliter of inoculum was combined with 100 ml of each fruit homogenate in Stomacher 400 bags to give 5.19 log CFU/ml and was pummeled for 1 min at normal speed. Homogenates incubated at 4 and 25°C for 1, 6, 24, and 48 h were analyzed for the presence (by enrichment) and populations of *Salmonella*. In a follow-up study, 10 and 50% date paste and raisin homogenates that had been inoculated at 2,767 CFU/ml and incubated at 4 and 25°C for 1 and 6 h and for 1, 2, 6, 10, 14, 20, 34, 49, 70, and 84 days were analyzed for presence and populations of *Salmonella*.

**Microbiological analyses.** Uninoculated, dried fruit (25 g) was combined with 225 ml of sterile 0.1% peptone water in a Stomacher 400 bag and was pummeled in a stomacher for 1 min at normal speed. Triplicate undiluted samples and samples serially diluted in peptone water were analyzed for mesophilic aerobic counts, coliforms, and yeasts and molds using 3M Petrifilm Aerobic Count, Coliform, and Yeast and Mold plates (3M Company, St. Paul, MN), respectively, according to the manufacturer’s instructions.

Five-serotype cell suspensions used to inoculate dried fruits and homogenates were serially diluted in peptone water and spiral plated (WASP2, Microbiology International, Frederick, MD) on TSA. Sand inoculum (10 g) was combined with 90 ml of peptone water, stomached 2 min at normal speed, and serially diluted in peptone water; the sand wash was spiral plated on TSA. Plates were incubated for 24 h at 37°C before colonies were counted.

Uninoculated and inoculated dried fruits were analyzed for the presence (by enrichment) and populations of *Salmonella*. Fruits inoculated with salmonellae were analyzed within 10 min after inoculation (0 h) and after storage for 1 h and 1, 6, 21, 42, 84, 126, 182, and 242 days at 4 and 25°C. Triplicate 25-g samples of dried fruits in Stomacher 400 bags were combined with 225 ml of lactose broth (LB; BD) and were pummeled in a stomacher for 1 min at normal speed. To minimize lethality to *Salmonella* upon exposure of cells to the acidic pH of the strawberry and LB homogenate, LB was adjusted to pH 4.50 by adding 12 M NaOH before adding strawberries and pummeled. The pH values of cranberry, date paste, raisin, and strawberry and LB homogenates were 4.38, 5.79, 4.55, and 4.50, respectively. Undiluted samples (quadruplicate 0.25-ml samples and duplicate 0.1-ml samples) and samples serially diluted in sterile 0.1% peptone water were surface plated on bismuth sulfite agar (BSA; BD) and TSA. *Salmonella*-presumptive colonies that formed on BSA within 48 h at 37°C and on TSA after 24 h at 37°C were counted. Selected colonies were subjected to confirmation tests using BBL Enterotube II (BD) and API 20E (bioMérieux, Vitelc, Hazelwood, MO) assays, and a *Salmonella* latex agglutination test (Oxoid, Basingstoke, UK). Bags containing fruit and LB homogenates were incubated for 24 h at 37°C. The preenriched homogenate was streaked on BSA, and plates were incubated for 48 h at 37°C before examination for *Salmonella*-presumptive colonies and confirmation of randomly selected isolates. For uninoculated samples and inoculated samples anticipated to contain low numbers of *Salmonella* cells, 1 ml of preenriched LB homogenate was added to 10 ml of tetrahionate broth (BD) and 0.1 ml was added to 10 ml of Rappaport-Vassiliadis broth (BD). Broths were incubated for 24 h at 37 and 42°C, respectively, before streaking on BSA. *Salmonella*-presumptive colonies that formed on BSA within 48 h at 37°C were randomly selected for confirmation tests.

