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Viability of *Salmonella* and *Listeria monocytogenes* in Delicatessen Salads and Hummus as Affected by Sodium Content and Storage Temperature

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ABSTRACT

A study was conducted to determine survival and growth behavior of *Salmonella* and *Listeria monocytogenes* in commercially prepared mayonnaise-based potato salad, macaroni salad, and coleslaw and in hummus (initial mean pH values were 4.80 to 4.94, 4.18 to 4.31, 3.87, and 4.50 to 4.52, respectively) as affected by sodium concentration (133 to 364, 190 to 336, 146 to 272, and 264 to 728 mg/100 g, respectively) and storage at 4 or 10°C for up to 27 days. *Salmonella* did not grow in any of the test products. Initial populations (2.02 to 2.38 log CFU/g) decreased in coleslaw to undetectable levels (<1 CFU/25 g) within 13 days and in most formulations of macaroni salad within 20 to 27 days. *Salmonella* survived in highest numbers in potato salad and hummus. The presence of added sodium in macaroni salad stored at 4°C and hummus stored at 4 or 10°C appeared to protect *Salmonella* against inactivation. *L. monocytogenes,* at an initial population of 1.86 to 2.23 log CFU/g, did not grow in test products, but with the exception of coleslaw containing sodium at a concentration used in the standard (control) recipe, this pathogen was detected by direct plating (≥1.0 log CFU/g) in all products stored at 4 or 10°C for 27 days. *L. monocytogenes* populations were significantly ($P < 0.05$) lower in potato salad and hummus with no added sodium than in test products with added sodium after storage at 4°C. Sodium concentration did not markedly affect aerobic plate counts over the 27-day storage period. Results confirm that the acidic pH of mayonnaise-based salads and hummus is a major factor preventing growth and influencing rates of inactivation of *Salmonella* and *L. monocytogenes*. In the absence of added sodium, death of these bacteria may be more rapid. However, in general decreasing or increasing the sodium concentration in selected delicatessen salad and hummus recipes does not markedly affect the behavior of *Salmonella* and *L. monocytogenes* when products are stored at 4 or 10°C for up to 27 days.

In recent decades, the daily intake of sodium in the United States has increased substantially *(5, 24)*. Most of the sodium in food originates from sodium chloride, which is an added ingredient. Excess sodium intake contributes to obesity and increases the risk of high blood pressure, stroke, and heart disease. The World Health Organization *(57)* and the U.S. Food and Drug Administration *(51)* have recommended reductions in daily intake of sodium. However, health benefits that may result from these reductions must be weighed against risks associated with potential enhancement of conditions favoring survival, growth, and toxin production by foodborne pathogens *(49)*. Of particular interest are ready-to-eat (RTE) foods with high water activity (a_w) that are not pasteurized and require refrigeration to control pathogenic and spoilage microorganisms. Mayonnaise-based salads and hummus are in this microbiologically sensitive food category.

Surveys have been done to determine the prevalence of *Listeria monocytogenes* in prepared (delicatessen) salads. Gombas et al. *(17)* found that 2.36% of 8,549 retail delicatessen salads collected at two geographic locations in the United States were positive for this pathogen. Prevalence in in-store-packaged samples was significantly higher than that in manufacturer-packaged samples. The same trend was observed in the United Kingdom for prepacked meats and sandwiches containing salad vegetables as an ingredient *(30)*. *L. monocytogenes* was detected in 3.7% of 404 pasta- and rice-based salads obtained at points of sale or service to the customer in Wales *(37)*. In a study to determine the prevalence of *L. monocytogenes* in RTE foods in Belgium, Uyttendaele et al. *(52)* detected this pathogen in 80 (6.7%) of 1,187 25-g samples. Vegetable salads ($n = 53$) had the highest prevalence (13% of samples). Outbreaks of listeriosis associated with consumption of chicken salad purchased from a retail food establishment in the United States *(34),* coleslaw in Canada *(46),* and rice salad in Italy *(44)* have been documented. *Salmonella, Campylobacter, Clostridium perfringens, Staphylococcus aureus,* and norovirus have been isolated from salad meals (delicatessen salads) *(29)*. Salmonellosis has been linked to the consumption of contaminated macaroni salad *(53),* potato salad *(33, 53),* and hummus *(9)*.

Many opportunities for cross-contamination and transmission of foodborne pathogens exist in RTE foods in retail and home settings. Sauders et al. *(45)* conducted a cross-

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sectional study of *L. monocytogenes* contamination in 121 retail establishments in the United States. The pathogen was detected in at least one food or environmental sample obtained from 60% of the establishments. Strains were widely distributed, and some persisted for more than 1 year. In New York State, the odds of *L. monocytogenes* being found in retail delicatessen establishments were reported to be twice as high for large establishments, establishments located in New York City, and establishments with poor inspection history compared with establishments without these attributes *(22)*. A study of consumer practices for storing RTE foods, including delicatessen salads, revealed that improvement in practices is warranted *(8)*. Individuals with lower levels of education were more likely to follow recommended storage time guidelines than were individuals with higher levels of education. A nationally representative survey ($n = 2{,}060$) of consumer knowledge and use of ''open'' dates in the United States revealed that only 18% correctly defined the use-by date *(26)*. Risks of foodborne illness associated with consumption of reduced-sodium delicatessen salads after the intended use-by date are unknown.

Mayonnaise is a common ingredient in commercially prepared and homemade RTE salads. Numerous studies have been conducted on the behavior of *Salmonella (12, 13, 16, 28, 30–32, 39, 41, 59), Escherichia coli* O157:H7 *(14, 21, 42, 56, 60), L. monocytogenes (12, 13, 16),* and *S. aureus (18)* in various types of mayonnaise. Rates of inactivation of *Salmonella (11, 13, 43), E. coli* O157:H7 *(1, 58), L. monocytogenes (13, 23),* and *S. aureus (11)* and growth of naturally occurring microbiota *(6)* in mayonnaise-based salads prepared using traditional recipes have been reported. Other researchers have described microbiological changes in salad dressings *(2, 4, 38, 47)*. A growth–no growth model for *L. monocytogenes* has been developed *(19, 54)* and validated *(55)* for mayonnaise-based salads. However, these studies did not specifically address sodium content as a variable that might influence the behavior of *Listeria* or other foodborne pathogens.

We undertook a study to determine survival and growth characteristics of *Salmonella* and *L. monocytogenes* in commercially prepared delicatessen salads and hummus as affected by sodium content. The behavior of these pathogens as affected by temperature (4 and 10°C) over a 27-day storage period was also determined, and aerobic plate counts were monitored.

MATERIALS AND METHODS

Strains used. The five-serotype mixture of *Salmonella enterica* used as an inoculum contained serotypes Anatum, Enteritidis, Heidelberg, and Typhimurium (Poultry Diagnostic Research Center, University of Georgia, Athens) and Newport H1275 (isolated from a patient in an outbreak associated with alfalfa sprouts).

