



Combined Effects of High Pressure Processing and Addition of Soy Sauce and Olive Oil on Safety and Quality Characteristics of Chicken Breast Meat

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ABSTRACT: This study was conducted to evaluate the combined effect of high pressure (HP) with the addition of soy sauce and/or olive oil on the quality and safety of chicken breast meats. Samples were cut into 100 g pieces and 10% (w/w) of soy sauce (SS), 10% (w/w) of olive oil (OO), and a mixture of both 5% of soy sauce and 5% olive oil (w/w) (SO) were pressurized into meat with high pressure at 300 or 600 MPa. Cooking loss was lower in OO samples than SS samples. With increased pressure to 600 MPa, the oleic acid content of OO samples increased. The total unsaturated fatty acids were the highest in SO and OO 600 MPa samples. Lipid oxidation was retarded by addition of olive oil combined with HP. The addition of olive oil and soy sauce followed by HP decreased the amount of volatile basic nitrogen during storage and reduced the population of pathogens. Sensory evaluation indicated that the addition of olive oil enhanced the overall acceptance and willingness to buy. In conclusion, the combination of HP with the addition of soy sauce and/or olive oil is an effective technology that can improve chemical, health, sensory qualities and safety of chicken breast. (**Key Words:** High Pressure, Soy Sauce, Olive Oil, Chicken Breast Meat, Quality)

INTRODUCTION

High quality food is considered synonymous with healthy food by consumers. Especially, healthy meat products are characterized by lower content of fat, salt, additives, and preservatives. One strategy to obtain high quality meat products is to replace or reduce the amounts of the non-healthy ingredients with some healthy and functional ingredients, thereby resulting in improved both quality and eating characteristics (Fernandez-Gines et al., 2005). It has been well documented that addition of

conjugated linoleic acid, selenium, soy protein, and natural products, such as herbs and spices improve meat quality (Zhang et al., 2010). In addition, introduction of vegetable oil or seasonings to meat products has been shown to improve physicochemical, microbiological, and sensory properties (Weiss et al., 2010; González and Hänninen, 2011).

The consumption of chicken meat has increased in many countries due to beneficial health effects and nutritional value of chicken meat (Jayasena et al., 2013). The bacteria from the skin surface and carcass cavity become the main cause of contamination of chicken products during portioning, skinning, and deboning processes (Kondjoyan and Portanguen, 2008). In addition to cross-contamination during processing, chicken products can be contaminated even after slaughter. Incidences of *Salmonella* spp., *Listeria monocytogenes*, *Campylobacter jejuni*, and *Escherichia coli* contamination in chicken are a public health issue and have been recently reported (Alterkruse et al., 1999; Rodrigo et al., 2005; Anang et al.,

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2007).

High pressure (HP) processing is a preservation technology that is free from chemical additives, only mildly destructive for food but eliminates pathogenic and spoilage microorganisms. In particular, HP has good application potential in the meat industry (Garriga et al., 2004). The capacity of HP to eradicate microorganisms regardless of the geometry of the product and without the use of preservatives/additives (Zhang and Mittal, 2008), make this technology accepted as safe and consumer friendly (Rastogi et al., 2007). However, HP treatment can increase lipid oxidation and induce color and texture changes in red meat (Yagiz et al., 2009).

Therefore, the aim of this study was to investigate the effect of simultaneous application of HP and flavoring agents such as soy sauce and olive oil on sensory and physico-chemical characteristics of chicken breast meat with potential to create value-added products highly desired by meat consumers.

MATERIALS AND METHODS

Samples preparation

Chicken breast meat (Orpum Co., Ltd., Sangju, Korea), soy sauce (Sampyo Co., Ltd., Seoul, Korea), and olive oil (Sajo Co., Ltd., Incheon, Korea) were purchased from a local super market in Daejeon, South Korea.

Chicken breast meat was sliced into pieces of approximately 100 g and immersed in 10% (w/w) of soy sauce (SS), 10% (w/w) of olive oil (OO), and a mixture comprising 5% (w/w) of soy sauce and 5% (w/w) olive oil (SO), respectively, based on the weight of the chicken breast meat. The mixture of 5% (w/w) of soy sauce and 5% (w/w) olive oil (SO) was prepared by weighing all flavoring agents separately and mixing them prior to submerging of meat samples in the mixture. The samples were vacuum packaged in polyethylene-nylon packaging bags (Sunkyoung Co., Ltd, oxygen permeability 22.5 mL m²/24 h atm at 60%; 60 mm thickness; RH/25°C).

