# DESCRIPTIVE ANALYSIS OF PRECOOKED EGG PRODUCTS AFTER HIGH-PRESSURE PROCESSING COMBINED WITH LOW AND HIGH TEMPERATURES


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## ABSTRACT

*The quality descriptors of precooked scrambled egg patties were evaluated after high-pressure treatment at low and high temperatures. A commercial egg patty was thermally pressurized at 90C/0.1–675 MPa and 30–90C/675 MPa. A trained descriptive panel evaluated untreated and treated products. Additional tests included texture profile analysis, color, pH and water loss. After treatment at 30C/675 Mpa, the egg patty maintained its sensory profile. Treatments at gelation temperatures ≥70C and 675 MPa increased firmness and density scores, and water loss, compared to lower temperatures. Formulation modification with xanthan gum, ethylenediaminetetraacetic acid (EDTA) and flavors reduced the instrumental hardness by 25–41%, while syneresis decreased 50–55%, in agreement with findings of smaller particle size, smoother mouthfeel and lower dryness scores. The flavor profile of modified formulation after 70C/675 MPa or 90C/675 MPa treatments was similar to controls. Reformulation with xanthan gum, EDTA*



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*and flavors allowed maintenance of initial characteristics after thermal pressurization. High-pressure processing at low temperatures is promising for preserving precooked scrambled egg patties while retaining sensory profile at selected conditions.*

## INTRODUCTION

Precooked specialty egg products such as egg patties, omelets or cook-in-bag scrambled eggs are mainly sold in frozen form to fast-food outlet chains in the food service industry (Baker and Bruce 1995). However, precooked egg products, to be stored at room temperature, are not yet offered. In fact, only a few companies offer ready-to-eat scrambled eggs and whole hard-cooked/peeled eggs with a shelf life of 6–12 weeks at refrigerated conditions (AEB 2003). The main challenge is to assure product safety during cooling, packaging and postpackaging stages. This requires either additional thermal treatment, or an alternative treatment that has minimal effects on the product's final quality. Furthermore, egg patties and omelets are often vacuum-packaged in multiple amounts. If a thermal postpackaging treatment is applied, these products will need to handle long periods of heat exposure, to reach the target process temperature throughout the entire package volume.

Long-time exposure to temperatures higher than 70C can cause deleterious effects on products, such as color degradation, texture changes and syneresis or liquid separation (Wesley *et al*. 1982). In fact, the development of shelf-stable egg-based breakfast items through commercial sterilization techniques has been a significant challenge because of the deleterious effect on egg product appearance (Baliga *et al*. 1969; Luechapattanaporn *et al*. 2005). During retort process, undesirable phenomena such as green-gray discoloration of egg products from formation of ferrous sulfide (Song and Cunningham 1985), the development of off-flavors, and syneresis after heat treatment (Cotterill 1995) can occur.

High-pressure processing (HPP) is commercially used today as an alternative preservation method for prepackaged processed products such as ham. The use of low or mild heat prevents flavor degradation and nutrient content reduction compared to conventional heat treatments (San Martín *et al*. 2002). Furthermore, HPP possesses the advantage of instant volumetric pressurization throughout the entire package volume. As a result, instant pressure "penetration" allows attaining similar pressurization times for larger packages.

Pressure vessels at initial room temperature and pressures from 200 to 800 MPa have been used to inactivate vegetative pathogenic and spoilage bacteria (Margosch *et al*. 2004). In addition, when elevated initial temperatures (e.g., between 60 and 90C) are combined with pressures greater than 600 MPa in the pressurization vessel, product sterilization times can be reduced compared to retort processes (Matser *et al.* 2004). The main reason for bacterial spore inactivation is internal compression heating, which can reach in-process temperatures ranging from 90C to greater than 121C, depending on the pressure applied and the initial temperature of the food and vessel.

Microbial studies proved that an initial chamber/product temperature of 75–80C and a pressure of 600–827 MPa can effectively inactivate target heat-resistant spore-forming bacteria commonly used as indicators of food safety and shelf stability (Heinz and Knorr 2001). For example, *Bacillus stearothermophilus* spores were reduced 6 log in egg patties at 75C/700 MPa/5 min (Koutchma *et al.* 2005; Rajan *et al.* 2006). Furthermore, studies on target microorganism for inactivation and safety assurance of canned food products, *Clostridium botulinum*, have shown a large variation in the pressure resistance of different spore strains between 80C/600 MPa/1 s and 75C/827 MPa/20 min (Reddy *et al.* 1999, 2003; Margosch *et al.* 2004; Margosch 2005). Because spore resistance also proved to be product-dependent, more research is needed to find the optimum inactivation pressure/temperature/time conditions for *C. botulinum* strains in precooked egg products, which seem to be a suitable medium for spore germination (Margosch 2005).

The use of high pressure in combination with heat has been identified as a promising approach for providing commercially sterile precooked specialty egg products with improved appearance and greater appeal than retort products. Indeed, a number of high-pressure high-temperature (HPHT)-treated low-acid foods such as meat, milk and vegetable products showed more desirable texture, color and flavor and aroma retention in comparison to retorted products and, in some cases, to frozen products (Hoogland *et al.* 2001; Krebbers *et al.* 2002, 2003; Matser *et al.* 2004).

Previous studies on high-pressure formation of gels of whole liquid eggs, egg white, egg yolk and egg yolk/white (Messens *et al.* 1997; Ponce *et al.* 1998; Lee *et al.* 1999; Ma *et al.* 2001; Ahmed *et al.* 2003) have shown that pressures greater than 600 MPa not only increase apparent viscosity, but also provide instantaneous gelation of egg yolk and egg white. Pressure-formed egg-based gels have been shown to retain vitamins, amino acid residues, flavor and color compared to heat-induced gels (Hayashi *et al.* 1989; Guamis *et al.* 2005). However, no research has been conducted on the sensory profile and physical characteristics of precooked formulated egg products after HPP. Thus, the need to identify stabilized precooked egg products and acquire data on attributes of these products after high-pressure treatment at low and high temperatures has led to this study.

The objective of this research was to analyze preformulated egg patties treated at high-pressure/low- and high-temperature conditions using sensory descriptors and physical analyses.

## MATERIALS AND METHODS

### Preparation of Egg-Based Products

Michael Foods Egg Products Company (Gaylord, MN) provided a round commercial scrambled egg patty (#1, code 46025-30020-00) and a modified formulation (#2, code 03-1426-10). The selected egg patties were 42.5 ± 7.1 g in weight and 88.9 ± 6.4 mm in diameter. Formulation #1 is a standard Michael Foods patty and has the following basic ingredients: whole eggs, water, soybean oil, modified food starch, whey solids, salt, nonfat dried milk and citric acid. Formulation #2 had added natural and artificial flavors, xanthan gum and ethylenediaminetetraacetic acid (EDTA), and a lower egg: water ratio.

