



**SURVIVABILITY · SUSTAINABILITY · MOBILITY  
SCIENCE AND TECHNOLOGY  
SOLDIER SYSTEM INTEGRATION**



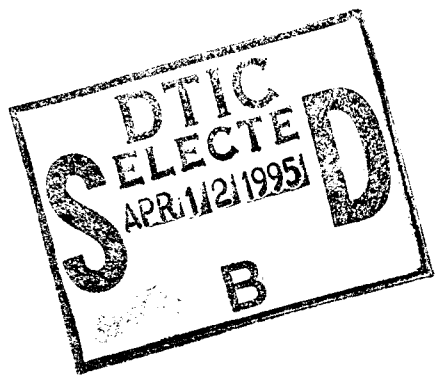
TECHNICAL REPORT  
NATICK/TR-95/020

AD \_\_\_\_\_

# **CONTROL OF THERMOPHILIC SPORE ACTIVITY WITH PRESSURIZED CO<sub>2</sub> AND EGG-WHITE LYSOZYME**

by

**Anthony Sikes  
and  
Cindy Martin**



March 1995

19950411 044

Final Report

October 1990 - September 1993

Approved for Public Release, Distribution Unlimited

**UNITED STATES ARMY NATICK  
RESEARCH, DEVELOPMENT AND ENGINEERING CENTER  
NATICK, MASSACHUSETTS 01760-5000**

**SUSTAINABILITY DIRECTORATE**

## DISCLAIMERS

The findings contained in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

## DESTRUCTION NOTICE

### For Classified Documents:

Follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

### For Unclassified/Limited Distribution Documents:

Destroy by any method that prevents disclosure of contents or reconstruction of the document.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE March, 1995	3. REPORT TYPE AND DATES COVERED Final Oct 90 - Sept 93		
4. TITLE AND SUBTITLE Control of Thermophilic Spore Activity with Pressurized CO <sub>2</sub> and Egg-White Lysozyme		5. FUNDING NUMBERS PR: TB040 PE: 040 WU: AH52 TA: AG: FB1298		
6. AUTHOR(S) Anthony Sikes and Cindy Martin				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U. S. Army Natick RD&E Center ATTN: SATNC-WRA Kansas Street Natick, MA 01760-5018		8. PERFORMING ORGANIZATION REPORT NUMBER  NATICK/TR-95/020		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSORING/MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for public release, distribution unlimited		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words)  The shelf life of low-acid (pH 5.4-5.6), thermally processed military rations, such as mixed vegetables or stews, can be limited by the metabolic activity of gram-positive, heat-resistant spore-formers, such as <i>Bacillus stearothermophilus</i> . For that reason, an investigation was initiated to evaluate the feasibility of using carbon dioxide (CO <sub>2</sub> ) alone or in combination with egg white lysozyme to inactivate foodborne thermophilic sporeformers. Results showed that vegetative cells of <i>B. stearothermophilus</i> were very sensitive to hyperbaric (pressurized) CO <sub>2</sub> . During 3.5 h of incubation in AAMS broth at 25°C and 200 psi CO <sub>2</sub> , a 5-6 log <sub>10</sub> cycle decrease occurred in the cell density. Similarly, at 400 psi CO <sub>2</sub> , a 6-7 log decrease occurred in the cell population. However, in the spore state, results indicated that <i>B. stearothermophilus</i> was more resistant to CO <sub>2</sub> inhibition than vegetative cells. It was shown that when heat-resistant spores of <i>B. stearothermophilus</i> (10 <sup>3</sup> -10 <sup>4</sup> spores/mL) were cultured in AAMS broth treated with CO <sub>2</sub> (0 and 400 psi) and egg white lysozyme (0, 150 and 300 ppm) for up to 24 h at 37°C, inhibition occurred. In the presence of 400 psi CO <sub>2</sub> , samples treated with 150 ppm lysozyme averaged a 1.42 log decrease in spore density over 24 h incubation (37°C), while 300 ppm lysozyme resulted in an average spore reduction of 4.5 logs, under similar storage conditions. In the absence of CO <sub>2</sub> , enzyme-treated samples, 150 and 300 ppm, averaged a 0.91 and 3.36 log spore reduction during 24 h storage, respectively. Indications are that pressurized CO <sub>2</sub> may act synergistically with lysozyme.				
14. SUBJECT TERMS SHELF LIFE MILITARY RATIONS LYSOZYME		BACILLUS STEAROTHERMOPHILUS FOODBORNE VIRUS VEGETATIVE CELLS METABOLIC ACTIVITY	LYTIC ENZYMES CARBON DIOXIDE INACTIVATION SPORES	15. NUMBER OF PAGES 23
				16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	

## TABLE OF CONTENTS

	Page
LIST OF FIGURES AND TABLES. ....	v
PREFACE. ....	vii
INTRODUCTION. ....	1
MATERIALS AND METHODS. ....	2
RESULTS. ....	5
SUMMARY AND CONCLUSIONS. ....	14
REFERENCES. ....	16

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/_____	
Availability Codes	
Dist	Avail and/or Special
A-1	