High pressure treatment

The samples were transported to the Korea Food Research Institute (Seongnam, Korea) in a cooled container on ice and subjected to HP. Samples were placed in a pressure vessel submerged in hydrostatic fluid (Quintus food processor 6; ABB Autoclave Systems, Inc., Columbus, OH, USA) and pressurized at 300 MPa for 5 min with the initial temperature of the pressure vessel at 15±3°C. The pressure of 300 MPa was selected because it had the least detrimental effect on meat quality when compared with higher pressures (Kruk et al., 2011). The negative control samples were maintained under the same conditions during transportation and storage and under atmospheric pressure

at 4°C while the other samples were treated. Meat that had not been treated with soy sauce or olive oil but only with HP was used as a positive control.

The physicochemical analyses were performed during storage for 14 days at 4°C. In addition, in order to link the herein research with other studies as well as to increase the possibility of elevating intramuscular fat content and changing fatty acid composition another treatment was set by adding OO (10% w/w) and treating samples at 600 MPa for 5 min. All samples, including the controls were analyzed for sensory characteristics and fatty acid composition.

Proximate composition and pH

Proximate composition of the samples was carried out according to the AOAC (1990). Specifically, moisture content was determined by heating samples for 15 h at 102°C according to a dry oven method and measuring the amount of evaporated moisture. Crude fat content was measured according to the method of Soxhlet Extraction. Cooking loss was obtained by cutting muscle to a thickness of 2.5 cm, vacuum packaging them in the polyethylene-nylon packaging bags and heating it in a hot water bath at 80°C until the internal temperature reached 70°C. The weight lost after heating was considered as cooking loss. The pH measurement was carried out by adding 90 mL of distilled water to 10 g of sample, homogenizing the mixture for 1 min at 1,130×g using a homogenizer (T25 basic, Ika Co., Staufen, Germany) then measured using a pH meter (750 P, Istek Co., Seoul, Korea). All results were expressed as the average values obtained from three separate measurements.

Fatty acid composition

To determine the fatty acid composition, lipids were extracted according to the method described by Folch et al. (1957). The meat sample (30 g) was mixed with 150 mL of Folch solvent (methanol:chloroform 1:2). KCl (0.88%) was added to this solution and the samples were incubated at room temperature for 2 h. The upper layer was removed by aspiration, after which the lower chloroform layer was dehydrated and filtered with Na₂SO₄. After removing the solvent from the filtered solution, the total lipids were methylated by adding Boron trifluoride (BF₃) to methanol (Sigma-Aldrich Co., St Louis, MO, USA) at 90°C for 1 h. After cooling the samples, 1 mL of methylating reagent was added to 100 µL of the lipid sample and heated to 70°C for 30 min. The samples were removed from the water bath, allowed to cool, and 2 mL of hexane and 5 mL of distilled water were added. The samples were vortexed and the upper layers were removed. The fatty acid methyl esters dissolved in hexane were transferred to GC vials and the fatty acid composition was analyzed using GC (6890, Agilent Technologies, Inc., Santa Clara, CA, USA)

equipped with a capillary column (30 m×0.32 mm×0.25 µm film thickness, Omegawax 320, Supelco Inc., Bellefonte, PA, USA) and a flame ionization detector. During analysis, the temperatures of the oven, inlet, and detector were 200, 250, and 260°C, respectively. N₂ (99.999%) was used as the carrier gas at a linear flow rate of 0.79 mL/min and a split ratio of 100:1. Fatty acids were identified by comparison of the retention times to known fatty acid standards (Sigma Co., St. Louis, USA). The obtained chromatogram was integrated using GC Chemstation software (Rev. A.08.03, Agilent Technologies, Inc.). The relative quantities were expressed as a percent of total fatty acids on the basis of peak area.

Surface color

Breast meat surface color was measured using a spectrophotometer with Spectra Magic Software (CM-3500d, Minolta, Tokyo, Japan). Specifically, the sample was prepared as a 4 cm diameter and 1.5 cm thickness specimen and measured three times using a large size aperture (30 mm diameter). The color was expressed as L* (brightness), a* (redness), and b* (yellowness) on the Hunter color scale.