The five strains of *L. monocytogenes* used to prepare an inoculum were F8025, serotype 4b (isolated from celery); F8369, serotype 1/2a (from corn); F8385, serotype 1/2b (from carrot); H0222, serotype 1/2a (from potato); and G1091, serotype 4b (from a patient in an outbreak associated with coleslaw).

Preparation of inocula. Salmonellae were grown at 37°C for 24 h in 10 ml of tryptic soy broth (TSB; BD, Franklin Lakes, NJ), and cultures were transferred by loop at 24-h intervals. Cultures (5 ml) of each serotype were combined to produce a cell suspension containing 8 to 9 log CFU/ml. The suspension was serially diluted in sterile deionized water to produce a population of 3 to 4 log CFU/ml. This suspension, containing approximately equal populations of each serotype, was used as an inoculum for salads and hummus.

The five strains of *L. monocytogenes* were grown at 37°C for 24 h in 10 ml of brain heart infusion broth (BD), and cultures were transferred by loop at 24-h intervals. Cultures (5 ml) of each strain were combined to give a cell suspension containing 8 to 9 log CFU/ml and serially diluted to contain 3 to 4 log CFU/ml. This suspension was used as an inoculum for salads and hummus.

Preparation of salads and hummus. Three delicatessen salads (New York style potato salad, original macaroni salad, and shredded coleslaw) and hummus (classic style) were obtained from a regional food manufacturing company. Table 1 provides a list of ingredients in standard product recipes. Test products were formulated to contain four different concentrations of sodium: lowest (no sodium added), low, control (amount of sodium in the standard recipe), and highest (Table 2). The sodium in products with the lowest concentrations is from ingredients other than sodium chloride and seasoning blends used to formulate the products. Sodium in the low-sodium, control, and highest sodium recipes originated from sodium chloride in the seasoning blend. Products were packed in ice and shipped via overnight delivery to the Center for Food Safety (University of Georgia, Griffin). The temperature and pH of products were measured upon receipt.

Measurement of sodium concentration, a_w, and pH. The sodium concentration in test products was determined using inductively coupled plasma–optical emission spectroscopy at a private testing laboratory *(10, 25, 48)*. The a_w of products (5 g) was measured with an AquaLab model CX2 water activity meter (Decagon Devices, Pullman, WA). The pH was measured with an Accumet AccuCap electrode (glass body, gel-filled spear tip; Fisher Scientific, Fairlawn, NJ) and a pH meter (Denver Instrument Company, Denver, CO).

Inoculation and storage. Salads and hummus (1,000 g) containing four different concentrations of sodium were separately placed in sterile aluminum pans. The inoculum (10 ml) was deposited on the surface of test products and mixed thoroughly with a large sterile stainless steel spoon. Inoculated samples (25 g) were placed in Stomacher 400 bags (Seward Medical, London, UK), stored unsealed at 4 or 10°C for 0, 6, 13, 20, and 27 days, and analyzed for *Salmonella, L. monocytogenes,* and total aerobic microorganisms.

Microbiological analyses. In each of two replicate trails, triplicate 25-g samples of uninoculated salads and hummus containing various sodium concentrations were analyzed for the presence of *Salmonella* or *L. monocytogenes* and the population of aerobic microorganisms (aerobic plate count [APC]) on day 0 (day of inoculation). Triplicate 25-g samples of test products inoculated with *Salmonella* or *L. monocytogenes* also were analyzed on day 0 for the presence (by enrichment) and populations of these pathogens and for APCs. Triplicate 25-g samples of products inoculated with *Salmonella* or *L. monocytogenes* and stored at 4 or 10°C for 6, 13, 20, and 27 days were analyzed for both pathogens. Triplicate samples of products inoculated with *Salmonella* and stored under the same conditions were also analyzed for APCs.

TABLE 1. *Composition of delicatessen salads and hummus prepared using standard (control) recipes*

Food type	Ingredients
Potato salad (New York style)	Potatoes, mayonnaise (soybean oil, egg yolks with salt, water, vinegar, sugar, corn syrup, salt, spice, onion powder, garlic powder, calcium disodium EDTA [preservative]), carrots, celery, green peppers, onions, seasoning mix (salt, sugar, spices, potassium sorbate [preservative])
Macaroni salad (original)	Cooked enriched macaroni (water, durum semolina, niacin, ferrous sulfate, thiamine mononitrate, riboflavin, folic acid), salad dressing (soybean oil, water, sugar, vinegar, corn syrup, modified food starch, egg yolks with salt, salt, spice, onion powder, calcium disodium EDTA [preservative]), mayonnaise (soybean oil, egg yolks with salt, water, vinegar, sugar, corn syrup, salt, spice, onion powder, garlic powder, calcium disodium EDTA [preservative]), celery, pickle relish (cucumber, high fructose corn syrup, distilled vinegar, water, salt, calcium chloride, xanthan gum, natural flavors, polysorbate 80, sodium benzoate [preservative]), red peppers (with water, citric acid), onions, carrots, seasoning mix (salt, sugar, potassium sorbate [preservative]), spices, hydrolyzed corn protein, paprika (color), onion powder, garlic powder, modified cornstarch, spice extractives, extractive of paprika (color), extractive of turmeric (color), mustard (water, distilled vinegar, mustard seed, salt, turmeric)
Coleslaw (shredded)	Cabbage, mayonnaise (soybean oil, egg yolks with salt, water, vinegar, sugar, corn syrup, salt, spice, onion powder, garlic powder, calcium disodium EDTA [preservative]), salad dressing (soybean oil, water, sugar, vinegar, corn syrup, modified food starch, egg yolks with salt, salt, spice, onion powder, calcium disodium EDTA [preservative]), carrots, sugar, seasoning mix (sugar, citric acid, salt, spices, potassium sorbate [preservative]), guar and xanthan gum, sodium ascorbate (preservative), green peppers, lemon juice from concentrate (water, lemon juice concentrate, sodium bisulfite and sodium benzoate [preservatives], lemon oil), vinegar
Hummus (classic)	Chick peas (with water, salt, disodium EDTA to preserve color), olive oil, lemon juice from concentrate (water, lemon juice concentrate, sodium bisulfite and sodium benzoate [preservatives], lemon oil), tahini (sesame seeds), seasoning (salt, spices, citric acid, sodium benzoate and potassium sorbate [preservatives], garlic [with water and phosphoric acid])

To analyze samples for *Salmonella,* 225 ml of lactose preenrichment broth (LB; BD) was deposited in stomacher bags containing 25 g of sample, and the mixture was pummeled in a stomacher (Seward Medical) for 1 min at normal speed. To detect *Salmonella* in uninoculated products, quadruplicate undiluted 0.25-ml samples were surface plated on bismuth sulfite agar (BSA; BD). Plates were incubated at 37°C for 48 h and then examined for colonies typical of *Salmonella*. Quadruplicate 0.25-ml samples and duplicate 0.1-ml samples of homogenates containing LB and inoculated products were surface plated on BSA. Samples also were spiral plated (WASP2, Microbiology International, Frederick, MD); these plates were incubated at 37°C for 48 h and then examined for colonies typical of *Salmonella*.