## LIST OF FIGURES

Figures	Page
1. Survival of vegetative cells of <u>B. stearothermophilus</u> when exposed to 200 psi CO <sub>2</sub> for 3.5 h in AAMS broth (pH 6.8) at 25°C and enumerated on AAMS agar at 55°C. Data points are mean values (n = 4). . . . .	6
2. Survival of vegetative cells of <u>B. stearothermophilus</u> when exposed to 400 psi CO <sub>2</sub> or N <sub>2</sub> gas for 1.5 h in AAMS broth (pH 6.8) at 25°C and enumerated on AAMS agar at 55°C. Data points are mean values (n = 4). . . . .	7
3. Effect of egg-white lysozyme (150 and 300 ppm) the viability of <u>B. stearothermophilus</u> spores incubated in AAMS broth (pH 6.8) at 37°C and enumerated on AAMS agar at 55°C. Data points represent mean values of two replicates with two samples/replicate (n = 4). . . . .	11
4. Combined effects of egg-white lysozyme (150 and 300 ppm) and pressurized CO <sub>2</sub> (200 psi) on the viability of <u>B. stearothermophilus</u> spores incubated in AAMS broth (pH 6.8) at 37°C and enumerated on AAMS agar at 55°C. Data points represent the mean values of two replicate experiments with two samples/replicate (n = 4). . . . .	12
5. Combined effects of egg white lysozyme (150 & 300 ppm) and pressurized CO <sub>2</sub> (400 psi) on the viability of <u>B. stearothermophilus</u> spores incubated in AAMS broth (pH 6.8) at 37°C and enumerated on AAMS agar at 55°C. Data points represent the mean values of two replicate experiments with two samples/replicate. (n = 4). . . . .	13

## LIST OF TABLES

### Table

1. Effects of hyperbaric carbon dioxide on the viability of <u>B. stearothermophilus</u> spores. . . . .	8
--	---

## PREFACE

The research described herein analyzes the effects of a combination treatment of hyperbaric CO<sub>2</sub> and lytic enzyme (egg white lysozyme) on the inactivation of heat-resistant, bacterial endospores (Bacillus stearothermophilus). Preliminary results indicated that under low CO<sub>2</sub> pressure, e.g., ≤500 psi, vegetative cells of B. stearothermophilus tended to be highly sensitive to pressurized CO<sub>2</sub>; however, pressurized CO<sub>2</sub> in the range of 800-1100 psi had no apparent effect on the viability of B. stearothermophilus spores for as long as 96 hours of storage. Preliminary results also indicated in the presence of a lytic enzyme, such as egg white lysozyme, spore destruction could be achieved. In the presence of pressurized CO<sub>2</sub> (400 psi) and lysozyme (300 ppm), the results indicated that the rate of spore destruction was more rapid. Thus the focus of this research is on the relationship between pressurize CO<sub>2</sub> and lysozyme and its impact on spore viability.

This work, which began on 30 October, 1990 and ended 30 September, 1993, was supported under the project entitled "Hyperbaric Preservation," AH5240D00.

CONTROL OF THERMOPHILIC SPORE ACTIVITY WITH PRESSURIZED  
CO<sub>2</sub> AND EGG-WHITE LYSOZYME

INTRODUCTION

Carbon dioxide (CO<sub>2</sub>) has been shown to inhibit the metabolic activity of vegetative bacteria. This fact has been exploited in preventing bacterial food spoilage through modified atmosphere packaging (MAP). The ability of high concentrations of CO<sub>2</sub> to retard the growth of spoilage flora in red meat, poultry and fish is well documented (1,2,10,11,14).

The inhibitory effects of CO<sub>2</sub> increase when it is applied under pressure (2,5,6,8). Hyperbaric carbon dioxide has been shown to be effective against gram-positive thermophilic sporeformers (6). Egg white lysozyme has also been shown to have antibacterial properties (9). It is especially effective against gram-positive bacteria, such as Bacillus stearothermophilus (4). The current investigation looks at the antibacterial activity of the individual and combined effects of CO<sub>2</sub> and lysozyme against a foodborne, thermophilic sporeformer. Thus the objectives of the present investigation were to determine the effects of hyperbaric CO<sub>2</sub> alone and in combination with egg white lysozyme on the viability of vegetative cells and spores of B. stearothermophilus.

## MATERIALS AND METHODS

Spore preparation. A stock culture of Bacillus stearothermophilus spores (ATCC 12980) was obtained from the culture collection of the Microbiology Section, U.S. Army RD&E Center, Natick, MA. Cultures were maintained on Cook and Brown sporulation agar slants (3), stored at 1-4°C and transferred monthly to maintain active stock cultures. Before spores were prepared, stock cultures were activated by suspending a loopful of the stock in phosphate buffer, pH 6.8, surface plating on antibiotic assay agar + 0.1% soluble starch (AAMS) and incubating for 24 h at 55°C. Using phosphate buffer (0.05M potassium phosphate, pH 6.8), the sporulation inoculum was prepared by scraping (bent glass rod) the 24 h growth from the AAMS plates and adding 3 mL volumes to Fernbach flasks.