Aqueous homogenates of cranberries, date paste, raisins, and strawberries that had been inoculated with salmonellae and had been incubated at 4 and 25°C for 1, 6, 24, and 48 h were analyzed for the presence and populations of the pathogen. In a follow-up study, inoculated date paste and raisin homogenates stored for 1 and 6 h and 1, 2, 6, 10, 14, 20, 34, 49, 70, and 84 days and stored at 4 and 25°C were analyzed for *Salmonella*. Homogenates were pummeled for 30 s at normal speed. Undiluted samples (0.25 ml in quadruplicate and 0.1 ml in duplicate) and samples serially diluted in 0.1% peptone water were surface plated and spiral plated, respectively, on BSA supplemented with 50 μg/ml nalidixic acid. Plates were incubated for 48 h at 37°C, *Salmonella*-presumptive colonies were counted, and cells from selected colonies were subjected to confirmation tests.

**Statistical analysis.** Experiments were replicated twice. Two different lots of each fruit were designated as replicates 1 and 2. Three samples were analyzed for each combination of test parameters at each sampling time in each replicate trial. Values were analyzed with a general linear model on SAS software (version 9.1, SAS Institute, Cary, NC). The least significant difference test was used to determine significant differences (P \( \leq \) 0.05) in mean values.

**RESULTS AND DISCUSSION**

The \( a_w \) of dried fruits ranged from 0.21 (strawberry) to 0.69 (date paste); pH values were 2.52 (cranberry) to 5.08 (date paste) (Table 1). The high-to-low order of \( a_w \) and pH values of the four fruits was different, making any correlation that might exist between rate of inactivation of *Salmonella* and magnitude of either value difficult to assess. With the exception of date paste, *Salmonella* cells were deposited on the surface of fruits, where direct exposure to internal tissues with potentially higher acidity was minimal, also making it difficult to attribute pH as a factor influencing the inactivation rate of *Salmonella*. The \( a_w \) values of 10 and 50% fruit homogenates were 0.995 to 0.999 and 0.955 to 0.962, respectively; pH values were 2.60 ± 0.08 (cranberry) to 5.10 ± 0.02 (date paste) (Table 1).

Coliforms and *Salmonella* cells were not detected (<1 CFU/25 g in three 25-g samples) in uninoculated fruits (Table 2). Date paste, raisins, and strawberries had aerobic counts of 2.18 to 2.90 log CFU/g, and date paste and raisins had yeast and mold counts of 2.33 and 3.07 log CFU/g.
TABLE 1. Moisture content, aw, and pH of dried fruits and fruit homogenates

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Dry Moisture (%)</th>
<th>aw</th>
<th>pH</th>
<th>Homogenate Concn (%)</th>
<th>aw</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranberry</td>
<td>10.2</td>
<td>0.47</td>
<td>2.52</td>
<td>10</td>
<td>0.999</td>
<td>2.68</td>
</tr>
<tr>
<td>Date paste</td>
<td>21.4</td>
<td>0.69</td>
<td>5.08</td>
<td>50</td>
<td>0.962</td>
<td>2.52</td>
</tr>
<tr>
<td>Raisin</td>
<td>14.7</td>
<td>0.46</td>
<td>4.08</td>
<td>10</td>
<td>0.998</td>
<td>5.12</td>
</tr>
<tr>
<td>Strawberry</td>
<td>14.0</td>
<td>0.21</td>
<td>3.32</td>
<td>50</td>
<td>0.959</td>
<td>5.08</td>
</tr>
</tbody>
</table>

*aw* values are calculated from moisture content and water activity sensors. The results are presented as means of three replicate analyses. The pH values are presented as means of three replicate analyses.

*aw* values are calculated from moisture content and water activity sensors.