The preparation of precooked scrambled egg products has been reported in different patents developed by Michael Foods (Knipper *et al*. 2002; Merkle *et al*. 2003a,b). Whole eggs were mixed with dry and liquid ingredients, and then the mixture was pumped into a mold within a flat cooking belt. Egg mixture portions were cooked (or formed) in a convection oven at 180–250C for a predetermined time, then frozen and packaged.

Handling and shipping procedures for scrambled egg patties were performed according to an industrial setting, where patties would be stored in a frozen state before HPP treatment. Frozen samples from a single lot were received from Michael Foods and stored frozen at −30C. Each patty was cut in half and repackaged in retort pouches (Smurfit-Stone, Schaumburg, IL) measuring 6.0 × 10.3 cm. The vacuum packaging machine was a Tabletop vacuum chamber (KOCH 15-EasyPack, Kansas City, MO) used at 400-mbar absolute pressure. The retort packaging material composition was 12.2-µm PET/adhesive/aluminum foil/adhesive/4.0-mL polyolefin. The samples were kept frozen until high-pressure treatments.

### Preheating and High-Pressure Treatments

Egg patties were preheated using a water bath at boiling temperature (98C) (corresponding to 715 m above sea level) in a tilting steam kettle (DLT-40-1EG, Groen, DI Food Service Companies, Jackson, MS). The temperature of patties was measured using a thermocouple (T-type, Omega Engineering, Inc., Stamford, CT) affixed by a stuffing box (Ecklund Harrison Technologies, Fort Myers, FL) at the center of the egg patties.

Table 1 shows the factorial design of the two experiments performed. The first experiment processed two formulations at varied initial chamber temperatures and 675 MPa for 5 min. The main purpose was to identify the effect of temperature on the sensory attributes and physical characteristics of different egg formulations at high-pressure conditions which, combined with selected

TABLE 1.
EXPERIMENTAL DESIGN FOR SELECTED FORMULATIONS AND PROCESSING CONDITIONS

| Experiment | Treatment combinations | Levels | Design |
|---|---|---|---|
| 1 | Processing × Initial chamber/product temp. × Formulation | Control, pressure (675 MPa, 5 min)<br>30C, 50C, 70C, 90C<br>#1, #2 | 2 × 4 × 2 factorial three replicates |
| 2 | Processing × Pressure × Formulation | Control, pressure (chamber 90C, 5 min)<br>0.1 MPa, 300 MPa, 500 MPa, 675 MPa<br>#1 | 2 × 4 × 1 factorial two replicates |

temperatures, can pasteurize (low temperature) or sterilize (high temperature) egg products. Initial high-pressure chamber and product temperatures were the same. Comparisons were made with nonpressure-treated controls preheated up to the same initial product temperatures. Samples were preheated in a boiling water bath for 2.5 ± 0.2 min to reach 30C, 3.4 ± 0.2 min to reach 50C, 6.5 ± 0.5 min to reach 70C and 15 ± 1.0 min to reach 90C inside the half patty. The patties were placed in water baths at each respective preheat temperatures for 5 min to equilibrate, and then loaded into a cylindrical liner made of white polypropylene (internal diameter 75 mm, external diameter 100 mm, height 21.5 mm; McMaster-Carr, Atlanta, GA). The liner was also previously temperature-equilibrated and filled with water at the corresponding temperature to maintain the temperature of product/water/liner system at chamber temperature.

After equilibration, the liner containing egg patties was inserted into a 1.7-L high-pressure chamber (model #914-100, Engineered Pressure Systems, Inc., Haverhill, MA) with 5% Houghton Hydrolubic 123B soluble oil/water solution (Houghton & Co, Valley Forge, PA) as the pressure medium. The system was equipped with two thermocouples (T-type, Omega Engineering, Inc.), which controlled the water temperature inside the liner. Times for pressure came up averaging 2.5 ± 0.3 min for 300 MPa, 3.5 ± 0.5 min for 500 MPa and 4.2 ± 0.5 min for 675 MPa. Following the pressure treatment, pouches containing egg patties were cooled in an ice bath. The total process time, including the preheating step in boiling water bath, ranged from 18 to 21 min. Table 2 shows the liner temperatures before, during pressurization and after pressure release.

The second experiment (2) was performed in the same way by only using formulation #1 at initial product/liner/chamber temperature of 90C for

TABLE 2.
TEMPERATURE PROFILE AT DIFFERENT TEMPERATURE-PRESSURE COMBINATIONS INSIDE LINER

| Pressure (MPa) | Initial (C) | In-process initial* (C) | Final† (C) |
|---|---|---|---|
| 300 | 90.6 ± 3.0 | 106.4 ± 3.3 | 88.2 ± 2.9 |
| 500 | 90.9 ± 1.3 | 114.7 ± 1.6 | 85.8 ± 1.5 |
| 675 | 30.1 ± 1.5 | 50.2 ± 1.9 | 27.6 ± 1.9 |
| 675 | 51.5 ± 0.5 | 74.9 ± 1.5 | 47.4 ± 1.2 |
| 675 | 70.4 ± 3.2 | 98.4 ± 3.6 | 66.8 ± 2.1 |
| 675 | 91.0 ± 2.4 | 121.0 ± 3.5 | 83.3 ± 0.1 |

* Initial temperature at 675 Mpa.
† Temperature after pressure was released.

different pressures (Table 1). This experiment aimed to show the effect of pressure levels, lower than 675 MPa, on the final physical characteristics of egg patties when combined with a high initial temperature of 90C.

## Product Analyses

Egg products (before and after treatment) were evaluated by a trained descriptive panel, texture profile analysis (TPA), serum content, color and pH analyses.

**Trained Descriptive Panel.** A six-member (one man, five women) descriptive panel was trained to use 29 terms for appearance, texture and flavor attributes. All sensory parameters were based on a standard 0–14 unstructured line scale, arranged in a two-page sensory ballot (Fig. 1). Training was based on trial sessions (a total of 6 and 1 h of review for each subsequent month during the study), and the ability of panelists to discriminate and reproduce results was tested in replicate tests on freshly scrambled eggs and preheated egg patties. Evaluation instructions were given orally during training sessions according to grilled scrambled eggs prepared at different conditions (scorched, retorted), with added ingredients (hard-boiled egg yolk, salt, pepper, citric acid, oxidized oil, soybean oil), or cooked differently (egg patties). The panelists were trained to differentiate among these eggs according to each attribute. The panelists agreed to methods (compression with tongue on roof of mouth, time to wait before noting aftertaste) that would be used to determine levels for given attributes.