All spores used in this study were prepared on Cook and Brown sporulation agar (3) according to the procedures described by Feeherry et al. (7). After incubating for 4 d at 55°C, spores were harvested from Fernbach flasks and were washed 3x with phosphate buffer (pH 6.8). Subsequently, the pellets were suspended in 200 mL of containing 100 micrograms/mL of lysozyme and incubated with stirring at 37°C for 1 h. Enzyme-treated spores were washed 4x with cold, distilled water to remove vegetative debris. Pellets were resuspended in cold, sterile phosphate buffer and stored at ~4°C until used.

Spore activation. Prior to use in an experiment, the spore inoculum ( $10^6$  spores/mL) was heat activated by subjecting to flowing steam for 10 minutes.

Lysozyme preparation. Egg-white lysozyme and Micrococcus luteus (ATCC 4698) were obtained from Boehringer Mannheim Biochemicals, Indianapolis, IN. It was determined that the enzyme preparation contained approximately 34,600 units/mg. One unit of enzyme caused a decrease in turbidity at 540 nm of 0.0009/minute at pH 6.7 (13).

Hyperbaric treatment. Vegetative cells or spores were suspended in either sterile 0.05M phosphate buffer (pH 6.8), 0.05M acetate buffer (pH 4.5), 0.05M acetate buffer (pH 4.0) or AAMS broth (pH 6.8) in 16 x 150 mm screw-capped or 25 x 150 mm culture tubes. The caps were loosely secured to permit free gas exchange. The tubes were placed in the cylinder of Parr cell disruption bombs (Parr Instrument Company, Moline, IL; capacity: 1850 mL). After loading, the cylinders were sparged with either nitrogen or carbon dioxide at 200 psi for one minute to remove air. The cylinders were then pressurized (50-1100 psi) and stored at various temperatures (3°, 25°, 37°, 55°, 65°, 90° and 100°C) for 1 to 96 h.

Bacterial enumerations. Vegetative cells or spores were enumerated by spread plating (0.1 mL) on AAMS agar at 55°C. Serial dilutions were prepared with either sterile deionized water or 0.05M phosphate buffer, pH 6.8. All counts reported represent the mean of two replicates with duplicate

samples/replicate (n = 4).

## RESULTS

Effect on vegetative cells. Hyperbaric CO<sub>2</sub> has been shown to have a bactericidal effect on vegetative cells of B. stearothermophilus (12). Destruction of vegetative cells was shown to be dependent on both time of exposure and CO<sub>2</sub> pressure.

The effect of 200 psi CO<sub>2</sub> at 25°C on survival of vegetative cells over a 3.5 h period is shown in Fig. 1. The cell population decreased over 4 log cycles (log 6.3 to > log 2.0) during the 3.5 h treatment period at 25°C. The data in Fig. 2 suggest that 400 psi achieved sterilization treatment when a population of vegetative cells was exposed for 1.5 h at 25°C. Nitrogen gas at the same pressure had no adverse effect on viability of B. stearothermophilus vegetative cells (12).

Effect on endospores. Roskey and Sikes (12) found that heat-resistant endospores of B. stearothermophilus were extremely resistant to the bactericidal effects of hyperbaric CO<sub>2</sub> at 55°C. The effect of CO<sub>2</sub> and N<sub>2</sub> on the survival of B. stearothermophilus spores under varying conditions of temperature and pH is shown in Table 1. When spores (~log 4.7 spores/mL) were suspended in sterile 0.05M acetate buffer (pH 4.0), 0.05M acetate buffer (pH 4.5) or 0.05M phosphate buffer (pH 6.8) and then subjected to hyperbaric CO<sub>2</sub> (540-1100 psi) for 1 to 96 h, there was no apparent spore destruction, except at 90°C and pH 4.5.