Texture

Texture (chewiness, hardness, cohesiveness, gumminess, resilience, adhesiveness and springiness) was measured by using an A-XT2 texture analyzer (Stable Microsystems, Surrey, UK) equipped with a 75 mm diameter probe. Samples were cut into pieces (diameter 3.0 cm, height 2.0 cm), and the measurement speed was set at 1.00 mm/s with a trigger force of 0.005 kg. Texture analysis was automatically performed by the texture expert software (version 4,0,12,0. Stable Micro systems Ltd.), and following parameters were recorded: hardness (N/cm²) = maximum force required to compress the sample; cohesiveness = extent to which sample could be deformed prior to rupture (A₂/A₁, where A₁ is the total energy required for first compression and A₂ as the total energy required for the second compression); adhesiveness = work necessary to pull the compressing plunger away from sample (negative area under the baseline between the compression cycles); gumminess (N/cm²) = force necessary to disintegrate a semi-solid sample for swallowing (a combination of hardness and cohesiveness); chewiness (N/cm) = work to masticate the sample for swallowing (hardness×cohesiveness×springiness); resilience = negative force input/positive force input during the first compression; and springiness (cm) = ability of sample to recover its original form after a deforming force has been removed (time duration of force input during the second compression/time duration during the first compression) (Bourne, 1978).

Lipid peroxidation (2-thiobarbituric acid reactive substances/TBARS)

For measuring lipid peroxidation, 3 g of samples were homogenized (T25b; Ika Werke GmbH & Co. KG, Janke & Kunkel, Staufen, Germany) with 12 mL of distilled water and 50 µL 7.2% butylated hydroxyanisole (BHA) according to the method by Jung et al. (2012b). The homogenized mixture (5 mL) was transferred to a test tube with 5 mL of TBA/TCA solution (20 mM thiobarbituric acid in 15% trichloroacetic acid). The mixture was heated in a water bath for 15 min at 90°C. After cooling to 20°C, the mixture was centrifuged (3,000 rpm) (UNION 32R, Hanil Science Industrial, Co., Ltd., Korea) for 15 min. Absorbance of the supernatant obtained after the centrifugation, was determined by spectrophotometer (UV 1600 PC, Shimadzu, Tokyo, Japan) at 532 nm. Quantification was done based on a standard curve. Lipid peroxidation was expressed in mg of malondialdehyde/kg meat.

Volatile basic nitrogen (VBN)

VBN content was determined according to the method of Conway (1950). To 10 g of the sample, 30 mL of distilled water was added and homogenized (NS-50, Japan) for 5 min at 14,000 rpm. The homogenate was filtered through Whatman No. 1 paper and adjusted to total volume of 100 mL. The filtrate (approximately 5 mL) was placed in the outer chamber of a Conway unit (Conway, 1950) while 0.01 M Boric acid solution (5 mL) and two drops of Conway reagent (0.066% methyl red+0.066% bromocresol green, in 1:1 ratio) respectively prepared by mixing with ethanol, were added to the inner chamber. After adding 5 mL of 50% K₂CO₃ solution to the outer chamber, the cover of the Conway unit was closed, and kept at 37°C for 120 min. The Boric acid solution present in the inner chamber was titrated with 0.02 M H₂SO₄. VBN was recorded as mg %.

Microbiological analysis

Before inoculation, the samples were sterilized using electron beam irradiation (35 kGy at 2.5 MeV) with linear electron beam RF accelerator (EB Tech, Daejeon, Korea). The microbial strains used for the present test were *Listeria monocytogenes* (KCTC 3569), *Salmonella* Typhimurium (KCTC 1925), and *Escherichia coli* (KCTC 1682). Each strain was primarily cultured at 25°C for 24 h using tryptic soy broth (Difco, Laboratories, Detroit, MI, USA). After centrifuging the culture solutions at 3,000 rpm for 10 min, the cells were washed twice with sterile saline solution to obtain the final concentration of approximately 10⁸ colony forming units (CFU)/mL. The homogeneous upper solution was taken (0.1 mL) and inoculated on the surface of each sample, then vacuum packed in a polyethylene bag (oxygen permeability 22.5 mL m²/24 h atm at 60%; 60 mm thickness; RH/25°C). After sealing, the bag was stored at

4°C.

Microbial testing of samples was carried out by adding sterile saline (90 mL) to the sample (10 g), mixing for 120 s using Bag mixer (Model 400, Interscience, France), and diluting the mixture based on 10-fold serial dilution. Each diluent (100 mL) was inoculated to tryptic soy agar (Difco), and cultured for 48 h at 37°C. The number of colonies produced was counted and expressed as CFU/g.