Standard freshly grilled scrambled eggs were received by the trained panelists as the very first (reference) sample at the beginning of each session for panelist acclimation every test day. The panelists used the reference to recalibrate as necessary at the start of each panel, but the sample was removed

**Scrambled Eggs Sensory Evaluation**

**Sample number**____________ **Code** _______________

**Appearance**

| | | |
|---|---|---|
| **Dull/**Flat *surface intensity* | | **Glossy**/Shiny/Bright |
| **Yellow (***no grey-green***)** | | **Grey-Green** coloration |
| **Smooth**/Closed *(surface texture)* | Open/Spongy/Airy | **Rough**/Non-uniform |
| **Cohesive** (eggs hold together) | | **Crumbly** (eggs fall apart) |
| **No Syneresis (***no liquid separation***)** | Watery fluid | **Oily/Viscous** fluid (on plate) |

**Texture/Mouthfeel**

| | | |
|---|---|---|
| **Light**/Foamy/Airy | Yielding/Coll apsing/Compliant **(***Standard scrambled eggs)* | **Dense**/Heavy body |
| **Mushy**/Tender/Soft | Spongy/Squishy | **Firm**/Hard/Rigid/**Rubbery**/Springy/Chewy/Elastic |
| **Smooth** *mouthfeel* | | **Rough** *mouthfeel* |
| **Tiny particle size (***breakdown in mouth***)** | Mealy/Grainy | **Large**/Lumpy **(***breakdown of particles***)** |
| **Moist**/Moisture Release *in mouth* | | **Dry**/Crispy (no moisture release) |
| **Not** | | **Astringent**/Tangy/Tingling/Puckering/**Mouth Drying** |
| **Not** | | **Oily**/Silky/Slick/Slimy/Greasy |
| **Not** | Tacky/Adhesive/Sticky | **Pasty (***like paste in mouth)* |
| **No Mouth Coating (***residual***)** | | **Pronounced Mouth Coating** (circle: *pleasant or unpleasant***)** |

**Flavor/Aroma**

| | | |
|---|---|---|
| **Bland**/Flat Overall Flavor *(impact)* | | **Pronounced Overall Flavor***(circle:pleasant or unpleasant)* |
| **Not** | | **Salty** (more than expected) |
| **Not** | Buttery (*natural*) | Artificial **Butter** (*overlyhigh diacetyl*) |
| **Not** | Oily (*vegetable*) | **Oily**/Beany (*soybean*) |
| **Not** | Mild Sulfur (like eggs) Sulfurous (like over-boiled eggs) | **Skunky** (*cooked cabbage*) |
| **Not** | | **Over-cooked** (*toasted, burned, scorched*) |
| **Not** | Sweet | **Butterscotch**/Caramelized |
| **None** | | **Acid**/Sour/Buttermilk (*lactic acid, cheesy*) |
| **Not** | | **Rancid**, hydrolytic (*Romano, blue cheese*) |
| **Not** | | **Oxidized**/Rancid oil (*old paint, fishy*) |
| **None** | | **Retort** Flavor (*burnt hair + oxidized*) |
| **None** | | **Black Pepper**/Spice |
| **No** *Unexpected Flavor* | | **Foreign** (circle: *baking soda, cereal, grain, flowery, chemical, metallic, unknown*) |
| **Clean** (pleasant) | | **Unclean** (circle: *feed, manure, old, aged, musty, unknown dirty flavor*) |
| **No Lingering Flavor** | | Pronounced Lingering **Aftertaste** (circle: *pleasant or unpleasant; bitter; other*) |

ADDITIONAL COMMENTS:

FIG. 1. DESCRIPTIVE SENSORY BALLOTS DEVELOPED DURING PANELIST TRAINING SESSIONS AND USED FOR EVALUATION OF EGG PATTIES

A 14-cm unstructured line scale was used for each descriptor.

from the booth prior to evaluation of subsequent samples (monadic). Control patties, defrosted and heated in boiling water for 20 min, were compared with the same high-pressure-treated formulations. All samples were coded with random three-digit numbers, and served to the panelists in a randomized complete block design. After each sample, the panelists rinsed their palates with water and had approximately 1 min of resting time before the next sample. Samples were kept in a water bath at 50C and removed immediately at the time of serving. Samples were evaluated in a 2-day session to minimize the panelists' fatigue.

**TPA.** TPA tests were performed with a TA-XT2 Texture Analyzer (Stable MicroSystems Ltd, White Salmon, WA), fitted with a 5-kg load cell. 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 to 50% of initial height as per Montejano *et al.* (1985) using protein gels, Paraskevopoulou and Kiosseoglou (1997) using egg yolk gels, and Gujral *et al.* (2003) using sponge cakes. The crosshead speed (and posttest speed) was 1 mm/s according to Woodward and Cotterill (1986) in egg white gels. The TPA parameters hardness, adhesiveness, springiness, cohesiveness and resilience were obtained through numerical routines established in the software package of the texture analyzer, which calculated each parameter as defined by Bourne (2002) from the two compression cycles applied to the samples. Hardness (N) was calculated by measuring the peak force obtained during first compression cycle. Adhesiveness was determined (N·mm) from the work necessary to pull the probe away from the sample, which corresponds to negative area after first cycle. Springiness (dimensionless) was obtained from the ratio of two distances: the distance to reach the second force peak during the second compression cycle and the distance to reach the first force peak during the first cycle. Cohesiveness (dimensionless) was determined by dividing the positive force area during the second compression cycle between the area corresponding to the first compression. Resilience (dimensionless) describes how the product regains position after the first compression cycle, and was calculated as the ratio of the area corresponding to the force withdrawal to the area of compression up to peak force reached.

**Syneresis.** Water loss (i.e., syneresis) in % weight loss was evaluated by weighing one egg patty before packaging and after treatment. The following formula was used as adaptation of serum formula developed by Woodward and Cotterill (1986) for evaluating percentage of serum in heat-formed egg white gels, and by Feiser and Cotterill (1982) for evaluating cooked-frozen-thawed-reheated scrambled eggs:

$$\%\ weight\ loss = \frac{ipw - fpw}{ipw} \times 100\% \qquad (1)$$

where *ipw* and *fpw* are the initial and final weights of patty, respectively. A similar formula was used to determine expressible moisture as an indicator of water holding capacity in omelets (O'Brien *et al*. 1982) as well as percentage of weight loss in chicken meat batters with egg white before and after high pressure (Fernández *et al*. 1998).

**Color Measurement.** Testing of color degradation was by CIE System evaluation using a colorimeter (Minolta CM-2002 Spectrophotometer, Camera Co., Osaka, Japan). Color was evaluated through lightness $L^*$ and color intensity or *Chroma* calculated using Eq. (2).

$$Chroma = \sqrt{a^2 + b^2} \qquad (2)$$

where $+a^*$ represents the red direction, $-a^*$ represents the green direction, $+b^*$ represents the yellow direction and $-b^*$ represents the blue direction in the $L^*$, $a^*$ and $b^*$ color space.

**pH Measurement.** The pH was measured before and after pressure or heat treatment using a pH meter (model 420A, Orion Research, Inc., Boston, MA) with a glass electrode. Egg patties were blended and diluted with distilled water in a 1:10 ratio using a $10.0 \pm 0.1$-g sample.

### Statistics

A factorial design for egg panel descriptors, TPA parameter values, weight loss and color measurement and pH (Table 1) was studied using the general linear models procedure in the SAS statistical package (SAS/STAT Language, SAS Institute, Inc., Cary NC) to perform analyses of variance and least square difference ($\alpha = 0.05$).

