Environmental Conditions for Pathogenic Bacterial Growth

Microorganism	Temp. range for growth	pH range for growth	Min. water activity for growth	Growth (doubling time)	Death rate (90% reduction time)
1. Infective Microorganisms					
Yersinia enterocolitica	32°-111°F 0°-44°C	4.6-9.0			0.24-0.96 min. @ 145°F, 62.8°C
Listeria monocytogenes	32°-112°F 0°-44°C	4.5-9.5		7.5 days @ 32°F, 0°C	4.83 min @ 136°F, 57.8°C
				41 min. @ 95°F, 35°C	2.85 min. @ 140°F, 60°C
Vibrio parahaemolyticus	41°-109.4°F 5°-43°C	4.8-11.0	0.937		.08-48.2 min. @ 116°F, 47°C 1.7 min. @ 140°F, 60°C
***Salmonella* spp.**	35.6°-114°F 2.0°-45.6°C	4.1-9.0	0.92		5.3-48.3 min. @ 134.6°F, 57°C
Campylobacter jejuni	90°-113°F 32°-45°C	4.9-8.0		50 min. @ 107.6°F, 42°C	12-21 sec. @ 137°F 58.3°C
2. Toxin Producers or Spore-formers					
***Clostridium botulinum,* Type E and other non-proteolytic strains**	38°-113°F 3.3°-45°C	5.0-9.0	0.97		
Spores:					0.49-0.74 min. @ 180°F, 82.2°C
Toxin:					5 min. @ 185°F, 85°C
Staphylococcus aureus	43.8°-122°F 6.5°-50°C	4.5-9.3	0.83		
Vegetative cells:					5.25-7.82 min @ 140°F, 60°C
Toxin production	50°-114.8°F 10°-46°C	5.15-9.0	0.86		
Toxin:					134.2 min. @ 210°F, 98.9°C
Bacillus cereus	39.2°-122°F 4.0°-50°C	4.35-9.3	0.912	29 min. @ 73.4°F, 23°C	
Vegetative cells:					1 min. @ 140°F, 60°C
Spores:					2.7-3.1 min. @ 212°F, 100°C
Diarrheal toxin:					5 min. @ 133°F, 56.1°C

Emetic toxin:					Stable 90 min. at 258.8°F, 126°C
***Clostridium botulinum,* Type A and proteolytic B strains**	50°-118°F 10°-47.8°C	4.6-9.0	0.94	1.2 hours @ 68°F, 20°C	
Spores:					0.14-0.23 min. @ 250°F, 121.1°C
Toxin:					5 min. @ 185°F, 85°C
Clostridium perfringens	59°-127.5°F 15°-52.3°C	5.0-8.3	0.95	7.2 min 105.8°F, 41°C	
Vegetative cells:					7.2 min @ 138°F, 59°C
Spores:					26-31.4 min. @ 210°F, 98.9°C

REFERENCES

Angelotti, R., Foter, M.J. and Lewis, K.H. 1961. Time-temperature effects on *Salmonellae* and *Staphylococci*in foods. II. Behavior at warm holding temperatures. Am. J. Pub. Health 51(1):83-88.

Angelotti, R. Foter, M.J., and Lewis, K.H. 1961. Time-temperature effects on *Salmonellae* and *Staphylococci*in foods. III. Thermal death time studies. Appl. Microbiol. 9(4):308-315.

Beuchat, L.R. 1982. *Vibrio parahaemolyticus*: public health significance. Food Technol. 36(3):80-83.

Beuchat, L.R. and Worthington, R. E. 1976. Relationship between heat resistance and phospholipid fatty acid composition of *Vibrio parahaemolyticus*. Appl. Environ. Microbiol. 31(3):389-394.

Bergdoll, M.S. 1989. *Staphylococcus aureus*. In "Foodborne Bacterial Pathogens." pp. 463-523. Marcel Dekker, Inc., New York, NY.

Bradshaw, J.G., Peeler, J.T., and Twedt, R.M. 1977. Thermal inactivation of ileal loop-reactive *Clostridum perfringens* type A strains in phospate buffer and beef gravy. Appl. Environ. Microbiol. 34(3):280-284.