TABLE 2. Microbiological quality of dried fruits before inoculation with Salmonella

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Aerobic count</th>
<th>Coliform</th>
<th>Yeasts and molds</th>
<th>Salmonella</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranberry</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Date paste</td>
<td>2.18</td>
<td>ND</td>
<td>2.33</td>
<td>ND</td>
</tr>
<tr>
<td>Raisin</td>
<td>2.76</td>
<td>ND</td>
<td>3.07</td>
<td>ND</td>
</tr>
<tr>
<td>Strawberry</td>
<td>2.90</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

*aw*, none detected. For aerobic count, coliform, and yeasts and molds, *aw* (<10 CFU/g) in three 25-g samples; for Salmonella, *aw* by enrichment of three 25-g samples.

respectively. The aerobic count in cranberries and yeast and mold counts in cranberries and strawberries were <1 log CFU/g. None of the fruits showed visible evidence of microbial growth.

Shown in Table 3 are reductions in populations of *Salmonella* that had been mist inoculated onto dry fruits. Fruits were inoculated with *Salmonella* at populations of 6.57 to 7.01 log CFU/g. Reductions of 0.23 to 1.02 log CFU/g occurred within 10 min and 1 h, respectively, after inoculation. Reductions were more rapid in fruits subsequently stored at 25°C than in fruits stored at 4°C. *Salmonella* bacteria (>1 CFU in at least one of six 25-g samples) were recovered from cranberries and raisins stored at 25°C for 21 days but not 42 days, strawberries for 42 days but not 84 days, and date paste for 84 days but not 126 days. In contrast, *Salmonella* cells were recovered from cranberries, date paste, and raisins stored at 4°C for 242 days, and from strawberries stored for 182 days but not 242 days. The pathogen survived at highest numbers in date paste, which is attributable in part to the higher pH (5.08) compared with that of other fruits. The general order of rate of inactivation at 4°C was cranberry > strawberry > raisin > date paste.

Reductions of *Salmonella* populations on dry (sand)–inoculated fruits are shown in Table 4. Based on counts obtained by analyzing the sand on which *Salmonella* had been dried, the initial number of *Salmonella* was calculated to be 2.18 to 3.35 log CFU/g of fruit. Reductions of 0.37 to 1.45 log CFU/g occurred within 10 min after combining the sand inoculum and the fruits. Within 1 h, counts decreased by 0.47 to 1.40 log CFU/g. As with mist-inoculated fruits, *Salmonella* died more rapidly at 25°C than at 4°C, and survival was highest in date paste. The pathogen was detected in strawberries and raisins stored at 4°C for 182 days but not 242 days, and in cranberries and date paste stored for 242 days. Skips in detection occurred at some sampling times. Dry-inoculated cranberries, for example, were negative for *Salmonella* at 21, 42, 84, 182, and 242 days of storage at 25°C but were positive at 126 days. Raisins and strawberries stored at 4°C were negative at 42, 84, 126, and 242 days but were positive at 182 days.

These results indicate that some cells were able to survive the high-osmotic, low-pH conditions imposed by test fruits for at least 182 days (6 months) or, in the case of cranberries, date paste, and raisins, for at least 242 days (8 months). Rates of inactivation of *Salmonella* on mist- and dry (sand)–inoculated fruits were clearly affected by type of fruit and storage temperature but not by the form of the inoculum, i.e., wet or dry. Observations that inactivation was unaffected by the type of inoculum are in agreement with observations reported by Blessington et al. (3) showing that *Salmonella* Enteritidis died at similar rates on dry- and wet-inoculated almonds and walnuts stored at ambient temperature for up to 98 days.

Results of studies done to determine whether the rate of inactivation of *Salmonella* in mist-inoculated date paste is affected by the method used to grow cells used in the inoculum are shown in Figure 1. Regardless of the culture medium, i.e., TSBG or TSAG, death was more rapid at 25°C than at 4°C. However, within each storage temperature, the rate of inactivation of *Salmonella* grown on TSAG was slower than the rate of inactivation of cells grown in TSBG. This is particularly evident in date paste during the initial days of storage at 25°C and throughout the 242-day storage period at 4°C. Aside from the demonstrated protective effects of exposure of *Salmonella* to acidic environments against subsequent exposure to other stresses (11, 20), compared with planktonic cells, cells grown on solid (agar) media have been reported by others (17, 32) to exhibit increased tolerance to desiccation. Our observations
### TABLE 3. Reduction of Salmonella on mist-inoculated dried fruits stored at 4 and 25°C for up to 242 days (8 months)\(^a\)

