CONSUMER AND TRAINED PANEL EVALUATION OF HIGH PRESSURE THERMALLY TREATED SCRAMBLED EGG PATTIES

P. JULIANO[1], S. CLARK[2], T. KOUTCHMA[3], M. OUATTARA[2], J.W. MATHEWS[4], C.P. DUNNE[5] and G.V. BARBOSA-CÁNOVAS[1,6]

[1]*Departments of Biological Systems Engineering*

[2]*Food Science and Human Nutrition*
Washington State University
Pullman, WA

[3]*National Center for Food Safety and Technology*
Summit-Argo, IL

[4]*Michael Foods Egg Products Company*
Gaylord, MN

[5]*US Army Research*
Development and Engineering Command
Natick, MA

Accepted for Publication November 13, 2006

ABSTRACT

Consumer acceptability of three commercial scrambled egg patty formulations were evaluated before and after high pressure high temperature (HPHT) processing at 700 MPa/105C and 700 MPa/121C, and a selected formulation was also in-pouch retort treated to an F_0 *of 5.6 min. A 40-member consumer panel and a six-member trained sensory panel (29 attributes judged) evaluated treated and untreated patties. Samples were also stored at 37C for 3 and 6 months for shelf-life testing. Egg patty with added processed cheese was the most accepted formulation after treatment at 700 MPa/105C, maintaining most quality parameters after pressurization. Egg patty formulation with added xanthan gum gave similar acceptability scores at 700 MPa/105C and at 700 MPa/121C. After 6-month incubation, HPHT-treated products did not produce gas or decompose, while control patties degraded after 1 week storage at 37C. Thermal pressurization processing proved promising for the development of novel shelf-stable egg-based products.*

[6] Corresponding author. TEL: (+) 1-509-335-6188; FAX: (+) 1-509-335-2722; EMAIL: barbosa@mail.wsu.edu

Journal of Food Quality **30** (2007) 57–80.

PRACTICAL APPLICATIONS

High Pressure High Temperature (HPHT) sterilization is an emerging alternative processing method for the development and production of low-acid shelf-stable food products. Hydrostatic pressures of 600 MPa or higher allow shorter processing times, at reduced sterilization temperatures, and can potentially deliver novel high quality products that may not be achieved by conventional retort processing. In recent years, consumption of scrambled egg patties, in varied formulations, has increased in popularity in foodservice venues. This research explores the possibility of utilizing HPHT to produce acceptable shelf-stable egg patties for outdoor, humanitarian and military applications.

INTRODUCTION

Consumer demand in the U.S.A. for specialty precooked egg products has increased during the last decade (American Egg Board 2004). About one-third of the eggs produced are further processed into egg products for the foodservice and food-manufacturing industries. In 1984, the egg product sector in the U.S.A. was 15% of the total egg production, whereas today it is 32%, or 69.0 million cases of broken egg shells in egg products (American Egg Board 2004; Froning 2006). In fact, tremendous growth in the use of precooked frozen egg products, such as scrambled egg patties, has occurred in foodservice venues, ranging from gas stations to fast-food restaurants, especially as breakfast menu items (Turner 2003).

In particular, the production of refrigerated (extended shelf life) and shelf-stable precooked egg patties is finding a new niche in the ready-to-eat meal market, especially as military rations and outdoor food items. Manufacturing of shelf-stable egg products using conventional thermal processing remains a challenge, as retort processing yields undesirable flavors, greenish-black discoloration and detrimental changes in texture and syneresis (Baliga *et al.* 1969; Wesley *et al.* 1982; Luechapattanaporn *et al.* 2005). As a matter of fact, the U.S. Army recently stopped the production of retorted scrambled eggs (net weight 2.7 kg) in plastic institutional trays because of the dissatisfaction reported by military consumers with respect to the quality of this benchmark product (Dunne 2005). On the other hand, alternative food sterilization technologies, specifically high hydrostatic pressure processing in combination with heat, have potential to make the production of shelf-stable low-acid egg products feasible and acceptable.

High pressure high temperature (HPHT) processing, or pressure-assisted thermal processing (PATP), involves the use of moderate initial chamber temperatures between 60–90C, which through internal compression heating at pressures of 600 MPa or greater, can reach in-process temperatures of 90–130C. A number of publications prove the bactericidal effectiveness of 700 MPa and process temperature of at least 105C MPa for the accelerated inactivation of selected spores in selected matrices like phosphate buffer, beef, vegetable cream and tomato puree (Gola *et al.* 1996; Raso *et al.* 1998; Rovere *et al.* 1998; Meyer *et al.* 2000; Heinz and Knorr 2001; Balasubramaniam and Balasubramaniam 2003; Krebbers *et al.* 2003; Margosch *et al.* 2004; Ahn *et al.* 2005; Koutchma *et al.* 2005; Margosch 2005; Rajan *et al.* 2005, 2006).

Even though extensive research has been done on bacterial spore inactivation, few quality validation studies of low acid foods after HPHT treatment have been published. Furthermore, no consumer acceptability data on HPHT processed products have yet been reported; neither have comparisons in consumer acceptability between HPHT- and retort-treated products. Ludikhuyze and Hendrickx (2001) suggested that the three main characteristics of high-quality foods that determine consumers' acceptance are appearance, texture and flavor/aroma. These three characteristics have been measured using analytical methods on HPHT-treated broccoli juice, green beans, tomato puree and meat sauce (Van Loey *et al.* 1998; Rovere *et al.* 2000; Krebbers *et al.* 2002, 2003; Matser *et al.* 2004). In particular, sensory and analytical color testing on HPHT-treated tomato puree resulted in higher color appreciation values than the retorted samples, which correlated with lower content of lycopene found after retort (Krebbers *et al.* 2003).

Among the existing precooked egg products, scrambled egg patties have been identified as an adequate product for high pressure processing, especially during HPHT processing, because of their semisolid homogeneous structure (Juliano *et al.* 2005, 2006). Previous research on HPHT-treated scrambled egg patties showed that reformulation with pasteurized process cheese and xanthan gum significantly improved texture and water retention in egg patties compared with untreated egg patties, thereby providing more adequate egg products for an HPHT process (Juliano *et al.* 2005, 2006). Given the color and texture retention observed in selected egg patties after HPHT processing, it is important to determine whether these HPHT processed egg patties are acceptable to consumers and meet desired shelf stability.

Hence, the objective of this research was to evaluate selected scrambled egg patty formulations, after HPHT treatment, by using trained and consumer panels, and analytical methods and incubation tests.

MATERIALS AND METHODS

The following sections will describe commercial egg-based formulations chosen as well as HPHT processing and retort treatments selected for the experimental design. Tools to characterize the process and descriptions of consumer and trained panels are included.

Egg-based Products

Michael Foods Egg Products Company (Gaylord, MN) provided three commercial scrambled egg patties of 42.5 ± 7.1 g. Patties #1 and #2 were round (88.9 ± 6.4 mm diameter) and patty #3 was square (69.9 ± 6.4 mm × 76.2 ± 6.4 mm). Patty #1, the standard Michael Foods patty (code 46025-30020-00), had the following basic ingredients: whole eggs, water, soybean oil, modified food starch, whey solids, salt, nonfat dried milk and citric acid. Patty #2 (code 46025-70019-00) had the same ingredients as #1 patty, plus 20% of pasteurized process Cheddar cheese granules. Patty #3 (code 03-1426-10) also had #1 patty basic ingredients, but natural and artificial flavors, xanthan gum and ethylenediaminetetracetic acid (EDTA) were added.