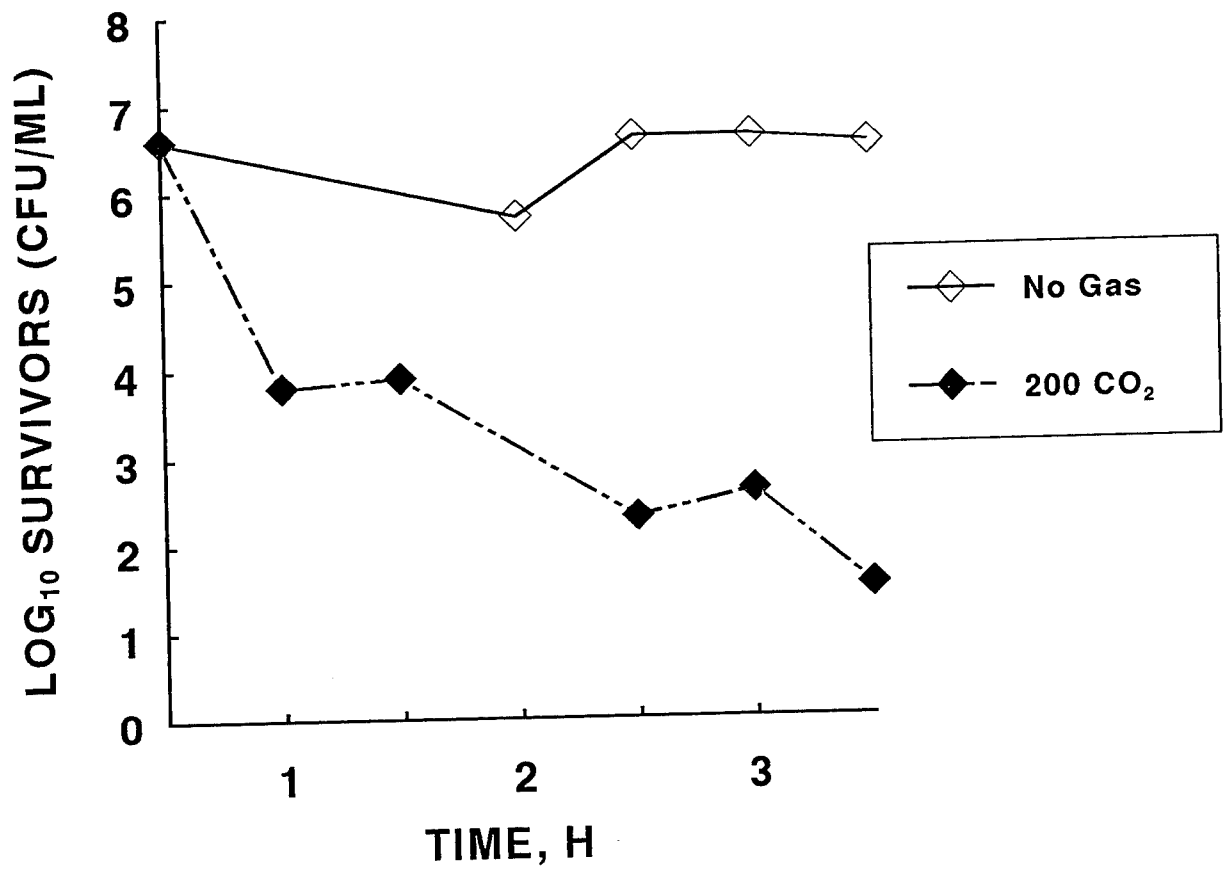


Figure 1. Survival of vegetative cells of *B. stearothermophilus* when exposed to 200 psi CO<sub>2</sub> for 3.5 h in AAMS broth (pH 6.8) at 25°C and enumerated on AAMS<sub>2</sub> agar at 55°C. Data points are mean values, n = 4 (12).