Sensory evaluation

Chicken breast meat samples, not treated with bacteria, were sliced into 1 cm thick portions and grilled on both sides (George Foreman Lean Mean Fat Reducing Grilling Machine, 2400 watts) for approximately 45 s to reach an internal temperature of 71°C to 75°C. Immediately after grilling, samples were provided to the sensory panel using a coded identifier. The sensory panel consisted of university students, 19 to 29 year old, 4 males and 11 females who had been trained and participated in numerous sensory evaluations of chicken and beef meat over a period of one and half years. Before tasting, panellists were familiarized with the assessment criteria, the meat attributes to be rated, and how to complete the questionnaire. Each panellist tasted at least one sample from every treatment. Water was provided to cleanse the mouth cavity between testing each sample. Panellists used a 9-point (1 to 9) hedonic scale to assess various meat quality attributes. Sensory-textural attributes scored were: meat colour (extremely light to extremely dark), aroma strength (very weak to very strong), aroma pleasantness (extremely dislike to extremely pleasant), tenderness — force required to bite the sample (extremely tough to extremely tender), juiciness (extremely dry to extremely juicy), texture — the experience during chewing samples, their stickiness to the roof of the mouth (extremely gooey to extremely smooth), flavour (extremely unpleasant to extremely enjoyable), overall satisfaction (disagreeable to enjoyable), and would you buy this meat (definitely not to definitely yes). Additionally, there was space provided for further flavour description and additional comments.

Statistical analysis

The experiment was a completely randomized design conducted as 3 independent trials with 2 observations for treatment combinations for each trial. Statistical analysis was performed by one-way Analysis of Variance (ANOVA), and when significant differences were detected, the differences between the mean values were identified by Student-Newman-Keul's multiple range test using SAS software with the confidence level at $p < 0.05$ (SAS, Release 8.01, SAS Institute Inc., Cary, NC). Mean values and standard error of the means are reported.

RESULTS AND DISCUSSION

Proximate composition and pH

It was found that the moisture content was significantly higher in the samples treated with olive oil (10%, OO) when compared with the other treatments but not significantly different from the controls (Table 1). The SS and SO treated samples had the lowest moisture, which could be due to the salt content in the soy sauce (Alvarado and McKee, 2007). The OO samples had the lowest cooking loss followed by the controls, SS and SO treatments. The difference between the treatments and controls were statistically significant whereas the difference between the negative and HP controls were not significant (Table 1). These results indicate that the SO, SS, and OO successfully penetrated into chicken breast meat, the SO treatment being the most efficient. Cooking loss is an important factor in quality and taste of cooked meat products (Aaslyng et al., 2003), it also reduces the yield of the final product and therefore is a major concern to the meat industry. HP, up to 300 MPa, treatment of beef *semitendinosus* muscle increased cooking loss by reducing sarcomere length, while at higher pressures (400 and 500 MPa) cooking loss did not increase (Kim et al., 2007). However, another research (Kruk et al., 2011) has found that HP of chicken breast fillets did not increase cooking loss at 300 MPa, while HP at 450 and 600 MPa increased the cooking loss by 6.4% and 19.7%, respectively.

Fat content in all treated groups was significantly higher when compared with the controls. Among all treatment groups, SO and SS showed the highest fat content with OO the lowest. Initially it is difficult to see how SS could increase fat content, but it may be possible that salt or some other component of the sauce solution affected the muscle texture, allowing subcutaneous and or inter-muscular fat from around the chicken meat to be forced into the muscle.

Table 1. Attributes of chicken breast meat with added olive oil and/or soy sauce and treated by HP at 300 MPa

Treatment ¹	Moisture (%)	Cooking loss (%)	Fat content (%)	pH
0.1 MPa	70.3 ^a	31.6 ^c	1.5 ^c	6.24 ^a
300 MPa	72.2 ^a	30.4 ^c	1.7 ^c	6.22 ^a
SS+300 MPa	66.9 ^b	33.7 ^b	6.3 ^a	6.15 ^{bc}
OO+300 MPa	72.0 ^a	28.7 ^d	5.1 ^b	6.14 ^c
SO+300 MPa	66.8 ^b	35.9 ^a	6.9 ^a	6.17 ^b
SEM ²	1.1	0.8	0.5	0.01

^{a-d} Different letters in the same column indicate a significant difference ($p < 0.05$).

¹ 0.1 MPa = Chicken breast without any treatment; 300 MPa = HP processed at 300 MPa; SS+300 MPa = HP processed with soy sauce (10%, w/w); OO+300 MPa = HP processed with olive oil (10%, w/w); SO+300 MPa = HP processed with soy sauce (5%, w/w) and olive oil (5%, w/w).

² Standard error of the means ($n = 15$).