Homogenates of LB and uninoculated or inoculated products were incubated at 37°C for 24 h. When colonies typical of *Salmonella* did not develop on BSA, the preenriched homogenates were streaked on BSA plates, incubated at 37°C for 24 h, and examined for colonies typical of *Salmonella*. For uninoculated samples and inoculated samples anticipated to have low levels of *Salmonella*, 1 ml of preenriched homogenate was added to 10 ml of tetrathionate broth (BD) and 0.1 ml of preenriched homogenate was added to 10 ml of Rappaport-Vassiliadis broth (BD). Broth cultures were incubated for 24 h at 37 and 42°C, respectively, and then streaked on BSA. Plates incubated at 37°C for 48 h were examined for colonies typical of *Salmonella*. Cells from randomly selected presumptive *Salmonella* colonies were subjected to confirmation tests using BBL Enterotube II (BD) or API 20E (bioMérieux Vitek, Hazelwood, MO) assays and a *Salmonella* latex agglutination test (Oxoid, Basingstoke, UK). The detection limit for enumerating *Salmonella* by direct plating was 10 CFU/g (1.0 log CFU/g). The detection limit by enrichment was 1 CFU/25 g.

Listeria enrichment broth (LEB; CM897, Oxoid) containing *Listeria* selective enrichment supplement (SR141, Oxoid) (225 ml) was added to each stomacher bag containing 25 g of uninoculated or inoculated salad or hummus, and the mixture was pummeled for 1 min at normal speed. Homogenates (quadruplicate 0.25-ml samples) of uninoculated products were surface plated on *Listeria* selective agar (LSA, Oxford formulation; CM856, Oxoid) containing *Listeria* selective supplement (Oxford formulation; SR140, Oxoid). Plates incubated at 37°C for 48 h were examined for presumptive *Listeria* colonies. Quadruplicate 0.25-ml samples

TABLE 2. *Sodium concentration in salads and hummus used in the challenge study*

	Sodium concn and %[a]							
	Lowest[b]		Low		Control[c]		Highest	
Food type	Concn (mg/100 g)	%	Concn (mg/100 g)	%	Concn (mg/100 g)	%	Concn (mg/100 g)	%
Potato salad (New York style)	133.1 ± 1.5	54.7	190.3 ± 1.9	78.2	243.5 ± 20.0	100	363.5 ± 22.3	149.3
Macaroni salad (original)	189.6 ± 14.9	67.5	250.6 ± 8.7	89.2	280.8 ± 1.6	100	335.6 ± 25.7	119.5
Coleslaw (shredded)	145.7 ± 11.6	66.9	198.8 ± 16.3	91.3	217.8 ± 9.7	100	272.0 ± 11.5	125.0
Hummus (classic)	263.6 ± 1.1	41.1	501.7 ± 15.9	78.2	641.5 ± 37.2	100	728.0 ± 19.6	113.5

[a] Percentage of sodium compared with amount in control (standard) recipe.
[b] No sodium added.
[c] Standard recipe.

and duplicate 0.1-ml samples of homogenates containing inoculated salad or hummus were surface plated on LSA. Samples also were spiral plated on LSA. Plates were incubated at 37°C for 48 h, and colonies typical of *L. monocytogenes* were counted. Homogenates containing uninoculated or inoculated salad or hummus were enriched at 30°C for 48 h. For samples not yielding *L. monocytogenes* by direct plating, 0.1 ml of enriched homogenate was spread on LSA. Plates were incubated at 37°C for 48 h and then examined for presumptive *Listeria* colonies. Cells from selected presumptive colonies that developed on LSA inoculated with either LEB plus sample homogenate or enriched homogenate were subjected to confirmation using an API *Listeria* assay kit (bioMérieux).

APCs were determined by surface plating LB homogenates prepared from test products that had been inoculated with *Salmonella*. Homogenates (quadruplicate 0.25-ml samples and duplicate 0.1 ml samples) were surface plated on plate count agar (PCA; BD). Undiluted homogenates were also spiral plated on PCA. Plates were incubated at 30°C for 48 h, and colonies were counted.

Statistical analysis. Populations of *Salmonella* and *L. monocytogenes* (expressed as log CFU per gram) as determined by direct plating samples of each food type were compared by sodium concentration, storage temperature, and storage time using a repeated-measures analysis of variance in the general linear model procedure (GLM) of SAS software version 9.1.3 (SAS Institute, Cary, NC). *Salmonella* and *L. monocytogenes* counts were logarithmically transformed to approximate normality. Data from three replicate samples in two replicate experiments ($n = 6$) were tested using Levene's test for homogeneity of variances. Variances between the two replicate experiments were not significantly different ($\alpha = 0.05$). Based on these findings, data from both replicate trials were pooled for each food type to obtain a set of six observations for each sampling day. A sample was considered positive when the results of the direct plating were positive or when enrichment results were positive when direct plating results were negative. The proportion of positive samples for *Salmonella* and *L. monocytogenes* was tabulated by food type, sodium concentration, storage temperature, and storage time. The percentage of samples positive for *Salmonella* or *L. monocytogenes* was compared by sodium concentration, storage temperature, and storage time using the GLM with binomial distribution and a logit link (GENMOD) procedure of SAS version 9.13.

RESULTS

Temperature of test products upon delivery from manufacturer. The temperature of the test products received at our laboratory via overnight delivery from the manufacturer ranged from 8 to 11°C.

Sodium concentration and a_w. Salads and hummus with the lowest concentrations of sodium, i.e., recipes with no added sodium, contained 41.1 to 67.5% of the sodium present in control recipes; 78.2 to 91.3% and 113.5 to 149.3% of the amount of sodium in control recipes were present in test products with low and highest concentrations, respectively (Table 2). Sodium concentrations in potato salad, macaroni salad, coleslaw, and hummus were 133 to 364, 190 to 336, 146 to 272, and 264 to 728 mg/100 g, respectively.

The a_w values of potato salad, macaroni salad, coleslaw, and hummus were 0.984 to 0.995, 0.985 to 0.995, 0.985 to 0.994, and 0.975 to 0.992, respectively. Lower values in each range are a reflection of higher sodium chloride concentration.

Changes in pH. The pH values of salads and hummus containing four different sodium concentrations, inoculated with either *Salmonella* or *L. monocytogenes,* and stored at 4 or 10°C for 0 and 27 days are listed in Table 3. The pH of test products tended to decrease with increased concentrations of sodium. Addition of sodium to potato salad (pH 5.07), macaroni salad (pH 4.47), coleslaw (pH 3.94), and hummus (pH 4.59) and inoculation with *Salmonella* (day 0) resulted in insignificant decreases in pH, i.e., by 0.12 to 0.23, 0.17 to 0.28, 0.04 to 0.15, and 0.05 to 0.12 units, respectively. Regardless of the sodium concentration, the pH decreased slightly in all products inoculated with *Salmonella* and stored at 4°C for 27 days; with the exception of macaroni salad, the same general trend was found in products stored at 10°C. The initial (day 0) mean pH of potato salad (5.13), macaroni salad (4.41), coleslaw (3.88), and hummus (4.56) to be inoculated with *L. monocytogenes* decreased by 0.18 to 0.55, 0 to 0.11, 0 to 0.05, and 0.03 to 0.18 after addition of sodium. In potato salad inoculated with *L. monocytogenes* and stored at 4°C for 27 days and in macaroni salad and coleslaw stored at 4 or 10°C for 27 days, the pH increased slightly. Changes in pH of potato salad stored at 10°C and hummus stored at 4 or 10°C either decreased or increased slightly, but changes did not appear to be correlated with sodium concentration.