Precooked scrambled egg products were manufactured as indicated in Michael Foods patents (Knipper and Beam 2002; Merkle *et al.* 2003a,b) by mixing whole pasteurized eggs with dry and liquid ingredients. The mix was pumped into a mold within a flat cooking belt and egg mix portions were cooked in a convection oven at 180 to 250C. After baking, patties were frozen and packaged. Frozen scrambled egg patties from a single lot were received from Michael Foods and stored at −30C. Each patty was repackaged in special flexible pouches of 127 × 127 mm (ALCAN, Chicago, IL), and defrosted overnight at 5C. ALCAN packaging material was composed of biaxial nylon/adhesive/EVOH (ethylene-vinyl alcohol copolymer film)/co-extruded sealant to provide physical, oxygen and water vapor barriers. Samples were refrigerated for a maximum of 24 h until HPHT treatments.

Prepackaged Precooked Egg-product Processing

Formulations and processing conditions were tested to gain understanding of their effect on the quality and acceptability of egg patties after HPHT treatment. Three factorial experiments (Table 1) were designed. Experiment 1 was designed to study the effects of HPHT processing on consumer acceptability of formulations #2 and #3, and explain subsequent sensory changes after treatment, as well as quality changes during 6-month storage at 37C. Egg patties #2 and #3, with added cheese and xanthan gum, respectively, had better texture (lower hardness and syneresis) after HPHT treatment than HPHT-treated egg patty #1 (Juliano *et al.* 2005). Therefore, it is important to know how consumers perceive these changes.

Experiment 2 aimed to compare quality after processing by novel in-pouch retort and HPHT at a standard scenario (121C) and at a lower

TABLE 1.
RESEARCH DESIGN*

Main variable	Design	Levels
1. Formulation	2 × 3 factorial: two replicates	[Control, HPHT1] × [formulations #1, #2, #3]
2. Processing	4 × 1 factorial: two replicates	[Control, HPHT1, HPHT2, Retort] × [formulation #3]
3. Water added	2 × 2 × 1 factorial: three replicates	[Control, HPHT1] × [0%, 5%] × [formulation #3]

HPHT1 – 700 MPa, 105C, 5 min.
HPHT2 – 700 MPa, 121C, 3 min.
* Controls and HPHT-treated samples were packaged in non-retortable flexible pouches, whereas retort-treated samples were packaged in retort pouches.
HPHT, high pressure high temperature.

pressurization temperature (105C). HPHT-treated patties #3 were compared with in-pouch retort processed ones as in-pouch retort offers shorter processing time than conventional retort processing (because of higher heat transfer rates through the thin polymeric films and smaller size of the samples).

Experiment 3 tested the effect of water addition on consumer acceptability of scrambled egg patties. Previous studies showed that the harder texture obtained after HPHT treatment could be softened by the addition of water into the structure of the patty before processing (Juliano *et al.* 2005). In this case, egg patty formulation #3 was added with 5% (w/w) water on its surface and the effect upon consumer perception of the product was tested.

Preheating and Processing. For each experiment, the initial temperature of the patties was 5C. Patties were preheated in a water bath using steam injection until 75C was reached, indicated by thermocouples (K-type, Omega Engineering Inc., Stamford, CT) located at the patty center. Preheated patties were placed into the high pressure vessel, initially preheated at 75C, to reach 105C during pressurization at 700 MPa for 5 min (HPHT1). In experiment 2 (Table 1), the pressure chamber was preheated at 90C to reach 121C at 700 MPa, pressurizing for 3 min (HPHT2). A Flow Pressure Systems QUINTUS Food Autoclave Type 35L-600 Sterilization Machine (Flow International Corporation, Kent, WA) with a 35 L vessel, was used with filtered city water as the pressure medium with no heat insulation. Four thermocouples (K-type, Omega Engineering Inc.) were used to measure temperature of the pressure medium as well as temperature inside the patty.

High pressure processing temperature and pressure conditions will be expressed in the following forms:

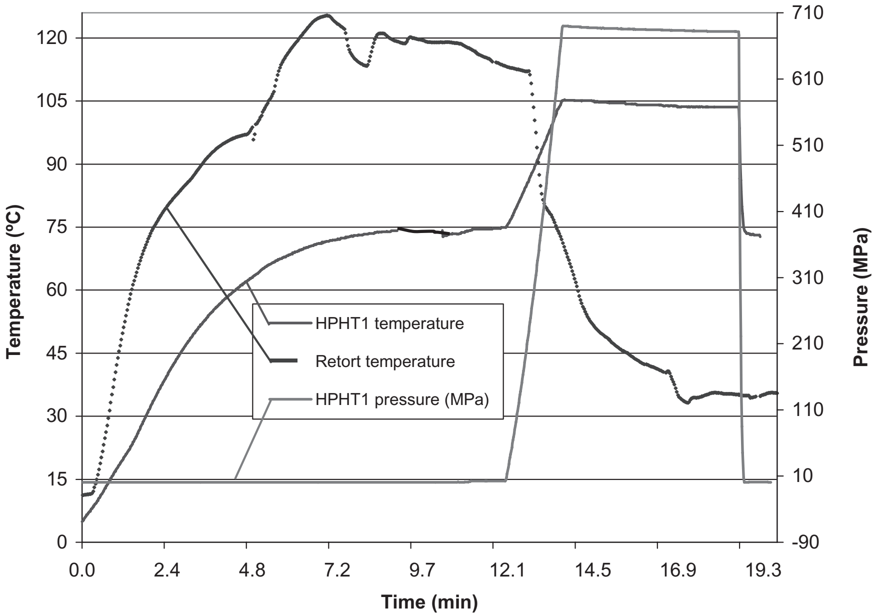

FIG. 1. TYPICAL TEMPERATURE AND PRESSURE PROFILES DURING PRESSURIZATION IN WATER/EGG PATTY SYSTEM AT 700 MPa/105C/5 min (HPHT1)
Retort temperature profile is also shown as read from the thermocouples inside the tested scrambled egg patties.

1. T(C)/P(MPa)/t(min) when expressing initial pressure chamber temperature, pressure level used, and pressure holding time (e.g., 90C/700 MPa/3 min);
2. P(MPa)/T(C)/t(min) when expressing pressure level used, product or transmission fluid temperature during pressurization, and pressure holding time (e.g., 700 MPa/121C/3 min).

In order to perform in-pouch retort treatment, egg patties (#3) were packaged in retort pouches (Smurfit-Stone, Schaumburg, IL) following the same procedure as high pressure-treated patties and were thermally processed using a steam rotary retort (Steritort, FMC Corporation, San Jose, CA). The in-pouch retort treatment was not conventional because it was performed using small egg product packages of about 45 g, allowing for higher heat transfer rate, and thereby a process time of 16 min. Figure 1 shows the temperature and pressure profile obtained during pressurization (HPHT), together with the temperature profile for the retort treatment. The recorded temperature profiles measured inside the products in both HPHT2 and retort processes were used to calculate the sterilization value F_0 (Eq. 1; Stumbo 1973):

$$F_0 = \int_0^t 10^{\left[\frac{T-121}{z}\right]} dt \approx \sum_0^t 10^{\left[\frac{T-121}{z}\right]} \cdot \Delta t \qquad (1)$$

where T is the process temperature (C) inside the egg patty, t is processing time (min), 121 corresponds to the reference temperature (C), and z, the z-value (or thermal sensitivity) [z for *Clostridium botulinum* is 10C]. The integral of Eq. (1) was calculated using the General Method (Holdsworth 1997). An approximation to the integral value was calculated by using the numerical quadrature formula shown at the right side of Eq. (1) and short time intervals of 1 and 2 s for the HPHT2 and retort processes, respectively.