Table 2. Fatty acid composition (%) of chicken breast meat with added olive oil and/or soy sauce and treated by HP at 300 MPa

Fatty acid composition	Treatment ¹						SEM ²
	0.1 MPa	300 MPa	SS+300MPa	OO+300MPa	SO+300MPa	OO+600 MPa	
C16:0	24.9 ^a	24.7 ^a	25.3 ^a	23.3 ^b	23.2 ^b	23.4 ^b	0.6
C16:1	3.5 ^a	2.9 ^{ab}	3.6 ^a	2.4 ^b	3.2 ^{ab}	3.6 ^a	0.4
C18:0	12.2	13.1	12.1	12.8	11.5	12.6	1.0
C18:1	31.2 ^c	30.3 ^c	33.5 ^c	35.3 ^{bc}	40.2 ^{ab}	41.8 ^a	2.9
C18:2	19.4 ^a	19.3 ^{ab}	18.0 ^{ab}	17.5 ^b	14.8 ^c	13.7 ^c	0.9
C18:3	0.54 ^a	0.47 ^a	0.56 ^a	0.46 ^a	0.48 ^a	0.32 ^b	0.06
C20:4	6.6 ^{ab}	7.5 ^a	5.7 ^{ab}	6.6 ^a	5.5 ^{bc}	3.7 ^c	0.9
C22:6	1.8 ^a	1.9 ^a	1.3 ^{bc}	1.6 ^{ab}	1.1 ^c	1.0 ^c	0.2
Saturated	37.2 ^{ab}	37.8 ^a	37.4 ^a	36.1 ^{ab}	34.7 ^b	36.0 ^{ab}	1.3
Monounsaturated	34.6 ^c	33.1 ^c	37.1 ^{bc}	37.7 ^{bc}	43.5 ^{ab}	45.3 ^a	3.2
Polyunsaturated	28.2 ^a	29.1 ^a	25.5 ^{ab}	26.2 ^a	21.9 ^{bc}	18.6 ^c	2.0
Unsaturated/saturated ³	1.69	1.65	1.67	1.77	1.88	1.78	

^{a-d} Different letters in the same row indicate a significant difference ($p < 0.05$).

¹ 0.1 MPa = Chicken breast without any treatment; 300 MPa = HP processed at 300 MPa; SS+300 MPa = HP processed with soy sauce (10%, w/w); OO+300 MPa = HP processed with olive oil (10%, w/w); SO+300 MPa = HP processed with soy sauce (5%, w/w) and olive oil (5%, w/w); OO+600 MPa = HP processed with 600 MPa with olive oil (10%, w/w).

² Standard error of the means ($n = 18$). ³ The ratio was calculated from treatment means.

The pH of the controls was significantly higher than that of SO, SS, and OO (Table 1).

Fatty acid composition

The effect of HPP and flavoring agents on chicken breast meat is presented in Table 2. Oleic acid (C18:1) is the main component of olive oil. Compared to the controls, the addition of a mixture of oleic acid with soy sauce (SO [5%+5%]) followed by 300 MPa pressure increased the oleic acid (C18:1) and monounsaturated fatty acid content and reduced the linoleic acid (C18:2), docosahexaenoic acid (C22:6) and PUFA contents.

Treatment with OO (10%) at 600 MPa resulted in a similar trend as the treatment with SO (5%+5%) at 300 MPa. These two treatments produced the highest increase in oleic acid (more than 35%). Treatment with OO (10%) at 300 MPa did not have a significant effect on any fatty acids when compared with the controls suggesting that HP processing under 300 MPa pressure is not strong enough for the olive oil to penetrate into the chicken breast meat. It seems that at 600 MPa the pressure is high enough to force the olive oil into the meat; while at 300 MPa some component of the soy sauce is causing the meat to become penetrable by mixture with olive oil; whereas, without soy sauce, at 300 MPa the olive oil cannot be forced into the meat.

Additionally the OO (10%) and 600 MPa caused a reduction of linolenic (C18:3) and eicosatetraenoic (C20:4) fatty acids, but did not affect the content of saturated fatty acids.

All the treatment groups that include olive oil alone and with soy sauce produced a higher ratio of unsaturated to saturated fatty acids. Although the significance of this ratio

could not be tested, the trend suggests that the addition of OO and/or SO produced favorable meat products in terms of fatty acid profile as well as higher palatability due to increased fat content. Olive oil has recently received attention, chiefly as a source of monounsaturated fatty acids (mainly oleic acid) (López-López et al., 2011) because it has a high biological value and contains antioxidants in optimum concentrations (Mahmoud and Badr, 2011). Therefore, the present method of preparing chicken breast meat has advantages compared to untreated meat in terms of improved palatability and health benefits due to fatty acid profile modification, as well as food safety enhancement.