Viability of *Salmonella* in salads and hummus. *Salmonella* was not detected (<1 CFU/25 g) in uninoculated salads and hummus. The mean populations, number of samples positive for *Salmonella* by enrichment, and percentage of inoculated samples positive for the pathogen in these foods containing various concentrations of sodium and stored for up to 27 days at 4 or 10°C are shown in Tables 4 and 5, respectively. Samples were analyzed for *Salmonella* within 30 min after inoculation and contained 2.02 to 2.38 log CFU/g. *Salmonella* did not grow in any of the test products regardless of the sodium concentration or storage temperature. *Salmonella* death was most rapid in coleslaw, followed in order by macaroni salad, hummus, and potato salad. Within 6 days, *Salmonella* populations decreased by up to 2.08 log CFU/g in coleslaw stored at 4°C (Table 4) or 10°C (Table 5) and was not detected (<1 CFU/25 g) by enrichment of samples stored at either temperature for 13 days. For macaroni salad stored at 4 and 10°C, *Salmonella* decreased by 0.50 to 0.78 and 0.62 to 1.02 log CFU/g, respectively, by day 6 and was not detected by enrichment on day 27 except when samples with the highest sodium concentration were stored at 4°C. *Salmonella* was quantifiable in potato salad by direct plating on day 27 regardless of the sodium concentration or storage temperature. For hummus stored at either 4 or 10°C, *Salmonella* was quantifiable in most samples through day 27; exceptions were samples with the lowest sodium concentration that were stored for 20 or 27 days, which were negative for the pathogen by enrichment.

TABLE 3. *Changes in pH of delicatessen salads and hummus as affected by inoculation with* Salmonella *or* L. monocytogenes*, sodium concentration, and storage temperature*

Food type	Sodium concn[a]	Temp (°C)	pH					
			Inoculated with *Salmonella*			Inoculated with *L. monocytogenes*		
			0 day	27 days	Change[b]	0 day	27 days	Change
Potato salad (New York style)	Lowest	4	5.07 ± 0.13	4.79 ± 0.39	−0.21	5.04 ± 0.11	5.13 ± 0.06	+0.09
		10		4.80 ± 0.37	−0.27		5.00 ± 0.05	−0.04
	Low	4	4.95 ± 0.04	4.43 ± 0.15	−0.56	4.86 ± 0.07	4.92 ± 0.11	+0.06
		10		4.29 ± 0.13	−0.66		4.94 ± 0.06	+0.08
	Control	4	4.89 ± 0.06	4.37 ± 0.71	−0.18	4.49 ± 0.04	4.56 ± 0.04	+0.07
		10		4.83 ± 0.01	+0.03		4.38 ± 0.11	−0.11
	Highest	4	4.84 ± 0.04	4.44 ± 0.12	−0.40	4.81 ± 0.06	4.95 ± 0.11	+0.14
		10		4.12 ± 0.00	−0.72		4.77 ± 0.09	−0.04
Macaroni salad (original)	Lowest	4	4.47 ± 0.03	4.32 ± 0.33	−0.15	4.21 ± 0.36	4.41 ± 0.00	+0.20
		10		4.47 ± 0.13	0.00		4.47 ± 0.06	+0.26
	Low	4	4.30 ± 0.12	4.11 ± 0.33	−0.19	4.19 ± 0.19	4.38 ± 0.04	+0.19
		10		4.49 ± 0.04	+0.19		4.36 ± 0.04	+0.17
	Control	4	4.28 ± 0.04	4.01 ± 0.63	−0.27	4.21 ± 0.18	4.35 ± 0.02	+0.14
		10		4.35 ± 0.04	+0.07		4.38 ± 0.08	+0.15
	Highest	4	4.19 ± 0.10	4.14 ± 0.37	−0.05	4.10 ± 0.12	4.27 ± 0.01	+0.16
		10		4.34 ± 0.03	+0.15		4.31 ± 0.06	+0.21
Coleslaw (shredded)	Lowest	4	3.94 ± 0.04	3.79 ± 0.07	−0.15	3.88 ± 0.08	3.94 ± 0.16	+0.06
		10		3.81 ± 0.13	−0.13		3.96 ± 0.07	+0.08
	Low	4	3.85 ± 0.02	3.78 ± 0.12	−0.07	3.85 ± 0.06	3.87 ± 0.03	+0.02
		10		3.75 ± 0.19	−0.10		3.91 ± 0.01	+0.06
	Control	4	3.90 ± 0.04	3.74 ± 0.15	−0.16	3.91 ± 0.02	3.92 ± 0.01	+0.01
		10		4.03 ± 0.00	+0.13		4.01 ± 0.06	+0.10
	Highest	4	3.79 ± 0.03	3.74 ± 0.16	−0.05	3.83 ± 0.12	3.96 ± 0.01	+0.13
		10		3.59 ± 0.26	−0.20		3.97 ± 0.01	+0.14
Hummus (classic)	Lowest	4	4.59 ± 0.06	4.48 ± 0.09	−0.11	4.56 ± 0.08	4.55 ± 0.10	−0.10
		10		4.57 ± 0.12	−0.02		4.61 ± 0.04	+0.05
	Low	4	4.47 ± 0.14	4.11 ± 0.18	−0.36	4.51 ± 0.06	4.46 ± 0.12	−0.05
		10		4.37 ± 0.19	−0.10		4.50 ± 0.05	−0.01
	Control	4	4.54 ± 0.13	4.25 ± 0.57	−0.29	4.53 ± 0.01	4.54 ± 0.03	−0.01
		10		4.45 ± 0.11	−0.09		NM[c]	
	Highest	4	4.47 ± 0.12	4.10 ± 0.43	−0.37	4.38 ± 0.19	4.39 ± 0.17	+0.01
		10		4.32 ± 0.00	−0.15		4.50 ± 0.16	+0.12

[a] See Table 2 for sodium concentrations in test products.
[b] Change, change in pH during 27-day storage period.
[c] NM, pH was not measured.

Results of the analysis of mean *Salmonella* populations by test product and storage temperature over the 27-day sampling period are shown are Table 6. For potato salad and coleslaw, mean *Salmonella* populations were largely unaffected by sodium concentration. Compared with macaroni salad with control and highest concentrations of sodium stored at 4°C, counts were significantly lower ($P < 0.05$) in salad containing the lowest concentration of sodium. Survival of *Salmonella* in macaroni salad was unaffected by sodium when salad was stored at 10°C. Mean populations were significantly ($P < 0.05$) lower in hummus containing the lowest sodium concentration and stored at 4 or 10°C compared with hummus containing added sodium. However, there was no significant difference ($P > 0.05$) in percentage of samples that were positive for *Salmonella* in each test product among sodium concentrations, storage temperatures, and storage periods.