The relative thermal effect on food quality of the processed scrambled egg patties was also quantified using cook values (C_{100}). The cook values for the retort and HPHT2 were calculated using the following equation (Lund 1986):

$$C_{100} = \int_0^t 10^{\left[\frac{T-100}{z}\right]} dt \approx \sum_0^t 10^{\left[\frac{T-100}{z}\right]} \cdot \Delta t \qquad (2)$$

where the chosen z value for the processed egg products is 33C as it is generally used to calculate the overall quality loss (Lund 1986; Luechapattanaporn *et al.* 2005). The reference temperature of 100C (instead of 121C) used in Eq. (2) has been established for quality degradation studies after thermal processing (Lund 1986).

Sensory Evaluation

Two types of panels, trained and consumer, characterized egg patties before and after HPHT or in-pouch retort treatment. Consumers gave product acceptability values and trained panelists evaluated egg patties with a number of attributes on appearance, texture and flavor.

Trained Panels. Six panelists (Washington State University students, faculty and staff) were recruited to participate in a long-term sensory evaluation study. Twenty-nine appearance, texture and flavor attributes, arranged in sensory ballots (Juliano *et al.* 2006), were used to describe products of differing formulations and processing conditions. Several training and refresher training sessions were set up to develop the different sensory attributes and normalize the panelists according to common perceptions, as described below.

Training. Panelists were trained using standard and modified scrambled egg formulations in six 1-hour sessions for term generation and calibration for accuracy in interpretation and repeatability.

In Session 1, panelists tasted scrambled eggs with specific highlighted appearance, flavor and texture attributes. Panelists were invited to generate terms to describe personal observations. Session 2 consisted of generating additional descriptive terms. In Session 3, redundant descriptive terms were removed and samples exhibiting specific attributes were tasted to fine-tune terms to include on ballots. Session 4 was designed to establish ballot anchors where all attributes and their synonyms were fitted on a standard unstructured line scale (14 cm). To assist panelists, terms were used to describe each attribute at low intensity (0 cm) and high intensity (14 cm). In Session 5, the ballots were tested by panelists in individual booths with unknown representative samples. Collected data were analyzed by analysis of variance (ANOVA) (Minitab Release 8, 1991), and panelist deviations were assessed to determine where additional training was needed. During the last session, Session 6, tasting results and panelists' deviations were discussed, and specific terms and anchors were clarified. Additional products were tasted to confirm panelist agreements of terms and anchors. Official product testing began the week following training.

Refresher Training. In order to assure panel accuracy after extended time between tasting sessions, refresher trainings were conducted 1 week prior to official tasting sessions. Sessions were set up to refresh panelists' memories of already familiar term definitions and anchors by using samples representing specific attributes.

Evaluation Sessions. For experimental testing, samples were labeled with random three-digit codes, matched with panelist number, in a randomized complete block design. In each session, panelists received a maximum of five samples to evaluate. For acclimation, the first sample received, only by the trained panelists, was fresh grilled scrambled eggs (eggs 77%, skim milk 20%, butter 1% and salt 0.3% in a total of 436 g per sensory run). Scrambled eggs were prepared by mixing fresh eggs, skim milk and salt until smooth, and frying at 190C on a buttered preheated electric skillet (Model 06829, Presto, Eau Claire, WI) until just firm, with no residual liquid.

The remaining experimental samples were served to panelists in random order. Control patties, initially frozen, were heated in boiling water for 20 min. HPHT- and retort-treated patties were reheated in a water bath at 50C. Freshly scrambled eggs and egg patties were placed in packages labeled with the randomized three-digit codes. All packages were kept in the 50C water bath until served. Preheated patties (#s 1, 2 and 3) served as controls, and treatments were the same for patties after HPHT or retort processing. Each sample was presented to each panelist in individual booths lighted with incandescent lights. Bottled water at room temperature was provided for each panelist between samples.

Consumer Panels. Consumer tests were run in three sessions, with 40 untrained consumers, simultaneously with trained panels. Consumers received the same samples described in the section Evaluation Sessions, except non-standard scrambled eggs, as responses would skew results. Scrambled eggs were used only for trained panel acclimation.

Consumer panelists filled in questionnaires that later allowed characterization of the overall profile of the panel and the panelists' preferences for shelf-stable egg products. All three panels were composed of fairly equal amounts of females (44–53%) and males (47–56%). Ages ranged between 18 to 56 years, while higher proportions ranged from 27 to 35 (20%) and 41 to 45 (18%) years of age. All consumers have previously eaten scrambled eggs and 53–59% would be interested in purchasing shelf-stable ready-to-eat products. Panelists evaluated control and treated egg patties for overall acceptability, appearance, aroma/flavor and texture using a 9-point hedonic scale (1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much and 9 = like extremely).

Analytical Testing

Resistance to Compression. Texture Profile Analysis (TPA) tests were performed to monitor firmness stability during storage studies explained later in the section on Incubation Studies and Shelf-Life Tests. A TA-XT2 Texture Analyzer (Stable MicroSystems Ltd., White Salmon, WA), fitted with a 5-kg load cell was used. Measurements were carried out using a cylindrical probe of 50.8-mm diameter on cylindrical pieces (25-mm diameter and 8.2 ± 1.5-mm thickness) of egg patty at 20C. The samples were compressed until 50% of the initial height, as per Montejano *et al.* (1985) using protein gels and Juliano *et al.* (2005) using egg patties, at a cross-head speed (and post-test speed) of 1 mm/s. The parameter hardness (N), determined from the peak force during the first compression cycle (Bourne 2002), was used to represent changes in firmness of the egg patty structure during storage.

Color Measurement. Testing of color degradation was through the CIE System evaluation using a colorimeter (Minolta CM-2002 Spectrophotometer, Camera Co., Osaka, Japan). Color was evaluated through the lightness L^* and the color intensity, or *chrome*, calculated using Eq. (3).

$$chrome = \sqrt{a^2 + b^2} \tag{3}$$

where $+a^*$ represents the red direction, $-a^*$ the green direction, $+b^*$ the yellow direction, and $-b^*$ the blue direction in the $L^*a^*b^*$ color space. *Chrome* value increases from the center of the chromaticity circle outward, and has been shown to represent yellowness levels on egg patties (Juliano *et al.* 2006).

Incubation Studies and Shelf-Life Tests

Shelf stability of formulations #2 and #3 after HPHT processing was evaluated using the end-point method, which consists of incubating samples at 37C and evaluating gas formation or package bulging at selected times (Guan *et al.* 2003). Ten pouches of each formulation, control and processed at HPHT1, HPHT2 and retort (Table 1), were incubated at 37C for 3 months. Half of the pouches were removed for testing and the other half continued in incubation for three additional months. The pouches were checked for bulging every 2 to 3 days during incubation. Bulged pouches were indicative of presence of gas forming bacteria. At the end of the incubation period, all pouches were opened, and those without signs of gas formation or putrefaction were tested for TPA hardness, lightness L^* and *chrome* (Eq. 3) to evaluate texture and color degradation during the incubation period.

Statistical Analysis

Minitab statistical package (Minitab Release and State College, PA 1991) was used to differentiate means of all descriptive sensory terms. The significance level was established at $P \leq 0.05$ in a completely randomized block (panelist) design with a one-way treatment structure. Trained and untrained panelists were the units of replication and panelists were treated as random effects.

Statistical differences between means of analytical texture and color data from accelerated shelf-life studies were found using the General Linear Models procedure in the SAS statistical package Version 9 (SAS/STAT Language, SAS Institute Inc., Cary, NC 2004), which performed ANOVA, Least Square Means and determination of standard errors.