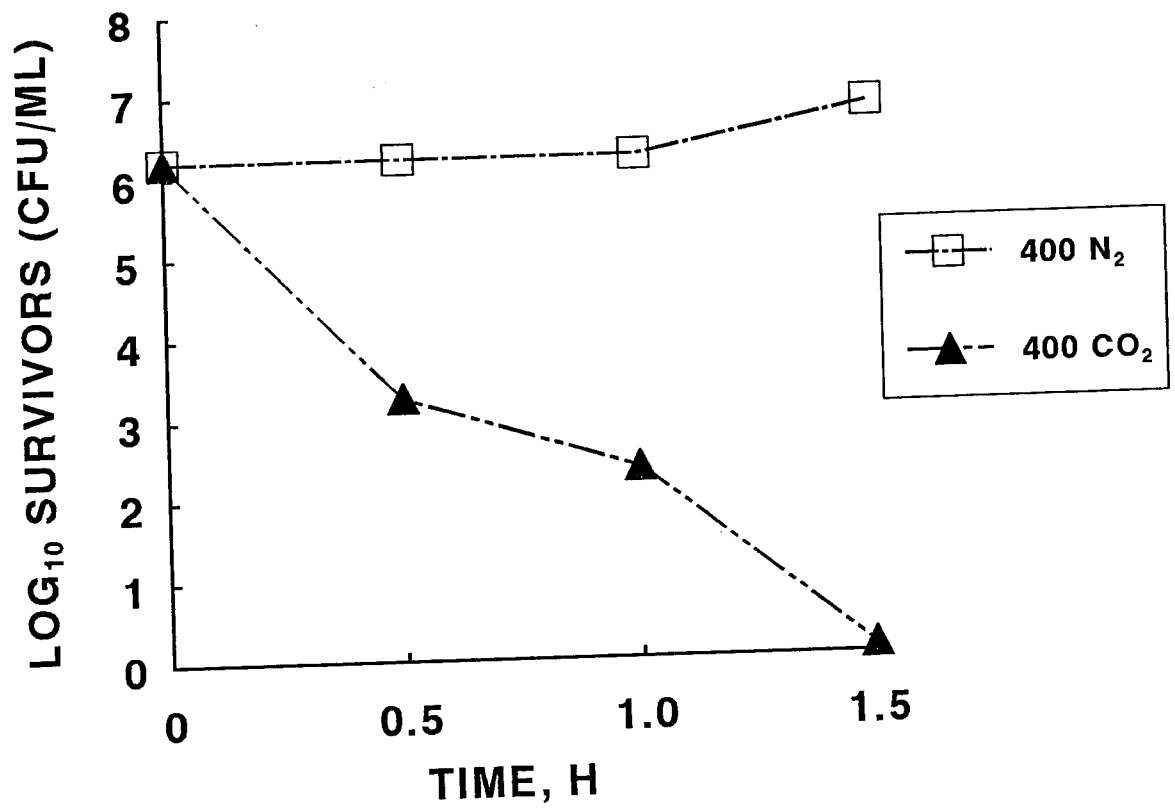


Figure 2. Survival of vegetative cells of *B. stearothermophilus* when exposed to 400 psi CO<sub>2</sub> or N<sub>2</sub> gas for 1.5 h in AAMS broth (pH 6.8) at 25°C and enumerated on AAMS agar at 55°C. Data points are mean values, n = 4 (12).

Table 1. Effects of hyperbaric carbon dioxide on the viability of Bacillus stearothermophilus spores (12).

pH	Temp. °C	Pressure psi	Time hrs	Survival Fraction		
				log <sup>b</sup> N <sub>CO<sub>2</sub></sub> / <sup>a</sup> N <sub>0</sub>	log <sup>c</sup> N <sub>A</sub> /N <sub>0</sub>	log <sup>d</sup> N <sub>N<sub>2</sub></sub> /N <sub>0</sub>
4	3	800-550	68	0.98	0.98	_____
4	25	840-890	68	0.94	0.93	_____
4	55	840-1050	68	0.99	0.87	_____
4	65	800-900	45	0.98	0.86	0.82
<hr/>						
4.5	3	820-540	96	1.04	1.06	1.06
4.5	25	830-850	96	1.01	.98	_____
4.5	65	840-900	23	0.99	.82	0.89
4.5	90	850-875	22	0.55	.78	_____
<hr/>						
7	25	800-930	23	1.01	0.96	1.01
7	55	940-1050	46	1.01	0.80	0.81
7	65	940-975	20	1.00	0.81	_____
7	75	875-1000	26	1.06	0.91	_____
7	100	900-1100	1	1.09	1.08	_____

<sup>a</sup>N<sub>0</sub> = initial population (mean initial population was log<sub>10</sub> 4.7)

<sup>b</sup>N<sub>CO<sub>2</sub></sub> = number present after CO<sub>2</sub> treatment.

<sup>c</sup>N<sub>A</sub> = number present after exposure to ambient gas atmosphere for the treatment period.

<sup>d</sup>N<sub>N<sub>2</sub></sub> = number present after exposure to N<sub>2</sub> gas at the same pressure as CO<sub>2</sub> for the same time.

Aliquots of the same spore suspensions subjected to ambient gas conditions and those subjected to hyperbaric N<sub>2</sub> were similarly unaffected.

Examination of the data in Table 1 also showed that spores exposed to high temperatures (90°C) and low pH may act synergistically with hyperbaric CO<sub>2</sub> (850-875 psi). Additional studies will be necessary to characterize more clearly the synergistic effects of high temperature, low pH and hyperbaric CO<sub>2</sub>.

Effect of lysozyme on endospores. When Bacillus stearothermophilus spores were incubated in AAMS broth containing 300 ppm egg-white lysozyme in the absence of pressurized CO<sub>2</sub> and, subsequently, plated on AAMS agar, the spore count was reduced to <1 CFU/mL, between 2 and 4 h incubation at 37°C (Fig. 3). Under similar experimental conditions, 150 ppm lysozyme had no apparent effect on spore viability during a 24 h incubation period (Fig. 3). Thus, it would appear that at 150 ppm lysozyme spore viability is unaffected, but spore germination/outgrowth was inhibited.

In the absence of enzyme treatment, B. stearothermophilus spores germinated and grew out to a density of log<sub>10</sub> 6-7 CFU/mL, during 24 h incubation (37°C) in AAMS broth (Fig. 3).

In the presence of 200 psi hyperbaric CO<sub>2</sub> and the absence of lysozyme, a slight increase (< 1 log<sub>10</sub>) occurred in the CFU/mL during the initial 2-4 h incubation in AAMS broth at

37°C (Fig. 4). Subsequently, spore numbers remained unchanged (Fig. 3).

In the presence of 150 ppm lysozyme and 200 psi CO<sub>2</sub>, a similar pattern of growth and dormancy was observed (Fig 3). In the presence of 300 ppm lysozyme and 200 psi CO<sub>2</sub>, spore viability was reduced to < 1 CFU/mL in less than 2 h incubation in AAMS broth (37°C; Fig. 4) .

Similarly, at a CO<sub>2</sub> pressure of 400 psi and lysozyme concentrations of 150 and 300 ppm, the CFU/mL increased slightly (< 1 log<sub>10</sub>) during the initial 2 h of incubation in AAMS broth (Fig. 5). Subsequently, the viable spore count remained essentially unchanged during the next 6 h of incubation but decreased slightly between 8 and 24 h (<1 log; Fig. 5). At an enzyme concentration of 300 ppm, the viability spore count was immediately and dramatically affected. After 2 h of incubation in AAMS broth, the viable spore count decreased to < 1 CFU/mL for a period of 22 h (Fig. 5).