Surface color

When considering the lightness (L^*), the lightest meat color was observed in 300 MPa pressurized samples either with or without olive oil (Table 3). Although the L^* value of OO 300 MPa treatment was higher than 300 MPa, the difference between the treatments was not statistically significant. This effect, that could be detected visually, demonstrates that although the application of olive oil increased the lightness of the meat, the pressure was the most detrimental whitening factor. The 300 MPa HP treatment with addition of soy sauce alone or in combination with olive oil significantly reduced the L^* value of the meat compared to treatment with olive oil, or pressure alone. However, the soy sauce did not reduce the lightness to that of untreated chicken breast meat (0.1 MPa).

Redness (a^*) was high in the chicken breast treated with SS, SO and control (300 MPa) followed by OO at 300 MPa ($p < 0.05$) and then the non-pressurized control (0.1 MPa, $p < 0.05$), respectively. Thus pressure has increased redness,

Table 3. Surface color of chicken breast meat with added olive oil and soy sauce and/or treated by HP at 300 MPa

Treatment ¹	Lightness (L*-value)	Redness (a*-value)	Yellowness (b*-value)
0.1 MPa	52.9 ^d	0.4 ^c	10.2 ^d
300 MPa	69.9 ^a	2.8 ^{ab}	13.4 ^{bc}
SS+300 MPa	59.0 ^c	4.3 ^a	15.3 ^{ab}
OO+300 MPa	71.6 ^a	1.6 ^{bc}	12.1 ^{cd}
SO+300 MPa	63.6 ^b	3.4 ^{ab}	16.4 ^a
SEM ²	1.4	0.9	1.0

^{a-d} Different letters in the same column indicate a significant difference ($p < 0.05$).

¹ 0.1 MPa = Chicken breast without any treatment; 300 MPa = HP processed at 300 MPa; SS+300 MPa = HP processed with soy sauce (10%, w/w); OO+300 MPa = HP processed with olive oil (10%, w/w); SO+300 MPa = HP processed with soy sauce (5%, w/w) and olive oil (5%, w/w).

² Standard error of the means ($n = 15$).

while OO has reduced redness compared to SS, but not compared to the control. Yellowness was higher in soy sauce containing samples. The SO treatment had the highest b* value followed by SS and 300 MPa (control) treatments. The mixture of soy sauce and olive oil gave the highest b* value that was significantly higher than the control, whereas the b* value of SS was higher than the control (0.1 MPa) but not statistically different from the pressurized control (300 MPa) or SO samples. Since 300 MPa, OO reduced the yellowness compared to the SS treatment, these differences in color parameters may be due to both the color of soy sauce itself (Jin et al., 2005) in conjunction with HP treatment. It has been reported that application of HP affects the color of beef muscle (Serra et al., 2007), minced muscle of albacore tuna, *Thunnus alalunga* (Ramirez-Suarez and Morrissey, 2006), and meat products such as sausages causing a brighter appearance (Crehana et al., 2000). Kruk et al. (2011) reported that the increase of pressure from 300 MPa to 600 MPa increased the L*, a*, and b* values of chicken breast meat, agreeing with the present results. Colour changes can be explained by the colour of the sauce, myoglobin denaturation, and/or heme displacement or release as well as ferrous oxidation caused by the pressure

treatment (Carlez et al., 1995; Mor-Mur and Yuste, 2003; Jung et al., 2012b).

Texture

The textural profiles were assessed as chewiness, hardness, cohesiveness, gumminess resilience, adhesiveness and springiness. Except for the springiness and adhesiveness, all other parameters have been reduced with the application of pressure and the additives. However, there was no significant difference in springiness. Similar systematic differences tended to be seen for all other textural traits (Table 4). The order of treatments were the non-pressurized control, SS 300 MPa, control 300 MPa and OO 300 MPa followed by SO 300 MPa. In this order, with two minor anomalies, the treatments reduced significantly in chewiness, hardness, cohesiveness, gumminess and resilience. This suggests that pressure affects the normal texture, SS partly reduces this affect, while OO and the interaction between S and O increase the reduction in textural characters.

The HP effects on meat hardness are dependent on rigor stage, pressure, temperature and their combination. Generally, low pressure (<200 MPa) treatment can tenderize pre-rigor meat, while tenderization of post-rigor meat with HHP can only be achieved at high temperature (40°C to 80°C) (Sun and Holly, 2010). Many researchers reported that the texture profile of meat, especially hardness, increased significantly with an increase of pressure. When Cod muscles were subjected to pressure the hardness increased, with treatment up to 400 MPa, because HP stimulates the formation of a hydrogen bonded gel (Angsupanich and Ledward, 1998). Master et al. (2000) showed that hardness of fish increased as a result of high pressure processing at 200 and 400 MPa. A similar effect of increased pressure on hardness was observed in beef muscle (Ma and Ledward, 2004) and chicken breast meat (Kruk et al., 2011). On the other hand, Suzuki et al. (1990) reported that pressures of 150 MPa or higher achieved tenderization effect on beef by fragmentation of myofibrillar proteins and reduction of gap filament integrity. Luruena-Martinez et al. (2004) reported that olive oil addition together with fat