Viability of *L. monocytogenes* in salads and hummus. *L. monocytogenes* was not detected (<1 CFU/25 g) in uninoculated salads and hummus. The mean populations of *L. monocytogenes* in these foods containing various sodium concentrations and stored for up to 27 days at 4 and 10°C are shown in Tables 7 and 8, respectively. The initial population (0 day), which was determined within 30 min after inoculation, was 1.86 to 2.23 log CFU/g. *L. monocytogenes* did not grow in any of the test products regardless of sodium concentration or storage temperature, but with the exception of the control coleslaw stored at 10°C, this pathogen was detected (>1.0 log CFU/g) by direct plating of samples of all products stored for 27 days. As with *Salmonella,* death of *L. monocytogenes* occurred most rapidly in coleslaw and most slowly in potato salad. Populations decreased by 1.21 to 1.59 and 1.42 to 2.06 log CFU/g in coleslaw stored for 27 days at 4°C (Table 7) and

TABLE 4. *Recovery of* Salmonella *from inoculated delicatessen salads and hummus stored at 4°C for up to 27 days as affected by sodium concentration*

		Salmonella recovered or detected after storage for:											
		0 days	6 days			13 days			20 days			27 days		
Food type	Sodium concn[a]	Population (log CFU/g)	Population (log CFU/g)	Enrichment[b]	% positive samples[c]	Population (log CFU/g)	Enrichment	% positive samples	Population (log CFU/g)	Enrichment	% positive samples	Population (log CFU/g)	Enrichment	% positive samples
Potato salad (New York style)	Lowest	2.18	2.30		100	1.96		100	1.69		100	0.80	2/2	100
	Low	2.23	2.27		100	2.18		100	1.74		100	1.01		100
	Control	2.36	2.22		100	2.12		100	2.11		100	1.30		100
	Highest	2.40	2.19		100	2.14		100	1.53		100	0.97	0/3	50
Macaroni salad (original)	Lowest	2.28	1.78		100	0.80	0/2	66.7	0.25	0/5	16.7	0	0/6	0
	Low	2.27	1.49		100	1.28	0/1	83.3	0.58	0/3	50	0	0/6	0
	Control	2.31	1.72		100	1.44		100	0.65	0/3	50	0	0/6	0
	Highest	2.34	1.79		100	1.30	1/1	100	1.04	1/1	100	0.16	1/6	16.7
Coleslaw (shredded)	Lowest	2.11	0.33	0/4	33.3	<1.00	0/6	0	<1.00	0/6	0	<1.00	0/6	0
	Low	2.02	0.17	0/5	16.7	<1.00	0/6	0	<1.00	0/6	0	<1.00	0/6	0
	Control	2.25	0.17	0/5	16.7	<1.00	0/6	0	<1.00	0/6	0	<1.00	0/6	0
	Highest	2.07	<1.00	0/6	0	<1.00	0/6	0	<1.00	0/6	0	<1.00	0/6	0
Hummus (classic)	Lowest	2.25	1.33		100	0.33	0/4	33.3	<1.00	0/6	0	<1.00	0/6	0
	Low	2.34	1.68		100	1.31		100	1.03	3/3	100	0.64	3/4	83.3
	Control	2.38	1.67		100	1.31	2/2	100	0.76	2/2	100	0.69	3/3	100
	Highest	2.22	1.46		100	0.89	1/3	66.7	0.72	0/3	50	0.54	1/4	50

[a] See Table 2 for sodium concentrations in test products.

[b] Enrichment, number of enriched samples positive for *Salmonella*/number of samples analyzed. Values are shown only for the number of samples (one to six) from triplicate samples analyzed in two replicate trials ($n = 6$). Samples were enriched when negative results were obtained by direct plating. Limit of detection by enrichment was 1 CFU/25 g.

[c] % positive samples, frequencies of samples ($n = 6$) positive for *Salmonella* by direct plating or enrichment.

TABLE 5. *Recovery of* Salmonella *from inoculated delicatessen salads and hummus stored at 10°C for up to 27 days as affected by sodium concentration*

		Salmonella recovered or detected after storage for:											
		0 days	6 days			13 days			20 days			27 days		
Food type	Sodium concn[a]	Population (log CFU/g)	Population (log CFU/g)	Enrichment[b]	% positive samples[c]	Population (log CFU/g)	Enrichment	% positive samples	Population (log CFU/g)	Enrichment	% positive samples	Population (log CFU/g)	Enrichment	% positive samples
Potato salad (New York style)	Lowest	2.18	2.03		100	1.93	0/2	100	0.99	0/2	66.7	0.57	1/4	50
	Low	2.23	2.22		100	0.98		66.7	0.84	0/3	50	0.17	0/5	16.7
	Control	2.36	2.25		100	1.93		100	2.00		100	0.94		100
	Highest	2.40	2.18		100	1.80		100	0.51	0/4	33.3	0.17	0/5	16.7
Macaroni salad (original)	Lowest	2.28	1.43		100	1.21	0/5	16.7	<1.00	0/6	0	<1.00	0/6	0
	Low	2.27	1.64		100	0.17	0/5	16.7	<1.00	0/6	0	<1.00	0/6	0
	Control	2.31	1.29	1/1	100	0.33	0/4	33.3	<1.00	0/6	0	<1.00	0/6	0
	Highest	2.34	1.72		100	0.17		16.7	<1.00	0/6	0	<1.00	0/6	0
Coleslaw (shredded)	Lowest	2.11	0.17	0/5	16.7	<1.00	0/6	0	<1.00	0/6	0	<1.00	0/6	0
	Low	2.02	<1.00	0/6	0	<1.00	0/6	0	<1.00	0/6	0	<1.00	0/6	0
	Control	2.25	0.17	0/6	16.7	<1.00	0/6	0	<1.00	0/6	0	<1.00	0/6	0
	Highest	2.07	<1.00	0/6	0	<1.00	0/6	0	<1.00	0/6	0	<1.00	0/6	0
Hummus (classic)	Lowest	2.25	0.57	1/4	50	0.17	0/5	16.7	<1.00	0/6	0	<1.00	0/6	0
	Low	2.34	1.62		100	1.13	3/3	100	0.38	1/3	66.7	0.32	2/4	66.7
	Control	2.38	1.70		100	1.20	2/2	100	0.70	2/2	100	0.38	1/4	50
	Highest	2.22	1.19	2/2	100	0.90	2/3	83.3	0.54	0/3	50	0.46	0/4	33.3

[a] See Table 2 for sodium concentrations in test products.

[b] Enrichment, number of enriched samples positive for *Salmonella*/number of samples analyzed. Values are shown only for the number of samples (one to six) from triplicate samples analyzed in two replicate trials ($n = 6$). Samples were enriched when negative results were obtained by direct plating. Limit of detection by enrichment was 1 CFU/25 g.