TABLE 2.
CONSUMER EVALUATION OF PREHEATED AND HPHT PROCESSED EGG PATTIES*

Patty type†	Treatment	Overall	Appearance	Aroma/flavor	Texture
#1	Control	6.7 ± 1.5 c	6.9 ± 1.6 c	6.5 ± 1.5 c	6.4 ± 1.7 c
#2	Control	6.8 ± 1.6 c	6.8 ± 1.4 bc	6.5 ± 1.7 c	6.8 ± 1.7 c
#3	Control	6.3 ± 1.8 c	6.2 ± 1.7 bc	6.0 ± 2.0 c	6.4 ± 1.8 c
#2	HPHT1	6.0 ± 1.7 bc	5.4 ± 1.8 ab	6.2 ± 1.8 c	5.4 ± 1.9 bc
#3	HPHT1	4.8 ± 1.8 a	5.0 ± 1.8 a	4.6 ± 2.0 a	4.8 ± 1.6 ab
#3 / 5 % water	HPHT1	4.9 ± 1.8 ab	4.7 ± 2.2 a	4.8 ± 2.0 ab	4.8 ± 2.1 ab
#3	HPHT2	4.4 ± 2.0 a	4.8 ± 2.1 a	4.8 ± 1.9 ab	3.8 ± 2.2 a
#3	In-pouch retort‡	6.0 ± 1.5 bc	5.6 ± 2.1 ab	6.0 ± 1.6 bc	5.9 ± 1.8 bc

Different letters indicate significant differences between means within a column ($P \leq 0.05$).
* Acceptability scores of 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, and 7 = like moderately.
† #1 (standard egg patty); #2 (added cheese); #3 (added xanthan gum and flavors).
‡ Non conventional, because of rapid processing and use of products of thin cross section in small retort pouches.
HPHT, high pressure high temperature.

RESULTS AND DISCUSSION

Consumer panel overall acceptability of HPHT-treated egg patties and their controls will be presented in the following paragraphs. The following sections will specifically discuss consumer scores for overall acceptability, appearance, aroma and flavor, and texture and mouthfeel, respectively (Table 2). Each section includes results from the trained panel and instrumental results in order to provide interpretations of consumers' acceptability for each parameter. Shelf stability results will be described in the section, Shelf Stability of Control and Treated Egg Patties.

Overall Acceptability

Mean scores for consumer overall acceptability of control and treated scrambled egg patties are included in Table 2. In general, overall acceptability of controls was greater than HPHT-treated egg patties. Acceptability of HPHT-treated egg patties #3 (xanthan gum, no cheese) was lower than HPHT-treated egg patties #2 (cheese) and the controls. In particular, controls for egg patties #1 (standard, no cheese) and #2 (cheese) received overall acceptability mean scores close to "moderately liked," whereas control #3 (xanthan gum) was closer to being "liked slightly." When egg patty #2 (cheese) was high pressure treated at 700 MPa/105C/5 min (HPHT1), it provided similar overall acceptability to control patty #3 (xanthan gum, no cheese). HPHT1-treated patty #2 (cheese) was "slightly liked" by consumers whereas HPHT-treated formulation #3 (xanthan gum, no cheese) received significantly lower scores in overall acceptability. When looking at all acceptability parameters (including appearance, aroma/flavor and texture) for the HPHT1-treated patty #2 (cheese), acceptability values were lower in appearance and texture than the controls (Table 2). Discussions on the effect of HPHT on acceptability are shown in the following sections in terms of acceptability of appearance, flavor/aroma and texture, by comparing with trained panel attributes and analytical descriptors.

The #3 patties (xanthan gum, no cheese) treated at HPHT1 (700 MPa/105C/5 min) showed higher acceptability scores, although not significantly different ($P > 0.05$), than when treated at HPHT2 (700 MPa/121C/3 min). A higher pressurization temperature affected the overall acceptability of formulation #3 at a standard scenario of 700 MPa/121C, by mainly affecting texture, as seen by the lower (although not statistically significant) scores shown. Further sections give special attention to the relation between overall acceptability and the other acceptability parameters.

Rapid in-pouch retort sample #3 was "liked slightly," showing a similar acceptability profile to the HPHT1-treated patty #2. Retort treatment mostly affected appearance acceptability, as it is further explained. Concerning formulation #3, acceptability was higher after in-pouch retort than after both HPHT1 and HPHT2. The fact that the in-pouch retort patty underwent a rapid processing at 121C, because of the use of small pouches and low thermal load, explains the acceptable results. Conventional retort treatment on scrambled eggs packaged in larger volumes, such as trays, yield a product of brownish color and rubbery and grainy structure (Baliga *et al.* 1969; Song and Cunningham 1985; Luechapattanaporn *et al.* 2005). The use of smaller packages increased heat transfer rate, thereby providing a shorter process time than conventional treatment in cans. In general, the thinner shape of retort pouches offers less resistance to the transfer of heat with respect to cans, thereby decreasing process time and increasing energy efficiency (Barbosa-Cánovas and Juliano 2004).

An F_0 value of 3.3 min was obtained for HPHT2 using the temperature profile obtained at a standard sterilization scenario of 700 MPa/121C/3 min. Processing using rapid retort resulted in an F_0 of 5.6 min. Cook values (C_{100}) for HPHT2 treatment and retort were 16.4 and 30.4 min, respectively. The lower value for HPHT2 shows that the quality damage because of thermal factor should be lower if treated using HPHT2. However, combined pressure and temperature produced changes in the overall quality of the scrambled egg patties, some of which affected the acceptability of formulation #3 after HPHT treatment.

Even though 5–15% water addition to egg patty #3 improved water holding capacity after HPHT treatment patty (Juliano *et al.* 2005), consumer panelists determined no difference from the overall acceptability of the HPHT-treated patties #3 (plus 5% water). It was expected that water would soften the egg matrix and improve texture acceptability in formulation #3, thereby improving the overall acceptability score. However, the water-added product remained "neither liked nor disliked" by the consumers after HPHT processing in terms of overall acceptability, appearance, aroma/flavor and texture. Moreover, all descriptors from the trained panel and the colorimeter did not significantly change because of the addition of water in patty #3.

The mean values for appearance, aroma/flavor and texture in tested formulations at each treatment condition were, in general, similar to the overall acceptability values (Table 2). However, the formulation #3, treated at HPHT2, received lower scores for texture than for overall acceptability, appearance and aroma/flavor.

Appearance

Regarding appearance, HPHT treatment affected acceptability, as controls #1 and #2 ("liked moderately") and #3 ("liked slightly") were more acceptable than HPHT-treated patties, which were "neither liked nor disliked" (Table 2). As already mentioned, lower scores (although not significant; $P > 0.05$) in appearance values probably contributed to the slightly lower overall acceptability value found in HPHT-treated #2 patty, with respect to controls. The same could be argued for the in-pouch retort-treated patty #3, which was not significantly different from HPHT1-treated #2 patty, and showed lower acceptability scores than controls.

The trained panel only found significant differences among controls and HPHT2-treated egg patty #3 in gloss intensity, whereas differences were also found in yellowness (*chrome*) obtained from the colorimeter (Table 3). It is possible that lower values of yellow intensity in HPHT-processed formulation #3 influenced appearance acceptability with respect to the control. Differences in gloss between controls and HPHT-treated patty #3 were not verified by the L^* values in egg patties, and did not show significant changes because of high pressure and thermal treatment.