It was also apparent from the data in Figures 3-5 that in the absence of enzyme treatment the viable spore count always was higher than any of the enzyme treated samples, even in the presence of CO<sub>2</sub> pressure.

Thus, at the treatment levels used in this study, the combination treatments (enzyme + pressure) may indicate that the combination treatments are more effective than individual treatments; however, more definitive data are required before this conclusion can be reached.

pressure CO<sub>2</sub> treatment (11).

### CO<sub>2</sub> PRESSURE: 0

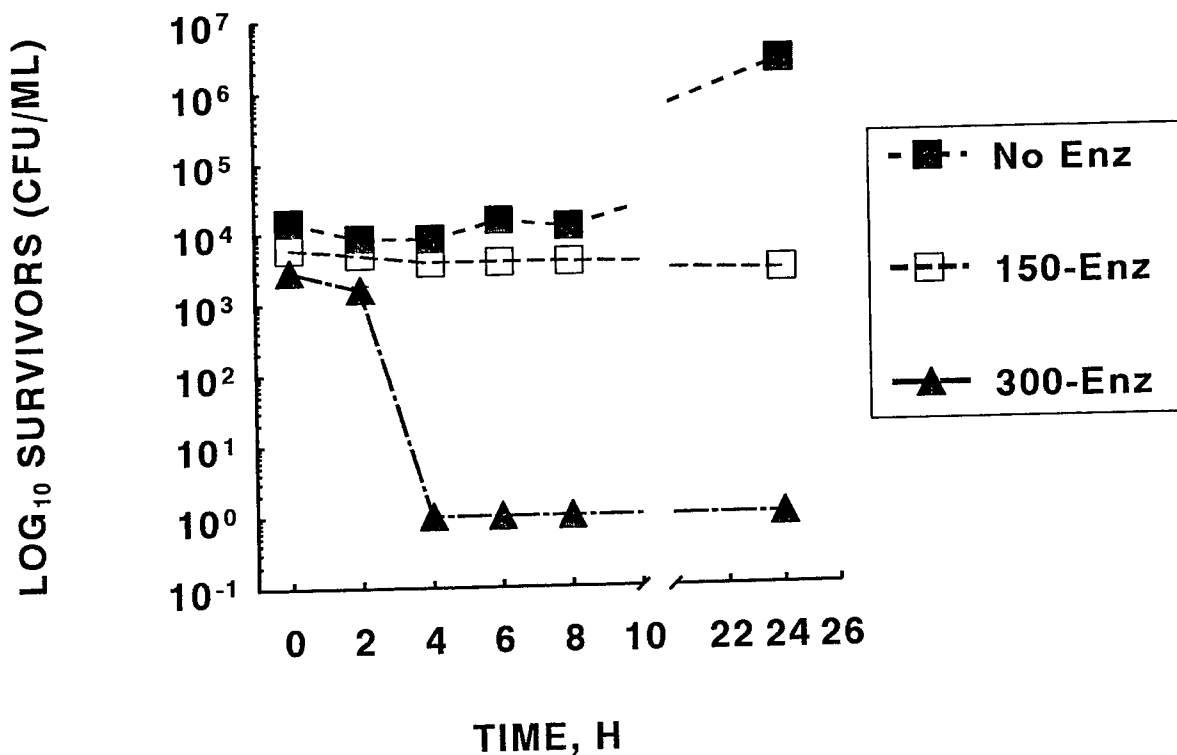


Figure 3. Effect of egg-white lysozyme (150 and 300 ppm) on the viability of *B. stearothermophilus* spores incubated in AAMS broth (pH 6.8) at 37°C and enumerated on AAMS agar at 55°C. Data points represent mean values of two replicates with two samples/replicate (n = 4).