[c] % positive samples, frequencies of samples ($n = 6$) positive for *Salmonella* by direct plating or enrichment.

TABLE 6. *Populations of* Salmonella *recovered from inoculated delicatessen salads and hummus stored at 4 and 10°C for 27 days as affected by sodium concentration*

Food type	Storage temp (°C)	*Salmonella* recovered (log CFU/g)[a] at various sodium concn[b]: Lowest	Low	Control	Highest	*P* value[c]
Potato salad (New York style)	4	1.79 A	1.89 A	2.02 A	1.84 A	0.17
	10	1.38 AB	1.05 C	1.79 A	1.17 B	<0.001
Macaroni salad (original)	4	1.02 C	1.12 BC	1.22 AB	1.33 A	0.02
	10	0.78 A	0.81 A	0.79 A	0.85 A	0.74
Coleslaw (shredded)	4	0.49 A	0.44 A	0.48 A	0.41 A	0.44
	10	0.45 A	0.40 A	0.48 A	0.41 A	0.26
Hummus (classic)	4	0.78 C	1.40 A	1.36 AB	1.17 B	<0.001
	10	0.60 C	1.16 AB	1.27 A	1.06 B	<0.001

[a] Values are means. Means were compared using least square means in the PROC GLM of SAS with repeated measures. Within each row, means followed by the same letter are not significantly different ($P > 0.05$).
[b] See Table 2 for sodium concentrations in test products.
[c] *P* values were adjusted for the repeated measurements dependency within each food type.

10°C (Table 8), respectively. In contrast, reductions of only 0.34 to 0.81 and 0.54 to 0.96 log CFU/g occurred in potato salad stored for 27 days at 4 and 10°C, respectively.

The mean populations of *L. monocytogenes* by test product and storage temperature over the 27-day sampling period are shown in Table 9. Compared with recipes with added sodium, populations were generally lower (and in some instances significantly lower) in test products with lowest sodium content than in products with added sodium, regardless of the storage temperature. However, there was no significant difference ($P > 0.05$) in percentage of samples of each test product positive for *L. monocytogenes* among sodium concentrations, by storage temperature, over the 27-day sampling period.

APCs in salads and hummus. APCs for salads and hummus inoculated with *Salmonella* and stored at 4°C (Fig. 1) and 10°C (Fig. 2) were determined. Initial (0 day) APCs in potato salad (2.16 to 2.44 log CFU/g), macaroni salad (2.28 to 2.44 log CFU/g), and coleslaw (1.96 to 2.67 log) largely reflect initial *Salmonella* populations (Tables 4 and 5). Initial APCs in hummus (2.73 to 3.12 log CFU/g) were about 1.4 log CFU/g higher than those for *Salmonella* (1.46 to 1.68 log CFU/g), indicating that higher levels of background microbiota were present in hummus compared with those in the salads. Small decreases in APCs during the initial days of storage were attributed largely to death of *Salmonella*. The sodium concentration in test products did not markedly affect the survival or growth of naturally occurring microbiota over the 27-day storage period.

DISCUSSION

Sodium chloride is used to enhance sensory quality and/or to preserve foods. Although health benefits may result from reductions in sodium intake, these benefits must be weighed against potential risks associated with enhancement of conditions for survival and growth of foodborne pathogens. To the best of our knowledge, the present study is the first to be specifically focused on determining the effects of sodium concentration in prepared (delicatessen) salads and hummus on the behavior of *Salmonella* and *L. monocytogenes* as affected by temperature over a 27-day storage period.

Regardless of the sodium concentration or storage temperature, *Salmonella* and *L. monocytogenes* died more rapidly in coleslaw than in other test products. This effect is attributed to the initial low mean pH of all recipes of coleslaw (3.87) compared with the pH of potato salad (4.80 to 4.94), hummus (4.50 to 4.52), and macaroni salad (4.18 to 4.31). Inactivation of *Salmonella* was slowest in potato salad, which had the highest initial mean pH among the four test products, and fastest in coleslaw, which had the lowest pH. *Salmonella* can grow at the pH range of the potato salad, hummus, and macaroni salad used in the study but is stressed at 4 and 10°C at acidic pHs. Kurihara et al. *(27)* reported that *Salmonella* Enteritidis grew rapidly in mayonnaise-based potato salad (pH 5.72) stored at 25°C for up to 30 h. Slight growth occurred at 10°C. Erickson et al. *(13)* observed a 2-log decline in *Salmonella* in macaroni salad prepared using real, reduced-calorie, and reduced-fat and -calorie mayonnaise. The initial pH (6 h after preparation) of salads was 4.54 to 4.62 but decreased to 3.94 to 4.11 within 2 days at 12.8°C. Decreases in pH corresponded with increases in lactic acid bacteria. In our study, the pH of macaroni salad at the time of inoculation with *Salmonella* was 4.19 to 4.47 and decreased to 4.01 to 4.32 during storage of salad for 27 days at 4°C. The decrease in pH also may have been caused by growth of lactic acid bacteria. In both studies, the acidic environment in macaroni salad undoubtedly contributed to inactivation of *Salmonella*.

Populations of *Salmonella* and *L. monocytogenes* decreased in all test products, regardless of food type, sodium concentration, storage temperature, or storage time. Small yet significant reductions in *Salmonella* occurred in macaroni salad stored at 4°C and hummus with the lowest sodium concentration (i.e., no sodium added) stored at 4 or 10°C. However, differences in populations of *Salmonella* in all food types with various sodium concentrations were small and should be interpreted with caution. Low

TABLE 7. *Recovery of* L. monocytogenes *from inoculated delicatessen salads and hummus stored at 4°C for up to 27 days as affected by sodium concentration*

		L. monocytogenes recovered or detected after storage for:											
		0 days	6 days		13 days			20 days			27 days		
Food type	Sodium concn[a]	Population (log CFU/g)	Population (log CFU/g)	% positive samples[b]	Population (log CFU/g)	Enrichment[c]	% positive samples	Population (log CFU/g)	Enrichment	% positive samples	Population (log CFU/g)	Enrichment	% positive samples
Potato salad (New York style)	Lowest	2.01	1.73	100	1.43		100	1.18	2/2	100	1.23		100
	Low	2.10	1.83	100	1.70		100	1.48		100	1.29		100
	Control	2.04	1.63	100	1.55		100	1.16	2/2	100	1.30	1/1	100
	Highest	2.02	1.92	100	1.75		100	1.60		100	1.68		100
Macaroni salad (original)	Lowest	2.01	1.54	100	1.22	1/1	100	1.08	3/3	100	0.97	4/4	100
	Low	1.86	1.50	100	1.04	1/1	100	1.02	4/4	100	0.98	2/2	100
	Control	2.09	1.29	100	1.01	5/5	100	1.11	3/3	100	0.96	5/5	100
	Highest	2.01	1.35	100	1.32	1/1	100	1.12	1/1	100	1.03	2/2	100
Coleslaw (shredded)	Lowest	2.22	1.54	100	0.97	4/4	100	0.95	6/6	100	0.63	4/6	66.7
	Low	2.23	1.58	100	0.95	6/6	100	1.01	5/5	100	0.95	6/6	100
	Control	2.00	1.61	100	0.98	3/3	100	0.95	6/6	100	0.79	5/6	83.3
	Highest	2.22	1.84	100	1.28		100	0.98	3/3	100	0.95	6/6	100
Hummus (classic)	Lowest	2.00	1.53	100	0.96	5/5	100	0.95	6/6	100	0.95	6/6	100
	Low	2.02	1.63	100	1.03	2/2	100	0.95	6/6	100	0.95	6/6	100
	Control	2.04	1.76	100	1.29	1/1	100	1.02	4/4	100	0.96	5/5	100
	Highest	1.86	1.65	100	1.45	1/1	100	1.29	2/2	100	1.03	3/3	100

[a] See Table 2 for sodium concentrations in test products.