Trained panel scores in #3 patties, retort and HPHT treated, did not significantly differ from controls in green (to yellow) color (Table 3). However, scores for in-pouch retort-treated patty #3 were four times higher in green color than fresh scrambled eggs and control patty #1, which was indicative of the production of green FeS compounds (Song and Cunningham 1985). *Chrome* (yellow color) values, were maintained in egg patty #2 after HPHT1, as opposed to lower values found in HPHT and in-pouch retort-treated #3 egg patties. Lower *chrome* values in retort are in agreement with

TABLE 3.
SIGNIFICANT APPEARANCE DESCRIPTORS† AND *L** AND *CHROME* VALUES FOUND FOR CONTROL AND HPHT PROCESSED EGG PATTIES

Product	Treatment	Gloss intensity	Green color	*L**	*Chrome*
#1	Control	5.1 ± 1.1 a	0.1 ± 0.1 a	77.3 ± 4.3a	35.6 ± 2.0b
#2	Control	4.2 ± 0.9 a	0.8 ± 0.8ab	73.3 ± 3.9a	34.8 ± 2.5b
#3	Control	5.7 ± 0.7 a	0.6 ± 0.3 a	77.6 ± 2.5a	35.0 ± 1.2b
#2	HPHT1	9.4 ± 2.2ab	1.2 ± 1.2ab	75.7 ± 2.4a	33.8 ± 1.2b
#3	HPHT1	8.8 ± 1.2ab	1.6 ± 0.5ab	73.0 ± 2.9a	26.2 ± 1.4a
#3	HPHT2	11.5 ± 0.6 b	2.7 ± 1.1ab	77.3 ± 3.0a	27.1 ± 1.5a
#3	In-pouch retort	7.3 ± 1.4ab	4.3 ± 1.4 b	76.2 ± 3.4a	29.3 ± 1.6a

† Evaluation by trained sensory panel with 14 cm unstructured line scale.
HPHT, high pressure high temperature.

Luechapattanaporn *et al.* (2005), who also reported a decrease on +*b** value after retorting freshly scrambled eggs in polymeric trays after an F_0 of 4.6 min (about 80 min processing time).

Xanthophylls lutein, zeaxanthin and crypotaxanthin, i.e., carotenoids that provide yellow pigmentation in egg yolk (Yang and Baldwin 1995), were probably degraded during thermal pressurization. The #2 egg patties maintained their original color because of higher egg yolk content and possibly because of the presence of cheese in the mix. Indrawati *et al.* (2004) stated that high pressure treatment slightly affects the carotene content in food products, reporting only 5% losses after a treatment of 75C/600 MPa/40 min in carrot homogenates.

Aroma and Flavor

Aroma and flavor of control egg patties, HPHT1-treated patty #2, and in-pouch retort patty #3 were "slightly liked" by consumers (Table 2). HPHT-treated #3 patties were "neither liked nor disliked" and had significantly lower acceptability of aroma/flavor than all other patties. However, the trained panel found no significant differences among controls and HPHT-treated patties in most flavor attributes except for butter flavor intensity in formulation #3 control, salty tones in formulation #2, and overcooked flavors in retort-treated formulation #3.

The trained panel detected degradation of flavors in #3 patties after HPHT and retort because of lower butter notes (Table 4), indicative of degradation or volatilization of diacetyl compounds in formulation #3 (Andres 1983). Little is known about the effect of high pressure on butter flavor compounds, and much less has been studied on the effect of high pressure combined with high temperature. Observations in decreased butter notes coincided with those

TABLE 4.
SIGNIFICANT FLAVOR DESCRIPTORS* FOUND FOR CONTROLS AND HPHT-TREATED EGG PATTIES

Product	Treatment	Butter	Sulfur	Overcooked	Salty
#1	Control	4.2 ± 1.3 ab	3.7 ± 0.8 a	2.3 ± 0.8 ab	0.7 ± 0.3 a
#2	Control	5.8 ± 2.0 ab	3.4 ± 1.1 a	2.9 ± 0.9 ab	4.1 ± 1.9 b
#3	Control	9.0 ± 1.1 b	3.0 ± 0.5 a	0.4 ± 0.2 a	0.8 ± 0.3 a
#2	HPHT1	6.0 ± 2.2 ab	3.4 ± 1.2 a	1.9 ± 1.2 ab	5.2 ± 0.9 b
#3	HPHT1	3.3 ± 1.5 a	7.1 ± 1.1 a	0.1 ± 0.1 a	0.4 ± 0.2 a
#3	HPHT2	1.5 ± 1.4 a	4.7 ± 1.6 a	1.5 ± 1.1 ab	0.6 ± 0.3 a
#3	In-pouch retort	2.0 ± 2.0 a	3.5 ± 1.0 a	5.0 ± 1.9 b	0.4 ± 0.3 a

Different letters indicate significant differences between means ($P \leq 0.05$) within a column.
* Evaluation by trained sensory panel with 14 cm unstructured line scale.
HPHT, high pressure high temperature.

found by Juliano *et al.* (2006) after treating formulation #3 at 675 MPa/98C/5 min in a 1.7-L machine. Decreased butter flavor likely accounts for the lower aroma/flavor acceptability scores by consumers for HPHT-treated patty #3.

The trained panel did not identify significant differences in sulfur notes between HPHT-treated egg formulations and the controls (Table 4). Sulfur containing volatiles, hydrogen sulfide being the major component after heating eggs, contribute significantly to the overall flavor of eggs, mainly originating from egg whites (Chen and Hsu 1981; Warren and Ball 1991). Compounds such as dimethyl and trimethyl sulfide, identified for providing "sulfurous, bad egg odor" (MacLeod and Cave 1975), were probably not present in high amounts in HPHT-treated patty #3 because the average consumer panel scores did not reach the lower "slightly disliked" threshold of 4.0 (Table 2). Alternatively, the level found was not offensive for this set of consumers.

Retort-treated #3 patties were higher in overcooked flavor/aroma tones than #3 patties HPHT treated and control (Table 4). Nose burn aroma note is related to the production of ammonia and hydrogen sulfide upon heating the proteins of the egg white (Germs 1973; Warren and Ball 1991). Overcooked was enhanced after retort processing, but did not occur during HPHT processing (Table 4).

The control and HPHT-treated #2 egg patties (cheese), were significantly more salty than egg #3 control, HPHT- and retort-treated patties (Table 4). Cheese contained in formulation #2 probably increased the impression of saltiness, and no difference in perceived saltiness was seen in patty #2 (cheese) before or after HPHT processing. Comments from the consumer panel included that HPHT-treated patty #2 was "a good match of salty and acidic," which probably led to higher flavor acceptability than formulation #3 after HPHT treatment (Table 2).

Texture and Mouthfeel

Texture of control patties and in-pouch retort patty #3 were "slightly" to "moderately liked" by consumers. Although HPHT1 processed patty #2 was neither liked nor disliked, it was not significantly different from control patties (Table 2). On the other hand, consumers slightly disliked the texture of HPHT-treated patty #3. Treatment of egg patties #3 at 700 MPa/105C/5 min yielded higher texture acceptability scores than when treated at 700 MPa/121C/3 min. Thus, higher temperature, in combination with 700 MPa, decreased texture acceptability of formulation #3. In fact, trends in both texture and overall acceptability scores of HPHT-treated egg patties suggest texture was the controlling factor.

The trained panel supported the decrease in overall acceptability of HPHT-treated patties by describing them as significantly higher in firmness than control patty #3 (Table 5). However, no significant differences were found in firmness between HPHT-treated samples and controls #1 and #2. Juliano *et al.* (2005, 2006) reported increases in TPA hardness values after treating selected egg patty formulations at initial chamber temperature of 70–75C and pressures greater than 300 MPa, because of accelerated protein gelation in egg patties. Furthermore, a higher firmness in HPHT-treated products corresponded to higher product density, as seen when comparing formulations #2 and #3 before and after HPHT processing (Table 5). HPHT treatment also increased particle size perception of #3 patties compared with the controls when masticated (Table 5). Previous research also found high particle size scores in formulation #3 tested in a 1.7-L machine at 675 MPa/98C/5 min (Juliano *et al.* 2006). Furthermore, TPA cohesiveness also increased for formulation #3 after 700 MPa/105C/5 min, as reported by Juliano *et al.* (2005).