Table 4. Texture characteristics of chicken breast meat with added olive oil and/or soy sauce and treated by HP at 300 MPa

Treatment ¹	0.1 MPa	300 MPa	SS+300 MPa	OO+300 MPa	SO+300 MPa	SEM ²
Chewiness	3,057 ^a	2,375 ^{bc}	2,767 ^{ab}	2,045 ^c	1,423 ^d	284
Hardness	7,889 ^a	7,094 ^{ab}	6,798 ^b	5,656 ^c	5,050 ^c	479
Cohesiveness	0.52 ^a	0.42 ^b	0.49 ^{ab}	0.44 ^{ab}	0.33 ^c	0.04
Gumminess	4,010 ^a	2,961 ^b	3,360 ^b	2,479 ^c	1,663 ^d	204
Resilience	0.17 ^a	0.14 ^{ab}	0.18 ^a	0.14 ^{ab}	0.11 ^b	0.02
Adhesiveness	-40 ^b	-13 ^{ab}	-3 ^a	-16 ^{ab}	-19 ^{ab}	15
Springiness	0.76	0.80	0.82	0.82	0.86	0.06

^{a-c} Different letters in the same row indicate a significant difference ($p < 0.05$).

¹ 0.1 MPa = Chicken breast without any treatment; 300 MPa = HP processed at 300 MPa; SS+300 MPa = HP processed with soy sauce (10%, w/w); OO+300 MPa = HP processed with olive oil (10%, w/w); SO+300 MPa; HP processed with soy sauce (5%, w/w) and olive oil (5%, w/w).

² Standard error of the means ($n = 15$).

reduction caused a significant decrease in hardness and the related parameters such as chewiness and gumminess due to high monounsaturated fat in the product. Our results concur with (Luruena-Martinez et al., 2004). Hardness is an important texture attribute to consumers and dictates the commercial value of a meat (Chambers and Bowers, 1993). These results support the conclusion that HP with OO or SO as used in the present study is advantageous as it can reduce the hardness of chicken meat.

Lipid oxidation (TBARS)

Lipid oxidation for all treatments increased with increasing storage time (Table 5). After 7 days of storage TBARS values of the non-pressurized control (0.1 MPa) increased approximately 1.7 fold, all of which occurred in the first 3 days. A similar result was obtained for the pressurized control (300 MPa) except that the TBARS values increased a further 1.7 fold over the next 4 days of storage. Treatment with OO overcame the detrimental effect of pressure (300 MPa). Treatment with soy sauce produced significant oxidation at day 0, which was partially overcome in the SO treatment, either by reduced soy sauce volume or the addition of olive oil.

Kruk et al. (2011) reported that HP at 450 and 600 MPa induced lipid oxidation of chicken breast during storage. However, it was demonstrated that oxidation of chicken breast treated at 300 MPa was not higher when compared with the control until day 3. A similar detrimental effect of pressure was observed at over 400 MPa (Wiggers et al., 2004), whereas there was no significant difference with HP at less than 300 MPa (Cheah and Ledward, 1996).

It has been reported that addition of olive oil into certain food makes them resistant to oxidation due to the presence of antioxidants such as β -carotene and phenolic compounds

Table 5. Lipid oxidation (TBARS) of chicken breast meat with added olive oil and/or soy sauce and treated by HP at 300 MPa

Treatment ¹	Storage period (day)			SEM ²
	0	3	7	
0.1 MPa	0.28 ^{cx}	0.48 ^{cy}	0.47 ^{cy}	0.06
300 MPa	0.27 ^{cx}	0.43 ^{cdy}	0.73 ^{bz}	0.08
OO+300 MPa	0.29 ^{cx}	0.36 ^{dy}	0.48 ^{cz}	0.03
SO+300 MPa	0.56 ^{bx}	0.69 ^{by}	0.86 ^{bx}	0.02
SS+300 MPa	0.91 ^{ax}	1.01 ^{ay}	1.04 ^{ay}	0.03
SEM ²	0.03	0.05	0.08	

^{a-d} Different letters in the same column indicate a significant difference ($p < 0.05$).

^{x-z} Different letters in the same row indicate a significant difference ($p < 0.05$).