[b] % positive samples, frequencies of samples ($n = 6$) positive for *L. monocytogenes* by direct plating or enrichment.

[c] Enrichment, number of enriched samples positive for *L. monocytogenes*/number of samples analyzed. Values are shown only for the number of samples (one to six) from triplicate samples analyzed in two replicate trials ($n = 6$). Samples were enriched when negative results were obtained by direct plating. Limit of detection by enrichment was 1 CFU/25 g.

TABLE 8. *Recovery of* L. monocytogenes *from inoculated delicatessen salads and hummus stored at 10°C for up to 27 days as affected by sodium concentration*

		L. monocytogenes recovered or detected after storage for:												
		0 days	6 days			13 days			20 days			27 days		
Food type	Sodium concn[a]	Population (log CFU/g)	Population (log CFU/g)	Enrich-ment[b]	% positive samples[c]	Population (log CFU/g)	Enrich-ment	% positive samples	Population (log CFU/g)	Enrich-ment	% positive samples	Population (log CFU/g)	Enrich-ment	% positive samples
Potato salad (New York style)	Lowest	2.01	1.67		100	1.58		100	1.42		100	1.21		100
	Low	2.10	1.88		100	1.74		100	1.54		100	1.56	1/1	100
	Control	2.04	1.74		100	1.35		100	1.24	2/2	100	1.08	2/2	100
	Highest	2.02	1.88		100	1.65		100	1.60		100	1.41		100
Macaroni salad (original)	Lowest	2.01	1.44	1/1	100	1.28		100	0.97	4/4	100	0.96	5/5	100
	Low	1.86	1.56		100	1.06	2/2	100	0.98	3/3	100	1.03	3/3	100
	Control	2.09	1.67		100	1.55		100	1.08	3/3	100	0.96	5/5	100
	Highest	2.01	1.69		100	1.44	1/1	100	1.08	3/3	100	1.03	2/2	100
Coleslaw (shredded)	Lowest	2.22	1.73		100	0.96	5/5	100	0.16	1/6	16.7	0.17	0/5	16.7
	Low	2.23	1.62		100	1.11	3/3	100	0.79	5/6	83.3	0.17	0/5	16.7
	Control	2.00	1.50		100	0.98	2/2	100	0.95	6/6	100	0	0/6	0
	Highest	2.22	1.71		100	1.29	1/1	100	0.97	4/4	100	0.80	4/5	83.3
Hummus (classic)	Lowest	2.00	1.59		100	1.22	1/1	100	1.02	4/4	100	0.95	6/6	100
	Low	2.02	1.89		100	1.55		100	1.24	3/3	100	0.96	5/5	100
	Control	2.04	1.84		100	1.65		100	1.36	2/2	100	1.03	3/3	100
	Highest	1.86	1.56		100	1.55	1/1	100	1.41		100	1.10	3/3	100

[a] See Table 2 for sodium concentrations in test products.

[b] Enrichment, number of enriched samples positive for *L. monocytogenes*/number of samples analyzed. Values are shown only for the number of samples (one to six) from triplicate samples analyzed in two replicate trials ($n = 6$). Samples were enriched when negative results were obtained by direct plating. Limit of detection by enrichment was 1 CFU/25 g.

[c] % positive samples, frequencies of samples ($n = 6$) positive for *L. monocytogenes* by direct plating or enrichment.

TABLE 9. *Mean populations of* L. monocytogenes *recovered from inoculated delicatessen salads and hummus stored at 4 and 10°C for 27 days as affected by sodium concentration*

Food type	Storage temp (°C)	*L. monocytogenes* recovered (log CFU/g)[a] at various sodium concn[b]: Lowest	Low	Control	Highest	*P* value[c]
Potato salad (New York style)	4	1.52 B	1.67 AB	1.54 B	1.79 A	0.002
	10	1.58 BC	1.75 A	1.49 C	1.71 AB	0.001
Macaroni salad (original)	4	1.36 A	1.28 A	1.29 A	1.37 A	0.320
	10	1.33 B	1.30 B	1.47 A	1.45 A	0.003
Coleslaw (shredded)	4	1.26 B	1.34 B	1.27 B	1.45 A	0.002
	10	1.05 C	1.18 B	1.09 BC	1.40 A	<0.001
Hummus (classic)	4	1.20 C	1.41 B	1.47 A	1.40 B	0.004
	10	1.36 B	1.53 A	1.58 A	1.49 AB	0.010

[a] Values are means. Means were compared using least square means in the PROC GLM of SAS with repeated measures. Within each row, means followed by the same letter are not significantly different ($P > 0.05$).
[b] See Table 2 for sodium concentrations in test products.
[c] *P* values were adjusted for the repeated measurements dependency within each food type.

concentrations of sodium chloride stimulate the growth of *Salmonella (40, 50),* and this stimulation is more pronounced at temperatures lower than those optimal for growth *(35).* Results from our study suggest that in the acid-stress environments in mayonnaise-based salads and hummus, the addition of sodium at levels not exceeding those in the standard recipe also appears to protect *Salmonella* against inactivation at refrigeration temperatures.

As with *Salmonella,* survival of *L. monocytogenes* was poorest in coleslaw among the four types of test foods. However, the ability of *L. monocytogenes* to survive was much greater than that of *Salmonella* in all test products. With the exception of the control coleslaw stored at 10°C, *L. monocytogenes* died slowly but was still detectable in all products for 27 days. Other researchers have reported reductions in *L. monocytogenes* in coleslaw stored at refrigeration temperatures. Burnett et al. *(7)* observed that *L. monocytogenes* decreased by 1.2 and 2.5 log CFU/g in coleslaw (pH 4.5) stored at 5 and 10°C, respectively, for 14 days. An initial *L. monocytogenes* population of 5 log CFU/g in coleslaw (pH 4.0) decreased to an undetectable level after storage for 5 days at 4, 15, or 25°C *(15).* Coleslaw at pH 5.0 was inhibitory at all three storage temperatures. Populations decreased when coleslaw at pH 6.0 was stored at 4 or 15°C, whereas at 25°C counts increased initially and remained constant for 25 days. In contrast, *L. monocytogenes* has been reported to grow on raw shredded *(3)* and chopped *(20)* cabbage stored at 5°C. Sodium chloride was more inhibitory to *L. monocytogenes* as the pH of TSB decreased from 7.4 to 4.6 and the temperature decreased from 30 to 5°C *(36).* The experimental design of our study did not allow these potential relationships to be evaluated across test products.