TABLE 5.
SIGNIFICANT TEXTURE AND MOUTHFEEL DESCRIPTORS* FOUND FOR CONTROLS AND HPHT-TREATED EGG PATTIES

Product	Treatment	Density	Firmness	Particle size	Oily
#1	Control	8.5 ± 0.8bc	7.4 ± 0.9bc	4.8 ± 1.2ab	4.1 ± 1.4ab
#2	Control	7.7 ± 1.1ab	7.6 ± 1.0bc	4.4 ± 1.7ab	1.0 ± 1.0 a
#3	Control	4.0 ± 0.8 a	3.2 ± 0.8 a	1.9 ± 0.7 a	1.2 ± 0.7 a
#2	HPHT1	11.9 ± 0.7 c	11.7 ± 0.7 c	7.9 ± 2.1 b	2.5 ± 1.9 a
#3	HPHT1	9.2 ± 1.2bc	10.5 ± 0.9 c	7.0 ± 1.3 b	8.0 ± 1.4 b
#3	HPHT2	12.5 ± 0.6 c	10.4 ± 1.4 c	8.1 ± 1.7 b	4.1 ± 1.8ab
#3	In-pouch retort	8.3 ± 2.2 b	6.3 ± 1.6ab	5.4 ± 1.4ab	4.7 ± 1.4ab

Different letters indicate significant differences between means ($P \leq 0.05$) within a column.
* Evaluation by trained sensory panel with 14 cm unstructured line scale.
HPHT, high pressure high temperature.

Even though firmness increased in egg patty #2 after HPHT treatment, overall and texture acceptability values (Table 2) were not significantly changed. Hence, an increase in firmness was not a determinant for the acceptability of formulation #2 after HPHT treatment, possibly because of the enhanced mouthfeel sensation provided by the added cheese.

Lower texture acceptability scores found by consumers in HPHT2-treated patty #3 with respect to in-pouch retorted patty #3 (Table 2), were also reflected in the trained panel. Higher firmness and density values were reported for the HPHT2-treated patty than retort #3 (Table 5). Hence, the sterilization scenario of 121C combined with 700 MPa, induced further gelation and hardening in comparison to a 121C treatment only.

In terms of mouthfeel, HPHT1-treated #3 patty was significantly more oily than #3 control (Table 5). An oily or slimy mouthfeel might be explained by increased oil leached out to the surface during pressurization (and protein gelation at high chamber temperatures). There is evidence that water leaches out of the egg patty matrix after treatment at egg gelation temperatures of 70C combined with pressures greater than 300 MPa (Juliano *et al.* 2006).

Because oily mouthfeel notes remained low in formulation #2, HPHT conditions might have only had an impact when cheese was not present in the formulation. Alternatively, and more likely, added cheese could have masked the oily mouthfeel. Shelke (2004) mentioned that cheese based ingredients "enhance" viscosity, and thereby creaminess and mouthfeel. In the case of HPHT-treated egg patties, a higher acceptability seen in HPHT processed formulation #2 (cheese) with respect to #3, is indicated by a lower oily mouthfeel tone as opposed to the scores obtained for HPHT-treated egg patties #3, which are closer to greasy and viscous notes.

HPHT2-treated egg patties #3 received higher mean scores for visual syneresis than control #3 patties. This is supported by findings by Juliano *et al.* (2006), who observed significantly higher syneresis (measured as % weight loss) in formulation #3 after HPHT treatment. A higher syneresis may have influenced the lower texture acceptability scores in formulation #3 obtained after HPHT treatment. On the other hand, patty #2 (cheese) maintained low visual syneresis scores after HPHT treatment, which was also supported by previous work (Juliano *et al.* 2006).

Shelf Stability of Control and Treated Egg Patties

Incubation tests at 37C were performed during 3 and 6 months. HPHT processed products did not produce gas or decompose for at least six months (Table 6). Control patties degraded after at least one week of incubation, some of them producing gas and some others undergoing proteolytic reactions; probably because of spoilage bacteria (Lake *et al.* 1985) that survived that the

TABLE 6.
PERCENTAGE OF PACKAGES SHOWING GAS FORMATION AND/OR PRODUCT DECOMPOSITION, AFTER 3- AND 6-MONTH INCUBATION AT 37C, OF EGG PATTY FORMULATIONS #2 (CHEESE) AND #3 (XANTHAN GUM) TREATED AT 700 MPa/105C (HPHT1), AND FORMULATION #3 TREATED AT 700 MPa/121C (HPHT2) AND IN-POUCH RETORTED

Patty	Treatment	Storage time at 37C	Gas formation/decomposition
#3	Control	3 months	Positive (100%)
#3	Control	6 months	Positive (100%)
#3	HPHT1	3 months	Negative
#3	HPHT1	6 months	Negative
#3	HPHT2 ($F_0 = 3.3$ min)	3 months	Negative
#3	HPHT2 ($F_0 = 3.3$ min)	6 months	Negative
#3	In-pouch retort ($F_0 = 5.6$ min)	3 months	Positive (10%)*
#3	In-pouch retort ($F_0 = 5.6$ min)	6 months	Positive (10%)*
#2	HPHT1	3 months	Negative
#2	HPHT1	6 months	Negative

* Complete product degradation without gas formation.
HPHT, high pressure high temperature.

milder heat treatment. In-pouch retort-treated patties #3 had 10% positive samples after 3 months of incubation. It is possible that some spore forming spoilage bacteria survived the in-pouch retort treatment.

After 3 months, a darker surface was observed in all patties because of browning, which was reflected by lower L^* values, indicating that 37C is a harsh condition for storage of egg-based products for long periods of time.

Egg patty #3, retort and HPHT treated, did not change significantly in hardness and *chrome* during incubation at 37C for up to 6 months (Table 7), whereas HPHT1-treated patty #2 showed increasingly higher hardness values and lower yellow color, indicated by L^* and *chrome* values. Changes in *chrome* can also be directly related to the browning occurring during storage; however, there are other reasons that could explain changes in texture in egg patty #2: (1) continuing gelation during storage at 37C; (2) low serum remaining in the package after thermal pressurization; and (3) permeation of water outside the package.

Gelation did not occur to a great extent in formulation number #3, as shown by hardness values, which remained practically unchanged throughout the storage time (Table 7). A factor that contributed to maintaining or increasing texture could be the water released inside the package after thermal pressurization. Previous work on egg patty formulations #2 and #3, showed that #2 patties gave 2–3% free liquid inside the package immediately after

TABLE 7.
ACCELERATED SHELF-LIFE TEST OF FORMULATIONS #2 (CHEESE) AND #3 (XANTHAN GUM) TREATED AT 700 MPa/105C (HPHT1), AND FORMULATION #3 TREATED AT 700 MPa/121C (HPHT2) AND IN-POUCH RETORTED

Patty	Treatment	Storage time at 37C	TPA hardness (N)	*L**	*Chrome*
#3	HPHT1	0 month	35.5 ± 7.0a	80.3 ± 0.8 c	26.2 ± 0.7 a
		3 months	35.6 ± 5.4a	73.3 ± 0.7 b	29.2 ± 0.6 a
		6 months	46.1 ± 6.1a	67.6 ± 0.9 a	29.7 ± 0.8 a
#3	HPHT2	0 month	36.5 ± 5.5a	78.7 ± 0.8 c	27.1 ± 0.7 a
	(F_0 = 3.3 min)	3 months	49.9 ± 5.5a	71.8 ± 0.8 b	27.7 ± 0.7 a
		6 months	49.7 ± 5.5a	65.5 ± 0.8 a	28.4 ± 0.7 a
#3	In-pouch retort	0 month	24.3 ± 5.7a	76.2 ± 0.9 b	29.3 ± 0.8 a
	(F_0 = 5.6 min)	3 months	24.7 ± 5.7a	72.3 ± 0.9 a	29.1 ± 0.8 a
		6 months	29.5 ± 5.5a	71.9 ± 0.8 a	28.5 ± 0.7 a
#2	HPHT1	0 month	35.1 ± 4.5a	77.1 ± 0.6 c	33.8 ± 0.5 a
		3 months	73.8 ± 6.1b	70.9 ± 0.8 b	32.6 ± 0.7 a
		6 months	120.7 ± 5.5c	53.2 ± 0.8 a	35.0 ± 0.7 b

TPA hardness and color values after 0, 3 and 6 months storage at 37C. Different letters within the same treatment indicate significant differences between means ($P \leq 0.05$) within a column.
TPA, texture profile analysis.
HPHT, high pressure high temperature.