## RESULTS AND DISCUSSION

### Effect of Initial Chamber Temperature and 675-MPa Treatment on the Sensory Profile of Formulation #1

Formulation #1 is a commercial Michael Foods egg patty, and its sensory profile after HPP at different initial temperature conditions was unknown. This section describes the appearance, texture/mouthfeel and flavor/aroma profiles of selected egg patties after HPP at low- and high-temperature conditions.

TABLE 3.
COLOR AND APPEARANCE OF PATTY FORMULATION #1 AS INDICATED BY COLORIMETER ($L^*$, *CHROMA*) AND DESCRIPTIVE PANEL

| Treatment | Color (analytical) | | Color (sensory) | | Appearance (sensory) | |
|---|---|---|---|---|---|---|
| | $L^*$ | *Chroma* | Gloss | Greenness | Surface homogeneity | Crumbliness |
| Control | 77.3 ± 0.8 a | 35.6 ± 0.9 a | 4.5 ± 0.6 a | 1.0 ± 0.4 a | 3.5 ± 1.0 a | 0.5 ± 0.1 a |
| 30C/675 MPa | 79.5 ± 0.9 a | 34.2 ± 1.1 ab | 5.2 ± 1.1 ab | 1.4 ± 0.7 a | 6.2 ± 2.0 a | 0.1 ± 0.3 a |
| 70C/675 MPa | 80.9 ± 0.7 a | 32.1 ± 0.9 b | 7.0 ± 1.6 ab | 3.4 ± 0.9 b | 4.6 ± 2.2 a | 0.0 ± 0.3 a |
| 90C/675 MPa | 78.7 ± 0.7 a | 32.2 ± 0.9 b | 8.8 ± 1.6 b | 3.6 ± 0.8 b | 6.7 ± 2.2 a | 0.0 ± 0.3 a |

Different letters indicate significant differences existing mean values ($P < 0.05$) within individual columns.

**Color and Appearance of Patty Formulation #1.** The descriptive panel did not detect significant differences ($P > 0.05$) in gloss and green between #1 egg patties treated at 30C/675 MPa and the control. This coincided with $L^*$ values and *Chroma* found with the colorimeter (Table 3). Gels from egg white and egg yolk induced by pressures above 500 MPa have been found to give a more lustrous surface than heat-induced gels (Hayashi *et al.* 1989). As egg patties were previously heat-formed, it is not surprising that there were no significant differences ($P > 0.05$) detected after pressure treatment.

When pressurized at 70C/675 MPa, the descriptive panel did not find differences in gloss with respect to the control, further supported by no significant ($P > 0.05$) changes in the $L^*$ value. However, the descriptive panel found slight, although significant ($P < 0.05$), differences in green color when patties were treated under HPHT conditions (>70C/675 MPa). Even though patties were formulated with an acidifying agent, citric acid, as well as an iron chelator, EDTA, to prevent discoloration (Cotterill 1995), the combination of high pressure and temperatures greater than 70C yielded green compounds. Cotterill (1995) explained that a lower pH is needed to avoid greening. Furthermore, Feiser and Cotterill (1982) reported that cooking, freezing, thawing and reheating increase pH. There is also evidence that high pressure induces pH changes in water, buffers or food compounds as a result of changes in the dissociation constants of acids and bases (Stippl *et al.* 2004). However, no significant changes ($P > 0.05$) in pH (average 6.9 ± 0.1) were detected after thermal pressurization. Cotterill (1995) reported that formation of green ferric sulfide compounds is likely in cooked egg products at pH values higher than 8.2. However, high-pressure thermal treatment favored the formation of green compounds at a lower pH.

High-pressure/high-temperature conditions (≥70C/675 MPa) mostly influenced the $+b^*$ value (data not shown), which indicated yellow intensity.

The #1 egg patties treated at 30C/675 MPa gave *Chroma* values not significantly different ($P > 0.05$) from the control. *Chroma* values, however, were slightly but significantly decreased ($P < 0.05$) at a pressure chamber temperature 70C or higher (Table 3). Changes in the *Chroma* of egg patty formulation #1 after treatment under HPHT conditions (≥70C/675 MPa) agreed with the color ratings by the descriptive panel.

Guamis *et al*. (2005) observed that liquid egg yolk treated at 500 MPa with no heat maintains a yellow color. Moreover, Hayashi *et al*. (1989) found that pressure-induced gels of egg yolk are vividly yellow even if treated above 800 MPa. The yellow color in egg products results from xanthophylls, in particular carotenoids lutein, zeaxanthin and crypotaxanthin (Yang and Baldwin 1995). Pressures up to 500 MPa, treatment times up to 5 min, and temperatures up to 40°C are not detrimental to carotenoids (Cano and de Ancos 2005). Carotenoids are heat-sensitive and can be degraded at conventional sterilization temperatures through oxidative reactions, which will provoke bleaching and subsequent loss in color (Elbe 1986; Luechapattanaporn *et al*. 2005). However, the degradation effect of these yolk compounds as a result of the combined pressure and temperature has not been previously reported. In addition, Indrawati *et al*. (2004) stated that high-pressure treatment slightly affects the carotene content of food products, reporting 5% losses after treatment at 75C/600 MPa/40 min in carrot homogenates. Krebbers *et al*. (2003) reported insignificant losses in lycopene from tomato paste after two cycles at 90C/700 MPa/30 s. No other significant appearance differences ($P > 0.05$), including surface homogeneity and crumbly appearance (Table 3), were noted.

**Texture and Syneresis of Patty Formulation #1.** The texture profile of formulation #1 after treatment at 30C/675 MPa was similar to the control, whereas #1 patties pressure-treated at 70 and 90C rated significantly higher ($P < 0.05$) in firmness, density, particle (particulates) size and mouthfeel roughness (Fig. 2). TPA analysis (Table 4) gave a similar profile comparing the high-pressure low-temperature-treated patty and the control. Changes in hardness values were noticeable at an initial chamber temperature of 50C and were significantly higher ($P < 0.05$) above 70C and a pressure level of 675 MPa.

A pressure level of 675 MPa is enough to provide complete and instantaneous gelation of egg yolks and egg whites, which was reported to occur above 600 MPa and 25C (Palou *et al*. 1999). Okamoto *et al*. (1990) tested pressure-induced egg white gels at 25C/600 MPa/30 min and obtained hardness and cohesiveness values within the same range as that of the #1 egg formulation control and #1 formulation treated at 30C/675 MPa. Even though egg proteins were already coagulated during the cooking process, high-pressure conditions at initial temperatures above 50C might have induced proteins to further aggregate, providing a firmer structure. Temperatures above

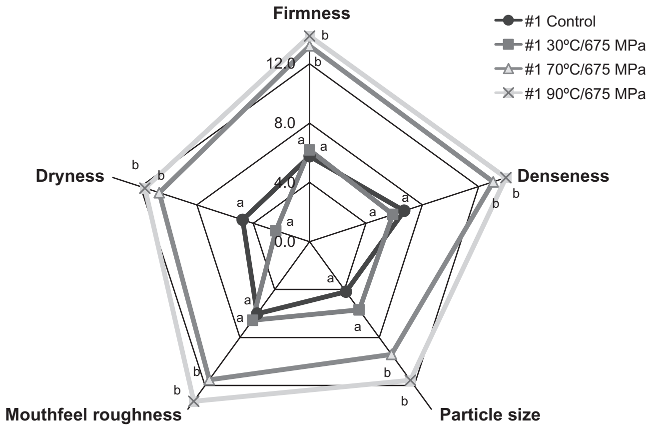


FIG. 2. RADAR-TYPE PLOT INDICATING THE TEXTURE PROFILE FOR EGG PATTY FORMULATION #1

Comparison between control and high-pressure-treated patties at 675 MPa and initial temperatures of 30, 70 and 90C. Different letters indicate significant differences between mean values ($P < 0.05$, least significant difference) in the 0–14 scale.