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Inoculum applied (log CFU/g)</th>
<th>Reduction (log CFU/g) after:</th>
<th>Storage temp (°C)</th>
<th>Reduction (log CFU/g) after storage for 1 to 242 days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10 min</td>
<td>1 h</td>
<td>21 (Enr(^b))</td>
</tr>
<tr>
<td>Cranberry</td>
<td>6.87</td>
<td>1.02</td>
<td>2.12</td>
<td>4</td>
</tr>
<tr>
<td>Date paste</td>
<td>6.57</td>
<td>0.26</td>
<td>0.43</td>
<td>4</td>
</tr>
<tr>
<td>Raisin</td>
<td>7.01</td>
<td>0.23</td>
<td>0.95</td>
<td>4</td>
</tr>
<tr>
<td>Strawberry</td>
<td>6.64</td>
<td>0.93</td>
<td>2.04</td>
<td>4</td>
</tr>
</tbody>
</table>

\(^a\) Reduction (log CFU per gram) compared with number applied to fruit. Values shown in bold print indicate that Salmonella was not detected by direct plating or enrichment. Limit of detection by direct plating was 10 CFU/g (\(n = 6\)). Limit of detection by enrichment was 1 CFU/25 g.

\(^b\) Enr, number of enriched samples positive for Salmonella/number of samples analyzed. Values are shown only for the number of samples (one to six) of triplicate samples analyzed in two replicate trials (\(n = 6\)) that were not positive by direct plating.

### TABLE 4. Reduction of Salmonella on dry (sand)–inoculated dried fruits stored at 4 and 25°C for up to 242 days (8 months)\(^a\)

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Inoculum applied (log CFU/g)</th>
<th>Reduction (log CFU/g) after:</th>
<th>Storage temp (°C)</th>
<th>Reduction (log CFU/g) after storage for 1 to 242 days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10 min</td>
<td>1 h</td>
<td>21 (Enr(^b))</td>
</tr>
<tr>
<td>Cranberry</td>
<td>3.35</td>
<td>1.45</td>
<td>1.40</td>
<td>4</td>
</tr>
<tr>
<td>Date paste</td>
<td>3.18</td>
<td>1.38</td>
<td>1.40</td>
<td>4</td>
</tr>
<tr>
<td>Raisin</td>
<td>2.18</td>
<td>0.37</td>
<td>0.47</td>
<td>4</td>
</tr>
<tr>
<td>Strawberry</td>
<td>2.28</td>
<td>0.70</td>
<td>1.35</td>
<td>4</td>
</tr>
</tbody>
</table>

\(^a\) Reduction (log CFU per gram) compared with number applied to fruit. Values shown in bold print indicate that Salmonella was not detected by direct plating or enrichment. Limit of detection by direct plating was 10 CFU/g (\(n = 6\)). Limit of detection by enrichment was 1 CFU/25 g.

\(^b\) Enr, number of enriched samples positive for Salmonella/number of samples analyzed. Values are shown only for the number of samples (one to six) of triplicate samples analyzed in two replicate trials (\(n = 6\)) that were not positive by direct plating.
Several studies have shown that Salmonella can survive in low-a_w foods for long periods of time (2). Survival is favored at refrigeration and freezing temperatures. Observations that high levels of sucrose may protect against death of Salmonella (14, 18, 24) have raised interest in determining its ability to survive in dried fruits, most of which contain high amounts of sugars. In a recent study designed to determine retention of viability of Salmonella on 12 types of dried fruits stored at 4 to 45 °C, Bontempo and Uesugi (4) found that the pathogen survived for up to 3 months on 11 of the fruit types. At 4 and 10 °C, Salmonella survived for more than 3 months, with levels dropping by 2 to 3 log. Salmonella did not behave the same on all fruits. Our studies support these findings. Clearly, death of Salmonella was more rapid at 25 °C than at 4 °C on all dried fruits and, at the same storage temperature, survival was markedly affected by the type of fruit.