## CO<sub>2</sub> PRESSURE: 200 PSI

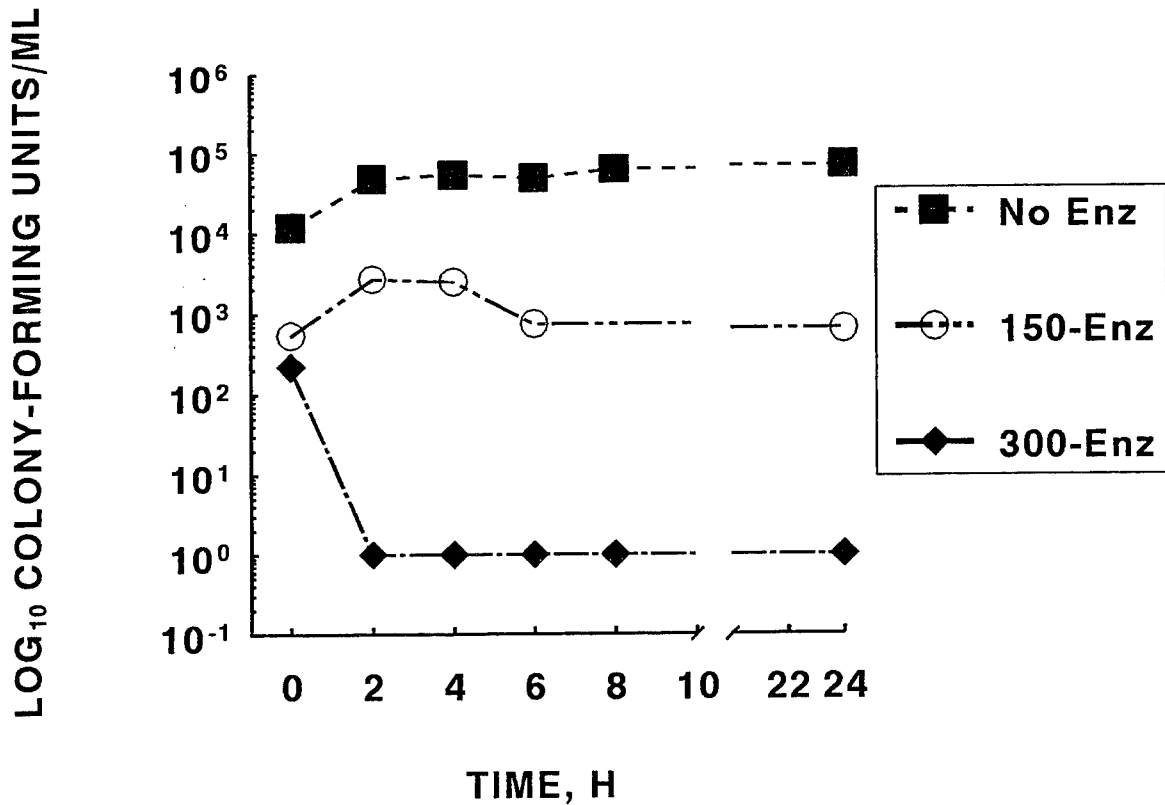


Figure 4. Combined effects of egg-white lysozyme (150 and 300 ppm) and pressurized CO<sub>2</sub> (200 psi) on the viability of *B. stearothermophilus* spores incubated in AAMS broth (pH 6.8) at 37°C and enumerated on AAMS agar at 55°C. Data points represent the mean values of two replicate experiments with two samples/replicate (n = 4).

## CO<sub>2</sub> PRESSURE: 400 PSI

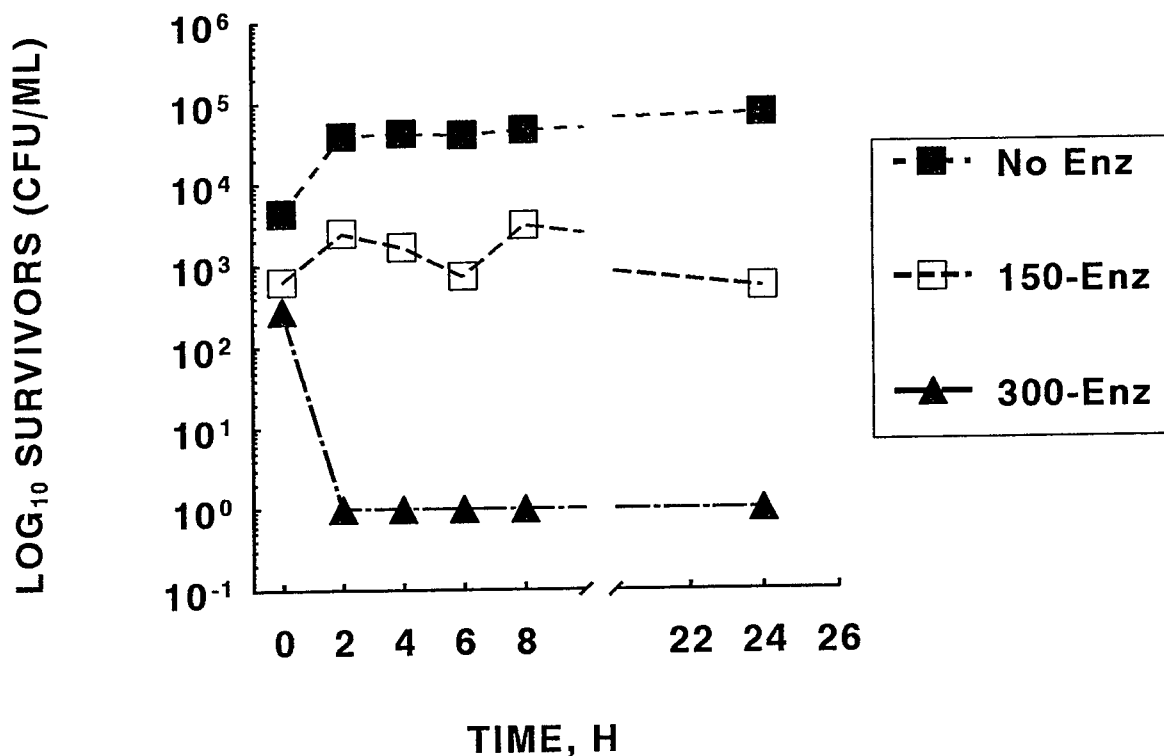


Figure 5. Combined effects of egg-white lysozyme (150 and 300 ppm) and pressurized CO<sub>2</sub> (400 psi) on the viability of *B. stearothermophilus* spores incubated in AAMS broth (pH 6.8) at 37°C and enumerated on AAMS agar at 55°C. Data points represent the mean values of two replicate experiments with two samples/replicate (n = 4).