TABLE 4.
TEXTURE PROFILE ANALYSIS OF EGG PATTY FORMULATION #1

| Treatment | Hardness (*N*) | Cohesiveness ($10^2$) | Adhesiveness (N·mm, $10^2$) | Springiness ($10^2$) | Resilience ($10^2$) |
|---|---|---|---|---|---|
| Control | 22.5 ± 2.2 a | 69.5 ± 1.2 a | –43.2 ± 9.1 a | 87.9 ± 7.8 a | 24.0 ± 1.6 a |
| 30C/675 MPa | 23.0 ± 3.2 a | 73.3 ± 1.7 b | –29.7 ± 12.8 a | 88.0 ± 11.0 a | 27.9 ± 2.3 b |
| 50C/675 MPa | 39.8 ± 2.6 b | 72.2 ± 1.4 b | –44.0 ± 10.4 a | 90.2 ± 9.2 a | 32.1 ± 1.9 b |
| 70C/675 MPa | 51.6 ± 2.0 c | 73.9 ± 1.1 b | –37.1 ± 9.1 a | 93.1 ± 7.0 a | 29.6 ± 1.5 b |
| 90C/675 MPa | 53.6 ± 1.8 c | 74.5 ± 1.0 b | –30.6 ± 7.4 a | 96.4 ± 6.4 a | 30.4 ± 1.3 b |

Comparison between control and high-pressure-treated patties at 675 MPa and initial temperatures of 30, 50, 70 and 90C.
Different letters indicate significant differences between mean values ($P < 0.05$) within individual columns.

56C are enough for fractional precipitation, and those above 73C are enough to allow egg protein coagulation (Cunningham 1995). Thus, combining pressure and temperature might have accelerated an additional gelation process toward a denser, more cohesive and harder texture.

Panelists did not find any difference ($P > 0.05$) between the #1 control and the 90C/675 MPa sample in terms of astringency, greasy, pasty and mouth coating (data not shown).

TABLE 5.
SYNERESIS RATED BY DESCRIPTIVE PANEL AND PERCENT WEIGHT LOSS AFTER PREHEAT OR TREATMENT AT 675 MPa AND SELECTED TEMPERATURES FOR 5 min

| Treatment | Syneresis (sensory) | Weight loss (%) |
|---|---|---|
| Control | 1.0 ± 0.6 a | 1.7 ± 1.1a |
| 30C/675 MPa | 0.5 ± 1.1 a | 2.3 ± 1.6a |
| 50C/675 MPa | na | 9.8 ± 1.3b |
| 70C/675 MPa | 3.5 ± 1.2 b | 12.5 ± 0.8b |
| 90C/675 MPa | 3.2 ± 1.2 b | 13.3 ± 1.0b |

Different letters indicate significant differences between mean values ($P < 0.05$) within individual columns.
na, not available.

Panelists found syneresis in the #1 formulation after 70C/675 MPa and 90C/675 MPa (Table 5) treatments to be significantly higher ($P < 0.05$) than the control and patty treated at 30C/675 MPa. This was supported by results in syneresis, which showed an increase in water loss of six to eight times greater than the control when initial chamber temperatures were higher than 50C (Table 5). Thus, syneresis is increased by a combination of temperature and pressure. As explained by Yang and Baldwin (1995), an increase in firmness of the egg coagulum can squeeze liquid out of the protein matrix, thereby increasing syneresis. The descriptive panel also found the #1 formulation to be significantly dryer (low moisture release at chewing, $P < 0.05$) when treated above a protein gelation temperature of 70C (Fig. 2).

**Flavor of Patty Formulation #1.** HPP of egg patty formulation #1 at low- and high-temperature conditions did not significantly affect ($P > 0.05$) the flavor descriptors oily, oxidized, scorch, rancid and foreign (data not shown). The soybean oil present in the formulation was equivalently perceived before and after HPHT treatment. Furthermore, no oxidized or other foreign unexpected tones were noted in formulation #1 by the panel even after treatment at 90C/675 MPa. Scorched flavor tones, developed when overcooking or burning the surface of egg patties during the manufacturing steps, were not altered after pressure treatment. All other flavor descriptors (Table 6) did not significantly change ($P > 0.05$) after egg patty formulation #1 was treated at 30C/675 MPa. Thus, the flavor profile of formulation #1 remained unchanged after high-pressure low-temperature processing. However, samples treated at 90C/675 MPa rated higher ($P < 0.05$) than control and treated patties ($P < 0.05$) at 30C/675 MPa in overall flavor, sulfur aroma, retort, unclean flavors and aftertaste (Table 6).

TABLE 6.
FLAVOR DESCRIPTORS FOUND SIGNIFICANTLY DIFFERENT WHEN COMPARING EGG PATTY FORMULATION #1 CONTROL WITH HIGH-PRESSURE-TREATED PATTIES AT 675 MPa AND 30, 70 AND 90C

| Treatment | Overall flavor | Sulfur aroma | Retort | Unclean flavors | Aftertaste |
|---|---|---|---|---|---|
| Control | 7.6 ± 0.5 a | 3.9 ± 0.4 a | 2.2 ± 0.9 a | 1.0 ± 0.6 a | 4.6 ± 0.6 a |
| 30C/675 MPa | 8.7 ± 1.0ab | 4.0 ± 0.9 a | 0.8 ± 1.8 a | 0.5 ± 1.2 a | 3.0 ± 1.2 a |
| 70C/675 MPa | 8.8 ± 1.0ab | 6.3 ± 1.0 ab | 5.2 ± 2.0 ab | 5.4 ± 1.3 b | 5.7 ± 1.3 ab |
| 90C/675 MPa | 10.8 ± 1.0 b | 7.8 ± 1.0 b | 7.5 ± 2.0 b | 5.3 ± 1.3 b | 8.8 ± 1.3 b |

Different letters indicate significant differences between mean values ($P < 0.05$) within individual columns.