Bradshaw, J.G., Peeler, J.T., Corwin, J.J., Hunt, J.M., Tierney, J.T., Larkin, E.P., and Twedt, R.M. 1985. Thermal resistance of *Listeria monocytogenes* in milk. J. Food Protect. 48(9):743-745.

Bryan, F.L., Bartleson, C.A. and Christopherson, N. 1981. Hazard analyses, in reference to *Bacillus cereus*, of boiled and fried rice in Cantonese-Style restaurants. J. Food Protect. 44(7):500-512.

Catsaras, M. and Grebot, D. 1984. Bull. Acad. Vét. France. 57:501-512. [Cited by D'Aoust, J.Y. (1989).*Salmonella* in "Foodborne Bacterial Pathogens." Doyle, M.P., Ed. p. 335. Marcel Dekker, Inc., New York, N.Y.]

Clark, A.G., and Bueschkens, D.H. 1986. Survival and growth of *Campylobacter jejuni* in egg yolk and albumen. J. Food Protect. 49(2): 135-141.

Doyle, M.P. and Roman, D.J. 1981. Growth and survival of *Campylobacter fetus* susp. *jejuni* as a function of temperature and pH. J. Food Protect. 44(8):596-601.

Gibson, A.M., Bratchell, N. and Roberts, T.A. 1987. The effect of sodium chloride and temperature on the rate and extent of growth of *Clostridium botulinum* type A in pasteurized pork slurry. J. Appl. Microbiol. 62:479-490.

Grau, F. H., and Vanderline, P.B. 1990. Growth of *Listeria monocytogenes* on vacuum-packaged beef. J. Food Protect. 53(9):739-741; 746.

Halpin-Dohnalek, M.I. and Marth, E.H. 1989. *Staphylococcus aureus*: Production of extracellular compounds and behavior in foods - a review. J. Food Protect. 52(4):267-282.

Hanna, M.O. Stewart, J.C., Zink, D.L., Carpenter, Z.L., and Vanderzant, C. 1977. Development of *Yersinia enterocolitica* on raw and cooked beef and pork at different temperatures. J. Food Sci. 42(5): 1180-1184.

Hauschild, A.H.W. 1989. *Clostridium botulinum*. In "Foodborne Bacterial Pathogens." Doyle, M.P. ed. pp. 110-189. Marcel Dekker, New York, NY.

ICMSF. 1980. "Microbial Ecology of Foods." Vol. I. Factors affecting life and death of microorganisms. p. 101. Academic Press, New York, N.Y.

Johnson, K. 1986. Personal communication. In Snyder, O.P. 1991. HACCP-based safety and quality assured pasteurized-chilled food systems, developing and operating HACCP-based TQM programs. Hospitality Institute of Technology and Management. St. Paul, MN.

Johnson, K.M. Nelson, C.L., and Busta, F.F. 1983. Influence of temperature on germination and growth of spores of emetic and diarrheal strains of *Bacillus cereus* in a broth medium and in rice. J. Food Sci. 48(1):286-287.

Kang, C.K., Woodburn, M., Pagenkopf, A., and Cheney, R. 1969. Growth, sporulation and germination of*Clostridium perfringens* in media of controlled water activity. Appl. Microbiol. 18(5):798-805.

Khan, M.A., Palmas, C.V., Seaman, A., and Woodbine, M. 1972. Survival versus growth of a facultative psychrotroph. Acta Microbiol. Acad. Sci. Hung. 19:357-362.

Koidis, P. and Doyle, M.P. 1983. Survival of *Campylobacter jejuni* in fresh and heated red meat. J. Food Protect. 46(9):771-774.

Kramer, J.M. and Gilbert, R.J. 1989. *Bacillus cereus* and other Bacillus species. In "Foodborne Bacterial Pathogens." Doyle, M.P., Ed. pp. 21-70. Marcel Dekker, New York, NY.

Labbe, R. 1989. *Clostridium perfringens*. In "Foodborne Bacterial Pathogens." Doyle, M.P. Ed., pp. 191-234. Marcel Dekker, Inc., New York, N.Y.

Lee, J.S. 1973. What seafood processors should know about *Vibrio parahaemolyticus*. J. Milk Food Technol. 36(8):405-408.

Lovett, J. 1989. *Listeria monocytogenes*. In "Foodborne Bacterial Pathogens." Doyle, M.P., Ed. pp. 283-310. Marcel Dekker, New York, NY.