Storage of dried fruits at refrigeration temperatures preserves sensorial qualities, thereby extending shelf life. Commercial bulk storage of raisins at 7 to 10 °C and cranberries at <60 °C, for example, is known to preserve quality for 12 to 18 months. Date paste is generally bulk stored at a lower refrigeration temperature, largely to control the growth of yeasts and molds. Our observations, as well as those reported by others on the ability of Salmonella to survive on dried fruits stored at 4 to 10 °C (4), emphasize the need to apply a process to inactivate Salmonella and prevent postprocess contamination, particularly if the fruits are intended to be eaten out-of-hand or used as ingredients in ready-to-eat products.

In the first set of experiments designed to determine the behavior of Salmonella (5.19 log CFU/ml) in 10 and 50% fruit and water homogenates held at 4 and 25 °C, all four test fruits were studied. Water activities of 10 and 50% homogenates were 0.995 to 0.999 and 0.955 to 0.962, respectively. Results are shown in Figure 2. Death over a 48-h period was more rapid in 50% cranberry, raisin, and strawberry homogenates than in 10% homogenates. Inactivation was more rapid in cranberry and strawberry homogenates held at 25 °C compared with 4 °C, regardless of the amount of fruit in the homogenate. Salmonella did not significantly decrease (P > 0.05) in 10 and 50% date paste homogenate or in 10% raisin homogenate held at 4 and 25 °C for 48 h. Although counts in the 10% raisin homogenate that was held at 25 °C did not increase significantly between 24 and 48 h, the trend was toward a higher count.

Based on observations that Salmonella retained high viability in 10% date paste and raisin homogenates for 48 h, experiments were done to determine how long the pathogen

FIGURE 1. Survival of Salmonella grown in TSBG and TSAG, inoculated into date paste, and incubated at 4 and 25 °C for up to 242 days. The dashed line indicates the limit of detection (10 CFU/g) by direct plating.

FIGURE 2. Survival of Salmonella in 10 and 50% cranberry, date paste, raisin, and strawberry homogenates incubated at 4 and 25 °C for up to 48 h.
would survive, and possibly grow, during extended storage times. Results are shown in Figure 3. Initially at 2.76 log CFU/ml of 10% date paste homogenate, *Salmonella* increased significantly (*P* ≤ 0.05) to 5.23 log CFU/ml within 2 days at 25°C and then decreased to an undetectable level (<1 CFU/ml) at 14 days. The pathogen decreased to 0.86 log CFU/ml of 10% homogenate held at 4°C for 70 days and was not detected (<1 CFU/ml) at 84 days. *Salmonella* did not grow in 50% date paste homogenate at 25°C and was not detected in samples stored for 6 and 49 days at 25 and 4°C, respectively.

The behavior of *Salmonella* in 10 and 50% raisin homogenates held at 25°C was similar to that observed for date paste homogenates. The pathogen increased significantly (*P* ≤ 0.05) from an initial population of 2.76 log CFU/ml to 5.00 log CFU/ml of 10% homogenate within 2 days and 5.25 log CFU/ml in 6 days before decreasing to an undetectable level at 14 days. No growth occurred in 50% raisin homogenate held at 25°C, and the pathogen was not detected in homogenate held for 6 days. *Salmonella* died more rapidly in 10 and 50% raisin homogenates compared with date paste homogenates held at 4°C; decreases to undetectable levels occurred within 70 and 14 days, respectively.

![Figure 3](http://meridian.allenpress.com/jfp/article-pdf/77/7/1102/1683102/0362-028x_jfp-13-549.pdf)

**FIGURE 3.** Survival of *Salmonella* in 10 and 50% date paste and raisin homogenates incubated at 4 and 25°C for up to 84 days.

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References