High pressure, in combination with high heat (initial temperature 90C), generates new flavor compounds that are perceived similarly to those developed by retort processing and have an unclean lingering flavor (Table 6). When egg white is heated at temperatures above 60C, there is an increase of –SH groups exposed from protein unfolding, which, through subsequent splitting of disulfide links, results in the release of hydrogen sulfide (Germs 1973; Cheftel *et al*. 1985), thereby increasing sulfur aroma (Yang and Baldwin 1995). Cheftel *et al*. (1985) also mentioned that thermal treatments at sterilization temperatures (>115C) result in irreversible chemical modification of cysteine and cystine protein residues and the formation of hydrogen sulfide, which contributes to the flavor of heated protein-based systems. Thus, increased sulfur aroma observed after 90C/675 MPa could be attributed to an increased production of $H_2S$. Changes seen after pressure treatment at temperatures above 70C indicated a need to modify the formulation to improve flavor at HPHT conditions.

## Effect of Pressure Level on the Physical Characteristics of Formulation #1 Preheated at 90C

When #1 egg formulation patties were treated at pressure levels of 300, 500 and 675 MPa and at an initial pressure chamber temperature 90C, no significant variations ($P > 0.05$) were found in the $L^*$ value (Table 7) with respect to control. Changes in *Chroma* values were also not significant ($P > 0.05$), when combining high temperature and a pressure of at least 300 MPa.

TPA descriptors, adhesiveness and springiness, were not affected by pressure processing and remained not significantly different ($P > 0.05$) from the control (data not shown). On the contrary, TPA hardness, cohesiveness and resilience (Table 7) were still higher ($P < 0.05$) than the control at lower pressurization conditions of 90C/300 MPa. Furthermore, these conditions

TABLE 7.
EFFECT OF PRESSURE APPLIED ON PATTIES TREATED AT AN INITIAL TEMPERATURE OF 90C AND PRESSURES OF 300, 500 AND 675 MPa FOR 5 min

| Treatment | *L** (lightness) | *Chroma* | Serum (% weight loss) | Hardness (*N*) | Cohesiveness ($10^2$) | Resilience ($10^2$) |
|---|---|---|---|---|---|---|
| Control | 77.3 ± 1.2 a | 35.6 ± 1.1 a | 1.7 ± 1.3a | 22.5 ± 2.6 a | 69.5 ± 1.3 a | 24.0 ± 1.5 a |
| 90C/300 MPa | 78.0 ± 1.6 a | 31.1 ± 1.4 ab | 14.3 ± 1.9b | 50.1 ± 3.0 b | 74.7 ± 1.4 b | 29.1 ± 1.7 b |
| 90C/500 MPa | 75.8 ± 1.6 a | 32.6 ± 1.4 ab | 13.2 ± 1.9b | 55.2 ± 3.0 b | 74.2 ± 1.4 b | 33.0 ± 1.7 b |
| 90C/675 MPa | 78.7 ± 1.3 a | 31.2 ± 1.0 b | 13.3 ± 1.2b | 53.6 ± 2.1 b | 74.5 ± 1.3b | 30.4 ± 1.2 b |

Different letters indicate significant differences between mean values ($P < 0.05$) within individual columns.

yielded similar values to the ones obtained by treating #1 egg formulation at 90C/675 MPa (Table 7). In addition, pressurization at 90C/300 MPa, or higher pressures, gave significantly higher ($P < 0.05$) released serum than egg formulation #1 control in all cases. Hence, even at 300 MPa, the initial high chamber/liner/product temperature of 90C significantly affected ($P < 0.05$) the texture and syneresis of formulation #1.

Temperatures higher than 70C have been reported to affect the conformation of the egg proteins livetins, conalbumins, globulins and ovomacroglobulin (Feiser and Cotterill 1982; Ma *et al*. 2001) in both liquid whole eggs and cooked-frozen-thawed-reheated egg products. On the contrary, only pressures higher than 500 MPa and room temperature were shown to affect the conformation of ovomacroglobulin and $\gamma$-livetins in liquid eggs (Ma *et al*. 2001). During the egg patty cooking process, all heat-sensitive proteins in the liquid egg mix were denatured, leading to the formation of a semisolid coagulum, or gelled foam, with a hardness value similar to the control. Preliminary testing showed that even though initially frozen egg patties were thawed and reheated up to 90C, the TPA hardness values did not change. However, when cooked-frozen-thawed-reheated egg patties were treated at pressures of at least 300 MPa, combined with a chamber temperature of 90C, egg matrix densification occurred as a result of the collapse of internal pores, which might have led to further protein gelation and therefore, a harder structure than the cooked-frozen-thawed-reheated control. Additional research, including microstructural analysis, is necessary to confirm that additional gelation occurs in preformed frozen egg patties during HPHT.

## Formulation Modification for Improvement of Sensory Characteristics of Scrambled Egg Patties Treated at Potential Sterilization Conditions

In previous sections, it was stated that commercial egg patty formulation #1 provided adequate descriptive characteristics after high-pressure treatment at low-temperature conditions (30C/675 MPa) as a prospective postpackaging pasteurization process. This was also found valid for modified egg patty formulation #2. Experimental data on formulation #1 showed that the combination of 675 MPa and initial chamber temperatures above 70C, i.e., conditions with potential for egg product sterilization, induced a rougher texture and differences in flavor compared to the control. Formulation #1 was modified by adding xanthan gum with the aim of improving water retention, thereby yielding formulation #2. The egg: water ratio was set higher in patty formulation #2 to evaluate if higher water content could reduce hardness and cohesiveness. Furthermore, EDTA was added to improve color retention, and natural and artificial flavors were added to evaluate whether flavor profiles are maintained after HPHT conditions.

TABLE 8.
COLOR RATED BY DESCRIPTIVE PANEL AND ANALYTICAL MEASUREMENTS OF SELECTED SCRAMBLED EGG PATTY FORMULATIONS UNTREATED AND TREATED AT 70C/675 MPa AND 90C/675 MPa

| Formulation # | Treatment | Color (Sensory) | | Color (Analytical) | |
|---|---|---|---|---|---|
| | | Gloss | Greenness | $L^*$ (lightness) | *Chroma* |
| 1 | Control | 4.5 ± 0.8 a | 1.0 ± 0.5 a | 77.3 ± 0.7 a | 35.6 ± 0.9 a |
| 2 | Control | 5.6 ± 1.5 ab | 0.7 ± 1.1 a | 77.7 ± 0.8 a | 32.3 ± 1.0 b |
| 1 | 70C/675 MPa | 7.0 ± 1.6 ab | 3.4 ± 0.9 b | 80.8 ± 0.6 a | 32.1 ± 0.7 b |
| 2 | 70C/675 MPa | 6.7 ± 1.4 ab | 2.2 ± 1.1 ab | 80.4 ± 1.1 a | 33.6 ± 1.4 b |
| 1 | 90C/675 MPa | 8.8 ± 1.6 b | 3.6 ± 0.9 b | 78.7 ± 0.6 a | 31.2 ± 0.8 bc |
| 2 | 90C/675 MPa | 6.0 ± 1.4 ab | 2.6 ± 0.8 ab | 79.6 ± 0.9 a | 28.8 ± 1.2 c |

Different letters show significant differences between mean values ($P < 0.05$) within individual columns.