Lovett, J., Bradshaw, J.G., and Peeler, J.T. 1982. Thermal inactivation of *Yersinia enterocolitica* in milk. Appl. Environ. Microbiol. 44(2):517-519.

Lynt, R.K., Kautter, D.A., and Solomon, H.M. 1982. Differences and similarities among proteolytic and nonproteolytic strains of *Clostridium botulinum* types A, B, E, and F: a review. J. Food Protect. 45(5):466-474; 478.

Morita, T.N. and Woodburn, M.J. 1977. Stimulation of *Bacillus cereus* by protein in cooked rice combinations. J. Food Sci. 42(5):1232-1235.

Read, Jr., R.B. and Bradshaw, J.G. 1966. Staphylococcal enterotoxin B thermal inactivation in milk. J. Dairy Science. 49(2):202-203.

Rosenow, E.M., and Marth., E.H. 1987. Growth of *Listeria monocytogenes* in skim, whole and chocolate milk, and in whipping cream during incubation at 4, 8, 13, 21 and 35°C. J. Food Protect. 50(6):452-459; 463.

Rosenow, E.M. and Marth, E.H. 1987. *Listeria*, listeriosis and dairy foods: a review. Cultured Dairy Products J. 22(4):13-17.

Roy, R.J., Busta, F.F., and Thompson, D.R. 1981. Thermal inactiviation of *Clostridium perfringens* after growth at several constant and linearly rising temperatures. J. Food Sci. 46(5):1586-1591.

Schneusner, D.L., Hood, L.L. and Harmon, L.G. 1973. Effect of temperature and pH on growth and entertoxin production by *Staphylococcus aureus*. J. Milk Food Technol. 36(5):249-252.

Shoemaker, S.P. and Pierson, M.D. 1976. "Phoenix phenomenon" in the growth of *Clostridium perfringens*. Appl. Microbiol. 32(6):803-807.

Silliker, J.H. 1982. *Salmonella* foodborne illness. In "Microbiological Safety of Foods in Feeding Systems." Advisory Board on Military Personnel Supplies Commission on Engineering and Technical Systems, National Research Council. Report 125. pp. 22-31.

Stern, N.J., Pierson, M.D. and Kotula, A.W. 1980. Effects of pH and sodium chloride on *Yersinia enterocolitica* growth at room temperature and refrigeration temperatures. J. Food Sci. 45(1):64-67.

Sutherland, J.P. and Varnham, A.H. 1977. Methods of isolation and potential importance of *Yersinia enterocolitica* in foods stored at low temperatures. (Abstract) J. Appl. Bacteriol. 43:xiii-xiv.

Tatini, S.R. 1973. Influence of food environments on growth of *Staphylococcus aureus* and production of various enterotoxins. J. Milk Food Technol. 36(11):559-563.

Twedt, R.M. 1989. *Vibrio parahaemolyticus*. in "Foodborne Bacterial Pathogens." Doyle, M.P., Ed., pp. 543-568. Marcel Dekker, Inc., New York, NY.

van Netten, P., van de Moosdijk, A., van Hoensel, P., Mossel, D.A.A., and Perales, I. 1990. Psychrotrophic strains of *Bacillus cereus* producing enterotoxin. J. Appl. Microbiol. 69: 73-79.

Willardsen, R.R., Busta, F.F., Allen, C.E., and Smith, L.B. 1978. Growth and survival of *Clostridium perfringens* during constantly rising temperatures. J. Food Sci. 43(2):470-475.

Woodburn, M.J., Somers, E., Rodriguez, J., and Shantz, E.J. 1979. Heat inactiviation rates of botulism toxins A, B, E and F in some foods and buffers. J. Food Sci. 44(6):1658-1661.

Robert J. Price, Ph.D., Extension Specialist, Seafood Products; Pamela D. Tom, M. Sc., Program Representative; Food Science & Technology, University of California, Davis, California 95616-8598

UCSGEP 92-10; November 1992

This work is sponsored in part by NOAA, National Sea Grant College Program, Department of Commerce, under grant number NA89AA-D-SG138, project number A/EA-1, through the California Sea Grant College Program, and in part by the California State Resources Agency. The U.S. Government may reproduce and distribute reprints for governmental purposes.

University of California, the United States Department of Agriculture, and the United States Department of Commerce cooperating.