HPHT1, whereas HPHT1-treated formulation #3 gave 8–10% (Juliano *et al.* 2006). Therefore, a higher serum surrounding the surface of patty #3 could have contributed to maintaining the softness of the patty #3, as opposed to patty #2.

Permeation of water out of the package could be another factor that may have increased the hardness in patty #2 during storage, besides the low residual serum yielded. Little is known about the vapor permeability of packages after HPHT treatment, which might be increased. In fact, after incubation, both formulations were observed to have reduced free liquid remaining in the package (data not shown). The surface of the HPHT1-treated patty #2 looked drier, and no residual fluid was left on it, indicative of slow water diffusion during storage at 37C, which thereby created a harder structure. This phenomenon depends not only on the type of packaging film used, but also on the thickness of the sample, which sets its ability to retain water.

CONCLUSIONS

Selected scrambled egg patty formulations were evaluated after HPHT treatment by using trained and consumer panels. The formulation with added cheese (#2) was found to provide highest acceptability (liked slightly) while the egg patty with added xanthan gum and flavors was neither liked nor disliked by consumers after HPHT processing. Addition of cheese significantly helped maintain color and appearance, flavor/aroma and texture/mouthfeel after HPHT treatment, regardless of the increased firmness observed by the trained panel. Degradation of yellow color and flavors, and a firmer texture induced by the thermal pressurization process at 105 or 121C were the main causes for lower overall acceptability values obtained in formulation #3. The main factor controlling overall acceptability was the change in texture acceptability, as also evidenced by increases in firmness, density and TPA hardness after HPHT.

Consumer acceptability of an HPHT-treated egg patty formulation with added processed cheese shows that HPHT processing may be a potential alternative for the production of novel shelf-stable egg products for an increasing ready-to-eat meal market. Further consumer acceptability studies should be carried out to evaluate treated egg-based products as ready-to-eat shelf-stable products, i.e., without presenting untreated controls or benchmark products to consumers. This would determine their potential as outdoor, humanitarian or military products intended for places with low availability of fresh eggs.

The small packages used for novel in-pouch retort, as applied to egg patty #3, provided a good environment for sterilization. Because of the short times needed to reach an F_0 value of 5.6 min, the time products were "slightly liked" by consumers. This is opposed to previous information on conventional retort treatment on scrambled eggs packaged in trays and cans, where product quality was deleterious. It is expected that when sterilizing egg products of larger size under HPHT conditions, instant compression heating will allow for a shorter process resulting than retort, and therefore will improve product quality. Results on accelerated shelf stability proved that the HPHT process maintained analytical descriptors for texture and color in egg patties, while preventing product decomposition and gas production. Thus, accelerated shelf-life testing has established that the HPHT process can potentially provide extended shelf stability for egg-based products at room temperature conditions. On the other hand, identification of suitable packaging capable of providing oxygen and water barriers following HPHT processing is essential to continuing further studies on shelf stability.

Compression heating not only allows a shorter process, but also gives the appropriate HPHT conditions for inactivation of spore-forming spoilage bacteria. Further data collection on inactivation on *C. botulinum* strains at HPHT conditions will enable validation of process sterilization conditions. This will allow guidance to authorities in the regulatory approval process for this technology. The fact that HPHT processing technology can yield acceptable egg products, a very heat labile material, indicates its potential for the production of prepared shelf-stable low-acid foods containing meats or vegetables.

ACKNOWLEDGMENTS

Financial and technical support was provided by the Defense Logistics Agency Combat Rations Network, Natick Soldier Center, and the International Marketing Program for Agricultural Commodities and Trade at Washington State University. We also thank Michael Foods Egg Products Company and ALCAN Packaging for their significant contribution to this project. Last but not least, we acknowledge Research Technologist Michael Costello, Washington State University, and all the trained and consumer panelists for their important and extremely valuable participation.

REFERENCES

AHN, J., BALASUBRAMANIAM, V.M. and YOUSEF, A.E. 2005. Effect of pressure-assisted thermal processing on the inactivation of selected *Clostridium* and *Bacillus* surrogate spores [abstract]. In Nonthermal Processing Workshop. USDA Eastern Regional Research Center, Philadelphia, PA. September 15–16.

AMERICAN EGG BOARD. 2004. *EGGSolutions™. The Complete Reference for Egg Products*, American Egg Board, Park Ridge, IL.

ANDRES, C. 1983. Concentrated natural butter flavor. Food Process. *44*(12), 76.

BALASUBRAMANIAM, S. and BALASUBRAMANIAM, V.M. 2003. Compression heating influence of pressure transmitting fluids on bacteria inactivation during high pressure processing. Food Res. Int. *36*(7), 661–668.

BALIGA, B.R., RAO, A.S. and LAHIRY, N.L. 1969. Prevention of browning in hard boiled eggs during canning. J. Food Sci. Technol. *6*(3), 200–204.

BARBOSA-CÁNOVAS, G.V. and JULIANO, P. 2004. Adaptation of classical processes to new technical developments and quality requirements. J. Food Sci. *69*(5), E240–E250.

BOURNE, M. 2002. *Food Texture and Viscosity. Concept and Measurement*, pp. 182–186, Academic Press, New York, NY.

CHEN, T.C. and HSU, S.Y. 1981. Quality attributes of whole egg and albumen mixtures cooked by different methods. J. Food Sci. *46*, 984–986.

DUNNE, C.P. 2005. U.S. Army Natick Soldier Center, Department of Defense. Personal communication, August 5.

FRONING, G.W. 2006. Food science and technology advisor. American Egg Board. Personal communication, February 7.

GERMS, A.C. 1973. Hydrogen sulfide production in eggs and egg products as a result of heating. J. Sci. Food Agric. *24*, 7–16.

GOLA, S., FOMAN, C., CARPI, G., MAGGI, A., CASSARA, A. and ROVERE, P. 1996. Inactivation of bacterial spores in phosphate buffer and in vegetable cream treated with high pressure. In *High Pressure Bioscience and Biotechnology* (S. Schuppan, ed.) pp. 253–259, Elsevier Science, Kyoto, Japan.

GUAN, D., GRAY, P., KANG, D.H., TANG, J., SHAFER, B., ITO, K., YOUNCE, F. and YANG, T.C.S. 2003. Microbiological validation of microwave-circulated water combination heating technology by inoculated pack studies. J. Food Sci. *68*(4), 1428–1432.

HEINZ, V. and KNORR, D. 2001. Effect of high pressure on spores. In *Ultrahigh Pressure Treatment of Foods* (M.E.C. Hendrickx and D. Knorr, eds.) pp. 77–116, Kluwer Academic/Plenum Publishers, New York, NY.

HOLDSWORTH, S.D. 1997. *Thermal Processing of Packaged Foods*, Blackie Academic and Professional, New York, NY.