**Appearance and Color.** Pressure-treated patty formulation #2 scored similarly in gloss values as controls even after sterilization conditions 90C/675 MPa, where a process temperature of 121C was achieved (Table 2). This was opposed to pressure-treated patty formulation #1 that had an increased gloss score after treatment at these sterilization conditions (Table 8). The lustrous appearance of high-pressure-induced egg gels (Hayashi *et al.* 1989; Palou *et al.* 1999) was less pronounced in the new formulation. In this case, lightness ($L^*$) did not differ significantly ($P > 0.05$) between formulations or after pressure treatment (Table 8). The surface appearance was not affected by pressure as no significant differences ($P > 0.05$) were found in the descriptors crumbly and surface homogeneity (data not shown).

*Chroma* value, representing yellowness, decreased for patty formulation #1 after 70C/675 MPa treatment but not for patty formulation #2 at the same conditions, when compared to the controls. Patty formulation #2 control was initially lower in yolk content, or initial concentration of yellow pigments, as a result of a lower egg : water ratio, thereby giving a lower initial *Chroma* value with respect to formulation #1 (Table 8). Even though the *Chroma* value of patty formulation #2 was maintained after 70C/675 MPa, it decreased after 90C/675 MPa. It is possible that the xanthophylls contained in patty #2 might have been reduced only at standard sterilization conditions 90C/675 MPa.

No significant differences ($P > 0.05$) in greening were found between patty #2 and controls after treatment at a pressure chamber temperature higher than 70C and 675 MPa (Table 8). In this case, the chelator EDTA was probably effective in formulation #2 at binding iron, preventing the formation of iron green compounds after high-pressure thermal treatment. Extensive syneresis has been shown to increase the area of discoloration in scrambled eggs after thermal treatments (Luechapattanaporn *et al.* 2005). Therefore, as further shown, a lesser extent of water released in formulation #2 as a result of HPHT treatment could help prevent discoloration. Gossett and Baker (1981) reported that 0.03% of EDTA was optimum for preventing discoloration in whole liquid eggs with an initial pH of 8.5 after cooking at 100C for 20 min and holding over a steam bath for 60 min. Similar EDTA concentrations were found by Song and Cunningham (1985) to prevent greening in retorted whole egg (121C, 60 min). Chiang and Yang (1999) reported that xanthan gum also helped inhibit greening in an egg white and egg yolk mixture after heat coagulation.

**Improved Texture, Water Retention and Mouthfeel.** TPA analysis showed lower hardness values in modified formulation #2 (41 and 25% lower after 675 MPa and initial chamber temperatures 70 and 90C, respectively) than formulation #1 (Table 9). Although firmness and density differences (Fig. 3) determined by the panel were not significant ($P > 0.05$) for formulations #1 and #2 at a pressure of 675 MPa and initial temperatures above 70C, all values were higher than the controls ($P < 0.05$). No previous literature reported the effects of thermal high-pressure treatments on interactions between xanthan gum and egg proteins.

No difference in firmness was found between the controls of formulation #1 and #2, regardless of the presence of xanthan gum. However, TPA hardness and cohesiveness were lower in formulation #2 control (Table 9). O'Brien *et al.* (1982) showed that scrambled egg omelets with added xanthan gum (0.5–1.5%) had higher tenderness levels. Higher water content in formulation #2 control, where xanthan gum bound water, also helped to provide lower hardness and cohesiveness than control patty formulation #1. Beveridge *et al.* (1980) found that the firmness of egg coagulum decreases with higher dilution, i.e., a lower egg : water ratio.

TABLE 9.
TEXTURE PROFILE ANALYSIS OF DIFFERENT SCRAMBLED EGG PATTY FORMULATIONS TREATED AT 70C AND 675 MPa*

| Formulation # | Treatment | Hardness (*N*) | Cohesiveness ($10^2$) | Resilience ($10^2$) |
|---|---|---|---|---|
| 1 | Control | 22.5 ± 2.7 b | 69.5 ± 1.6 b | 24.0 ± 2.0 a |
| 2 | Control | 10.8 ± 3.1 a | 52.9 ± 1.8 a | 19.7 ± 2.4 a |
| 1 | 70C/675 MPa | 51.6 ± 2.4 e | 73.9 ± 1.4 c | 29.6 ± 1.8 b |
| 2 | 70C/675 MPa | 30.0 ± 2.1 c | 73.5 ± 1.2 c | 34.2 ± 1.6 b |
| 1 | 90C/675 MPa | 53.6 ± 1.7 e | 74.5 ± 1.3 c | 33.0 ± 1.6 b |
| 2 | 90C/675 MPa | 40.0 ± 1.7 d | 75.8 ± 1.2 c | 30.4 ± 1.6 b |

Different letters indicate significant differences exist between mean values ($P < 0.05$) within individual columns.

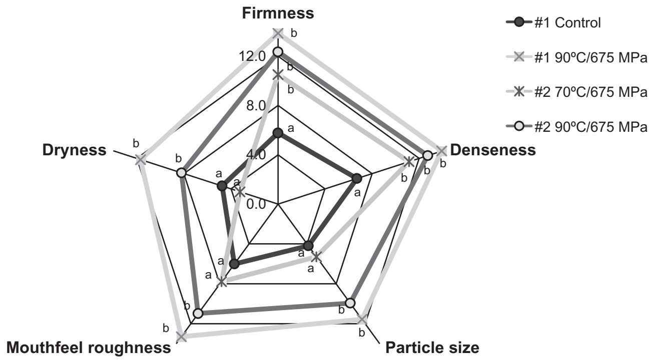


FIG. 3. RADAR-TYPE PLOT INDICATING THE TEXTURE AND MOUTHFEEL PROFILES AS DETECTED BY THE DESCRIPTIVE PANEL

Comparison between control #1, formulation #1 after 90C/675 MPa, and #2 treated at 70C/675 MPa and 90C/675 MPa. Significant differences ($P < 0.05$, least significant difference) are indicated using different letters in the 0–14 scale.

Previous work on xanthan gum solutions (0.25–1.5%) treated at pressures around 400 MPa showed that the viscosity of solutions was not affected by pressure treatment (Ahmed and Ramaswamy 2004). However, xanthan gum's helical structure is temperature-dependent (Pelletier *et al*. 2001) and it can stretch at high temperatures, therefore it can attain higher viscosity values when exposed to combined HPHT conditions (≥70C/675 MPa). A gum with higher viscosity dispersed within the egg matrix interfered with the egg matrix densification process, thereby providing a less hard structure. Hence, even though the descriptive panel did not find HPHT-treated patties with added xanthan gum significantly less firm than 90C/675 MPa #1 formulation, the TPA test showed significantly lower ($P < 0.05$) hardness in these patties.

The trained panel gave formulation #2 a lower score ($P < 0.05$) in particle size and mouthfeel roughness than formulation #1 when both were treated at 70C/675 MPa (Figs. 2 and 3). Furthermore, formulation #2 treated at 70C/675 MPa did not differ from the controls, probably because of the presence of xanthan gum and increased water content. TPA resilience (or elasticity during the first bite) of pressure-treated formulation #2 was higher than its control #2. However, TPA adhesiveness and springiness values did not significantly change ($P > 0.05$) after pressure treatment (data not shown).