## SUMMARY AND CONCLUSIONS

Vegetative cells of B. stearothermophilus were found to be extremely sensitive to relatively low levels of pressurized CO<sub>2</sub>. Complete destruction (no recovery at 55°C) of 10<sup>6</sup> vegetative cells/mL in AAMS broth was obtained by exposure to 400 psi CO<sub>2</sub> for 1.5 h (no survivors).

Spores, however, were more resistant and remained viable after exposure to 800-1100 psi CO<sub>2</sub> for as long as 96 h. Spores also survived CO<sub>2</sub> treatment at low (3°C) as well as high (100°C) temperatures and at pH 4, 4.5 and 7.0. However, the data obtained suggested that high pressure CO<sub>2</sub> (850-875 psi) exposure at high temperature (90°C) may act synergistically to compromise spore viability. In the absence of CO<sub>2</sub> (37°C), no apparent difference was evident between spore viability in the presence or absence of 150 ppm of lysozyme; however, at an enzyme concentration of 300 ppm (no CO<sub>2</sub>), spore viability was reduced to < 1 CFU/mL in < 4 h of incubation.

In the presence of CO<sub>2</sub> pressure (200 and 400 psi), there was a difference in spore viability in the presence or absence of enzyme. Under pressure, a 1-2 log<sub>10</sub> differential existed between the control (no enzyme treatment) and the 150 ppm lysozyme treatment. Pressurized CO<sub>2</sub> also resulted in a more rapid spore destruction rate (<2 h).

Since the rate of spore destruction was apparently more rapid in the presence of pressurized CO<sub>2</sub>, pressurized CO<sub>2</sub> and

lysozyme may act synergistically against B. stearotherophilus spores. To confirm this observation, additional research will be required.

## REFERENCES

1. Baker, R. C., R. A. Quereshi and J. H. Hotchkiss 1986. Effect of an elevated level of carbon dioxide containing atmosphere on the growth of spoilage and pathogenic bacteria at 2°, 5° and 13°C. *Poult. Sci.* 65: 729-737.
2. Blickstad, E., S. O. Enfors and G. Molin. 1981. Effects of hyperbaric carbon dioxide pressure on the microbial flora of pork stored at 4° or 14°C. *J. Appl. Bacteriol.* 50: 493-504.
3. Cook, A. M. and M. R. W. Brown. 1964. The relationship between activation and colony formation for spores of Bacillus stearothermophilus. *J. Pharm. Pharmacol.* 16:725-732.
4. Cunningham, F. E., V. P. Proctor and S. J. Goetsch. 1991. Egg-white lysozyme as a food preservative: an overview. *World's Poult. Sci. J.* 47: 141-164.
5. Doyle, M. P. 1983. Effect of carbon dioxide on toxin production by Clostridium botulinum. *J. Appl. Microbiol. Biotechnol.* 17: 53-56.
6. Enfors, S. O. and G. Molin. 1978. The influence of high concentration of carbon dioxide on germination of bacterial spores. *J. Appl. Bacteriol.* 45: 279-285.
7. Feeherry, F. E., D. T. Munsey and D. R. Rowley. 1987. Thermal inactivation and injury of Bacillus stearothermophilus spores. *Appl. Environ. Microbiol.* 53: 365-367.
8. Haas, G. J., H. E. Prescott, E. Dudley, R. Dik, C. Hintlian and L. Keane. 1989. Inactivation of microorganisms by carbon dioxide under pressure. *J. Food safety.* 9: 253-265.
9. Hughey, V. L. and E. A. Johnson. 1987. Antimicrobial activity of lysozyme against bacteria involved in food spoilage and food-borne disease. *Appl. Environ. Microbiol.* 53: 2165-2170.
10. Madden, R. H. and Moss B., 1987. Extension of shelf life of minced beef by storage in vacuum packages with carbon dioxide. *J. Food Protect.* 50: 229-233.

11. Molin, G. 1983. The resistance to carbon dioxide of some food related bacteria. *European J. of Appl. Microbiol. and Biotechnol.* 18: 214-217.
12. Roskey, C. T. and A. Sikes. 1994. Effect of hyperbaric carbon dioxide on spores and vegetative cells of Bacillus stearothermophilus. Technical Report, Natick/TR-94/019. U. S. Army Natick Research, Development and Engineering Center, Natick, MA 01760 (AD A280 115).
13. Shugar, D. 1952. The measurement of lysozyme activity and the ultra-violet inactivation of lysozyme. *BBA* 8:302-309.
14. Thomas, Y. O., A. A. Kraft, R. E. Rust and D. K. Hotchkiss. 1984. Effect of carbon dioxide flushing and packaging methods on the microbiology of packaged chickens. *J. Food Sci.* 49:1367-1371.