Among the test products, *L. monocytogenes* survived at highest populations in potato salad. Regardless of sodium

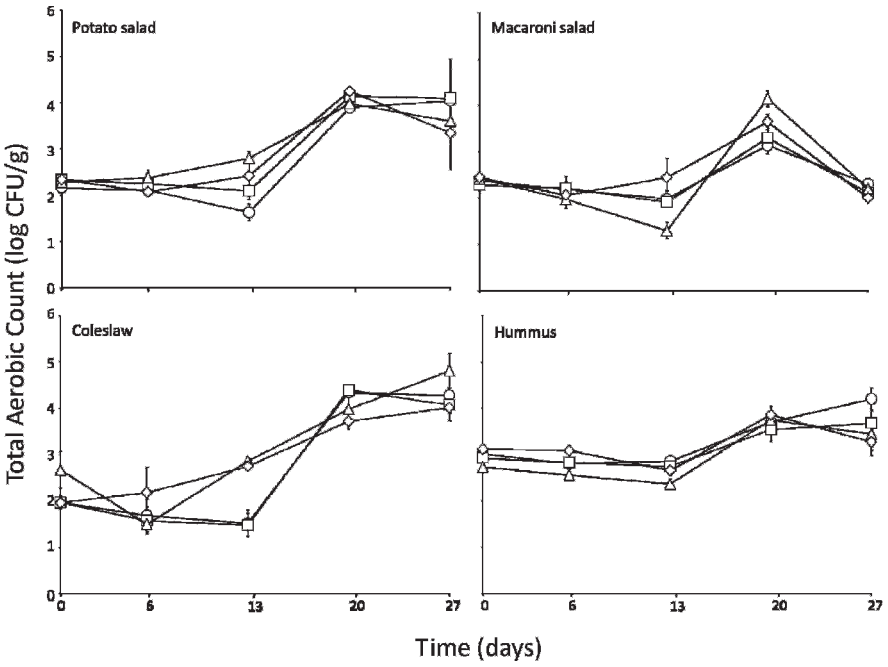

FIGURE 1. *Aerobic plate counts (APCs) for delicatessen salads and hummus inoculated with* Salmonella *and stored at 4°C for up to 27 days as affected by sodium concentration (see Table 2).*

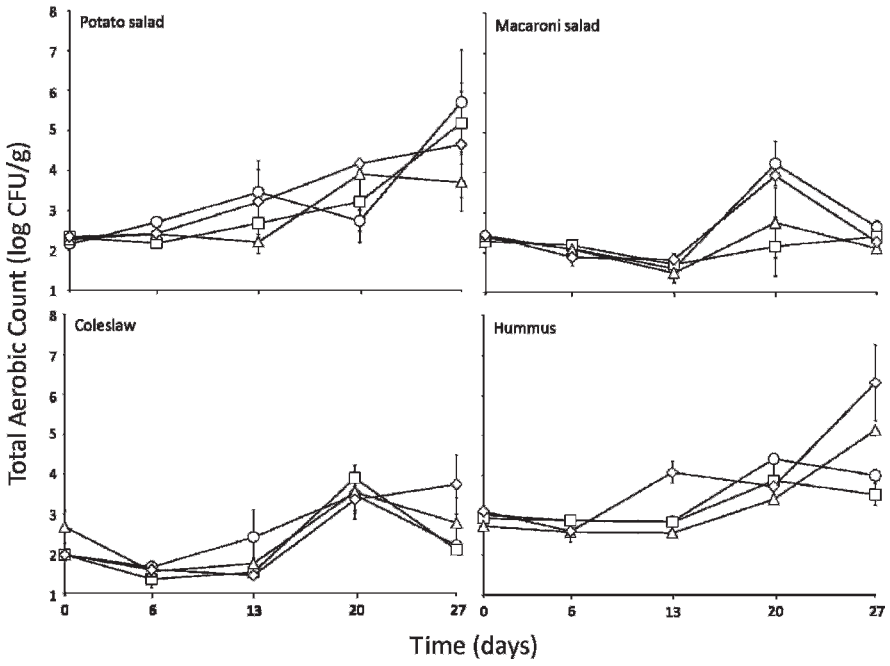

FIGURE 2. *Aerobic plates counts (APCs) for delicatessen salads and hummus inoculated with* Salmonella *and stored at 10°C for up to 27 days as affected by sodium concentration (see Table 2).*

concentration or storage temperature, reductions of less than 0.96 log CFU/g occurred during the 27-day storage period. In contrast, Hwang *(23)* reported that an initial *L. monocytogenes* population of ca. 2 log CFU/g decreased to <2 CFU/g in potato salad formulated with mayonnaise (pH 4.6) and stored at 8°C for 15 days or at 12°C for 3 days. In potato salad formulated with mayonnaise at pH 3.8, populations decreased to <2 CFU/g within 10 days at 4°C, 7 days at 8°C, and 3 days at 12°C. The pH of potato salad containing mayonnaise at pH 4.6 or 3.8 was not reported. Meaningful comparisons of the behavior of *L. monocytogenes* in that study with those observed in our study are therefore difficult. The initial pH of potato salad used in our study was 4.84 to 5.07, which aside from other potential contributing factors undoubtedly favored survival compared with that in other test products with initial lower pHs.

In our study, survival of *L. monocytogenes* in macaroni salad and hummus was intermediate to that in coleslaw and potato salad; the pH of macaroni salad and hummus also was intermediate. Erickson et al. *(13)* studied the behavior of *L. monocytogenes* in macaroni salad (pH 4.54 to 4.62) formulated with real and reduced-calorie mayonnaise and found that the initial population of 3 log CFU/g remained constant in salad stored at 4°C for 10 days. In contrast, we observed reductions of 0.36 to 0.80 and 0.69 to 1.08 log CFU/g in macaroni salad (initial population was 1.86 to 2.09 log CFU/g and initial pH was 4.01 to 4.21) stored at 4°C for 6 and 13 days, respectively.

In summary, although some of the mean populations of *Salmonella* and *L. monocytogenes* were significantly lower in salads and hummus with reduced sodium concentrations, the numerical differences in values were small and may not be biologically meaningful. A clear relationship exists between decreased pH and increased rates of inactivation of the two pathogens in salads and hummus, regardless of sodium concentration or storage temperature. We conclude that sodium concentrations ranging from 133 to 364, 190 to 336, 146 to 272, and 265 to 728 mg/100 g in potato salad, macaroni salad, coleslaw, and hummus recipes, respectively, have little or no effect on the behavior of *Salmonella* and *L. monocytogenes* when products are stored at 4 or 10°C for up to 27 days.

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