Patty formulation #2, treated at a pressure chamber temperature higher than 70C and 675 Mpa, did not have significantly different ($P > 0.05$) scores in greasy and astringent descriptors with respect to controls, as opposed to HPHT-treated formulation #1, which was higher in both descriptors. Xanthan gum and artificial flavors modifying formulation #2 might have masked tangy

TABLE 10.
SYNERESIS RATED BY DESCRIPTIVE PANEL AND PERCENT WEIGHT LOSS AFTER PREHEAT OR HIGH-PRESSURE THERMAL TREATMENT IN FORMULATIONS #1 AND #2

| Formulation # | Treatment | Syneresis (sensory) | Weight loss (%) |
|---|---|---|---|
| 1 | Control | 1.0 ± 0.6 a | 1.7 ± 0.8a |
| 2 | Control | 2.0 ± 1.2 a | 1.9 ± 0.9a |
| 1 | 70C/675 MPa | 3.5 ± 1.2 ab | 12.5 ± 0.8c |
| 2 | 70C/675 MPa | 3.2 ± 1.2 ab | 6.3 ± 0.8b |
| 1 | 90C/675 MPa | 3.2 ± 1.2 ab | 13.3 ± 1.0c |
| 2 | 90C/675 MPa | 3.8 ± 1.2 b | 5.8 ± 1.6b |

Different letters indicate significant differences between mean values ($P < 0.05$) within individual columns.

and tingling sensations present in formulation #1 after high-pressure thermal treatment. Slimy, silky and oily sensations associated with a greasy mouthfeel are also related to the addition of xanthan gum and flavors. Mouthfeel descriptors pasty and mouth coating did not change significantly ($P > 0.05$) after thermal pressurization with respect to controls (data not shown).

The descriptive panel found syneresis in #2 formulation to be low, although significant differences ($P < 0.05$) were detected between pressure-treated samples at 90C/675 MPa and controls (Table 10). When quantified as % weight loss, water released as a result of HPHT conditions was significantly decreased ($P < 0.05$) in egg patty formulation #2 with respect to formulation #1 by 50–55%.The high variability observed in % weight loss at 90C/675 MPa can be attributed to the higher temperature, which under high pressure conditions, affected water binding components differently, therefore affecting the extent of water retention within the egg matrix. Previous studies on precooked-frozen-reheated omelets (O'Brien *et al.* 1982) proved xanthan gum to effectively reduce expressible moisture, supporting results shown in Table 10. This significant increase ($P < 0.05$) in water retention found in patty formulation #2 after HPHT treatment coincided with lower dryness compared to formulation #1, mainly observed after 70C/675 MPa (Figs. 2 and 3). Xanthan gum's effect on moisture retention after HPHT treatment can also be associated with decreased values in hardness.

**Improved Flavor.** As previously mentioned in the *Flavor of patty formulation #1* section, formulation #1 scores for oily, oxidized, scorched and foreign flavor tones were not significantly ($P > 0.05$) affected by HPHT treatment at temperatures above 70C (data not shown). The same was observed in formulation #2 after HPHT treatment. Moreover, natural and artificial flavors added in formulation #2 changed the panelists' perceptions of HPHT-treated

TABLE 11.
FLAVOR AND AROMA DESCRIPTORS FOUND SIGNIFICANTLY DIFFERENT WHEN COMPARING EGG PATTY FORMULATIONS #1 AND #2 BEFORE AND AFTER HIGH-PRESSURE HIGH-TEMPERATURE TREATMENTS

| Formulation # | Treatment | Sulfur aroma | Retort | Unclean flavors | Aftertaste |
|---|---|---|---|---|---|
| 1 | Control | 3.9 ± 0.4 a | 2.2 ± 0.9 a | 1.0 ± 0.6 a | 4.6 ± 0.6 a |
| 1 | 90C/675 MPa | 7.8 ± 1.0 b | 7.5 ± 2.0 b | 5.3 ± 1.3 b | 8.8 ± 1.3 b |
| 2 | Control | 5.3 ± 1.2 ab | 0.3 ± 1.8 a | 0.4 ± 1.1 a | 4.1 ± 1.3 a |
| 2 | 70C/675 MPa | 5.3 ± 1.0 ab | 3.1 ± 1.8 ab | 1.3 ± 1.1 a | 3.9 ± 1.3 a |
| 2 | 90C/675 MPa | 6.8 ± 1.2 ab | 2.8 ± 1.8 ab | 1.1 ± 1.1 a | 7.1 ± 1.3 ab |

Different letters indicate significant differences between mean values ($P < 0.05$) within individual columns.

egg patties to flavor/aroma profiles similar to control (Table 11). It is possible that added flavors masked the retort effects, lingering flavors and aromas developed under HPHT conditions, as noted in the case of formulation #1.

Modification of formulation with added flavors facilitated obtaining high-pressure thermally treated products with profiles similar to control. These results show that adequate product formulation can ensure that egg products maintain their sensory characteristics after sterilization treatment using HPHT processing.

## CONCLUSIONS

Scrambled egg patties from standard and modified formulations maintained their overall sensory characteristics (appearance, texture and flavor) after high-pressure low-temperature treatment (30C/675 MPa/5 min). Hence, postpackaging pasteurization of commercial egg patties has definite potential in applications using HPP at chamber temperatures within the range of 30C at 675 MPa.

The standard egg patty formulation tested was not adequate for HPHT treatment conditions (≥70C/675 MPa). Even though appearance was maintained, the sensory descriptors for color, texture and flavor were significantly altered. In particular, the firmer, denser and rougher structure obtained after 70C/675 MPa/5 min treatment, also associated with higher syneresis, was indicative of a need to modify patty formulation. Even at a much lower pressure of 300 MPa, combined with a pressure chamber temperature of 90C, the analytical texture profile analysis descriptors were equally altered, giving similar values as for higher pressures.

Modification of standard egg patty formulation by addition of xanthan gum, EDTA and flavors provided better color, texture and flavor retention after pressure treatment at sterilization conditions (>70C and 675 MPa). While xanthan gum addition helped reduce hardness (25–41%) and syneresis (50–55%), addition of EDTA prevented greening. The use of natural and artificial flavors contributed to match the flavor tones obtained in egg patties preheated only. Even at initial chamber temperatures of 90C, which correspond to a standard sterilization temperature of 121C at 675 MPa, sensory improvements could be attained for scrambled egg patties through reformulation, making sensory profiles more similar to those of preheated patties.

Thus, HPP offers not only the possibility of producing pasteurized egg patties intended for storage under refrigerated conditions, but also a promising approach for the development of shelf-stable egg products produced by combining pressures around 700 MPa and chamber pressure temperatures greater than 70C, which are not yet accomplished using conventional thermal processing methods. Future studies should focus not only on verifying the final safety of precooked egg products after HPHT treatment, but also on testing consumer acceptability and shelf life in selected formulations.

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