INDRAWATI, V.A.N., LOEY, A. and HENDRICKX, M. 2004. High pressure processing. In *Nutrition Handbook for Food Processors* (C.J.K. Henryand C. Chapman, eds.) pp. 440–448, Woodhead Publishing, New York, NY.

JULIANO, P., TOLDRÁ, M., KOUTCHMA, T., BALASUBRAMANIAM, V.M., CLARK, S., MATHEWS, J.W., DUNNE, C.P., SADLER, G. and BARBOSA-CÁNOVAS, G.V. 2005. Texture and water retention improvement in high pressure thermally sterilized scrambled egg patties. J. Food Sci. *71*(2), E52–E61.

JULIANO, P., LI, B., CLARK, S., MATHEWS, J.W., DUNNE, C.P. and BARBOSA-CÁNOVAS, G.V. 2006. Quality and sensory analysis of precooked egg products after high pressure processing combined with low and high temperatures. J. Food Quality *29*(5), 505–530.

KNIPPER, A.J. and BEAM, L.S. (2002). Enhanced precooked egg product and process for formulation of precooked egg products. U.S. Patent 6, 413, 572. Michael Foods of Delaware, Inc., July 2.

KOUTCHMA, T., GUO, B., PATAZCA, E. and PARISI, B. 2005. High pressure – high temperature inactivation of *Clostridium sporogenes* spores: From kinetics to process verification. J. Food Process Eng. *28*(6), 610–629.

KREBBERS, B., MATSER, A.M., KOETS, M. and BERG, R.W. 2002. Quality and storage stability of high-pressure preserved green beans. J. Food Eng. *54*(1), 27–33.

KREBBERS, B., MATSER, A.M., HOOGERWERF, S.W., MOEZELAAR, R., TOMASSEN, M.M.M. and BERG, R.W. 2003. Combined high-pressure and thermal treatments for processing of tomato puree: Evaluation of microbial inactivation and quality parameters. Innov. Food Sci. Emerg. Technol. *4*(4), 377–385.

LAKE, D.E., GRAVES, R.R., LESNIEWSKI, R.S. and ANDERSON, J.E. 1985. Post-processing spoilage of low-acid canned foods by mesophilic anaerobic sporeformers. J. Food Prot. *48*(3), 221–226.

LUDIKHUYZE, L. and HENDRICKX, M.E.G. 2001. Effects of high pressure on chemical reactions related to quality. In *Ultra High Pressure Treatments of Foods* (M.E.G. Hendrickx and D. Knorr, eds.) pp. 167–188, Kluwer Academic/Plenum Publishers, New York, NY.

LUECHAPATTANAPORN, K., WANG, Y., WANG, J., TANG, J., HALLBERG, L.M. and DUNNE, C.P. 2005. Sterilization of scrambled eggs in military polymeric trays by radio frequency energy. J. Food Sci. *70*(4), 288–294.

LUND, D.B. 1986. Kinetics of physical changes in foods. In *Physical and Chemical Properties of Food* (M.R. Okos, ed.) pp. 367–381, American Society of Agricultural Engineers, St. Joseph, MI.

MACLEOD, A.J. and CAVE, S.J. 1975. Volatile flavor components of eggs. J. Sci. Food Agric. *26*, 351–360.

MARGOSCH, D. 2005. Behavior of bacterial endospores and toxins as safety determinants in low acid pressurized food. Dissertation, TU Berlin, Germany.

MARGOSCH, D., EHRMANN, M.A., GAENZLE, M.G. and VOGEL, R.F. 2004. Comparison of pressure and heat resistance of *Clostridium botulinum* and other endospores in mashed carrots. J. Food Prot. *67*(11), 2530–2537.

MATSER, A.M., KREBBERS, B., VAN DEN BERG, R.W. and BARTELS, P.V. 2004. Advantages of high pressure sterilization on quality of food products. Trends Food Sci. Technol. *15*(2), 79–85.

MERKLE, J., BALL, H. and MATHEWS, J. (2003a). Formulation and process to prepare a premium formulated fried egg. U.S. Patent 30, 118, 714. Michael Foods of Delaware, Inc., June 26.

MERKLE, J., BALL, H. and MATHEWS, J. (2003b). Formulation and process to prepare a premium formulated fried egg. U.S. Patent 30, 134, 030. Michael Foods of Delaware, Inc., July 17.

MEYER, R.S., COOPER, K.L., KNORR, D.E. and LELIEVELD, H.L.M. 2000. High-pressure sterilization of foods. Food Technol. *54*, 67–73.

MONTEJANO, J.G., HAMANN, D.D. and LANIER, T.C. 1985. Comparison of two instrumental methods with sensory texture of protein gels. J. Texture Studies *16*(4), 403–424.

RAJAN, S., AHN, J., BALASUBRAMANIAM, V.M. and YOUSEF, A.E. 2005. Combined pressure-thermal inactivation kinetics of *Bacillus amyloliquefaciens* spores [abstract no. 23.] Nonthermal Processing Workshop. USDA Eastern Regional Research Center, Philadelphia, PA. September 15–16.

RAJAN, S., PANDRANGI, S., BALASUBRAMANIAM, V.M. and YOUSEF, A.E. 2006. Inactivation of *Bacillus stearothermophilus* spores in egg patties by pressure assisted thermal processing. LWT-Food Sci. Technol *39*(8), 844–851.

RASO, J., BARBOSA-CÁNOVAS, G.V. and SWANSON, B.G. 1998. Sporulation temperature affects initiation of germination and inactivation by high hydrostatic pressure of *Bacillus cereus*. J. Appl. Microbiol. *85*, 17–24.

ROVERE, P., GOLA, S., MAGGI, A., SCARAMUZZA, N. and MIGLIOLI, L. 1998. Studies on bacterial spores by combined pressure-heat treatments: Possibility to sterilize low acid foods. In *High Pressure Food Science, Bioscience and Chemistry* (N.S. Isaacs, ed.) pp. 354–363, The Royal Society of Chemistry, Cambridge.

ROVERE, P., SQUARCINA, N., GOLA, S., SANDEI, L., IAMETTI, S. and CARPI, G. 2000. Effect of thermal treatment under high pressure on the quality of a meat sauce. High Pressure Res. *19*, 99–107.

SHELKE, K. 2004. Cheese targets all the trends. Food Process. *65*(10), 41–47.

SONG, I.S. and CUNNINGHAM, F.E. 1985. Prevention of discoloration in retorted whole egg. J. Food Sci. *50*(3), 841–842.

STUMBO, C.R. 1973. *Thermobacteriology in Food Processing*, 2nd Ed., Academic Press, New York, NY.

TURNER, J. 2003. Eggs-traordinary. Food Prod. Des. *13*(8), (November Suppl.)

VAN LOEY, A., OOMS, V., WEEMAES, C., VAN DEN BROECK, I., LUDIKHUYZE, L., INDRAWATI, D.S. and HENDRICKX, M. 1998. Thermal and pressure-temperature degradation of chlorophyll in Broccoli (*Brasssica oleraces L. italica*) juice: A kinetic study. J. Agric. Food Chem. *46*, 5289–5294.

WARREN, M.W. and BALL, H.R. 1991. Effect of concentration of egg yolk and white on fresh scrambled egg flavor. Poult. Sci. *70*, 2186–2190.

WESLEY, R.D., ROUSSELLE, J.R., SCHWAN, D.R. and STADELMAN, W.J. 1982. Improvement in quality of scrambled egg products served from steam table display. Poult. Sci. *61*(3), 457–462.

YANG, S.H. and BALDWIN, R.E. 1995. Functional properties of egg products. In *Egg Science and Technology*, 4th ed. (W.J. Stadelman and O.J. Cotterill, eds.) pp. 405–464, Food Products Press, New York, NY.