¹ 0.1 MPa = Chicken breast without any treatment; 300 MPa = HP processed at 300 MPa; SS+300 MPa = HP processed with soy sauce (10%, w/w); OO+300 MPa = HP processed with olive oil (10%, w/w); SO+300 MPa = HP processed with soy sauce (5%, w/w) and olive oil (5%, w/w).

² Standard error of the means ($n = 15$).

(Aparicio et al., 1999; Kim et al., 2009). Ansorena and Astiasarán (2004) reported that the addition of olive oil to sausages was more effective than using vacuum packaging methods for avoiding lipid oxidation during storage. As found in this study, the use of olive oil is beneficial for suppressing lipid oxidation induced by HP. In contrast, the addition of soy sauce promotes lipid oxidation perhaps because of salts and other reactive compounds in the sauce.

Volatile basic nitrogen (VBN)

Total VBN concentration in chicken breast meat has been used as an index of meat freshness (Yamanaka and Matsumoto, 1989; Ohashi et al., 1991). There was no difference between the treatments and controls in VBN content at day 0 except the SS samples which had significantly higher VBN value (Table 6). All treatments increased VBN by day 7 of storage. The SS samples further increased VBN values after 3 days of storage and remained at this level till day 7. In contrast, the non-pressurized control showed significant differences at each time interval, over 4 fold increase in VBN after 7 days, while the pressurized control (300 MPa) produced a 2 fold, increase in VBN between days 3 and 7. The OO, SO, and SS treatments reduced the increase in VBN to less than 1.5 fold over the 7 days.

VBN in meat can be increased by either bacterial or enzymatic degradation of proteins (Egan et al., 1981). A previous study that used higher pressures reduced the VBN content in chicken meat, which was associated with a decreased bacterial count (Kruk et al., 2011). These results support the theory that HP treatment helps to maintain meat freshness via eliminating contaminating microorganisms and protecting against enzymatic degradation of meat

Table 6. Volatile basic nitrogen (mg %) in chicken breast meat treated with olive oil and/or soy sauce and treated by HP at 300 MPa

Treatment ¹	Storage period (day)			SEM ²
	0	3	7	
0.1 MPa	15.4 ^{bz}	28.0 ^{ay}	65.8 ^{ax}	1.9
300 MPa	14.7 ^{by}	17.5 ^{cy}	34.3 ^{bx}	1.9
OO+300 MPa	15.4 ^{by}	18.2 ^{cy}	22.4 ^{cx}	1.9
SO+300 MPa	16.8 ^{aby}	17.5 ^{cy}	23.8 ^{cx}	0.9
SS+300 MPa	18.9 ^{ay}	22.4 ^{bx}	24.5 ^{cx}	1.2
SEM ²	1.2	1.7	1.9	

^{a-c} Different letters in the same column indicate a significant difference ($p < 0.05$).

^{x-z} Different letters in the same row indicate a significant difference ($p < 0.05$).

¹ 0.1 MPa = Chicken breast without any treatment; 300 MPa = HP processed at 300 MPa; SS+300 MPa = HP processed with soy sauce (10%, w/w); OO+300 MPa = HP processed with olive oil (10%, w/w); SO+300 MPa = HP processed with soy sauce (5%, w/w) and olive oil (5%, w/w).

² Standard error of the means ($n = 15$).

proteins. It is possible that the salt in the soy sauce treatments could further reduce VBN production either by enzymatic or microbial inhibition. The mechanism causing the effect of olive oil on VBN is not known.

Inactivation of pathogens

The application of 300 MPa HP alone or in combination with flavorings reduced the 3 major pathogens on average by 1 to 2 log CFU/g: *E. coli*, 2.1 log CFU/g; *L. monocytogenes*, 1.3 log CFU/g and *S. Typhimurium*, 1.1 log CFU/g (Table 7). The most beneficial effects of HP alone, or with SO, SS, or OO were observed on *E. coli*, *L. monocytogenes* then *S. Typhimurium*, respectively.

Kruk et al. (2011) and Jung et al. (2012a) reported that the pressures 450 and 600 MPa almost completely eliminated the 3 major pathogens including *S. Typhimurium*, *E. coli*, and *L. monocytogenes*, but this study only produced 1 to 2 log unit reductions with 300 MPa pressure, which showed limited effect on food safety enhancement. Malicki et al. (2005) showed that pressure between 100 and 400 MPa efficiently reduced strains of *Salmonella*. Styles et al. (1991) reported a >7 log reduction in *L. monocytogenes* at approximately 340 MPa pressure. The microbial cellular membrane is affected by high pressure, resulting in osmotic changes, lysis, alterations of nuclear materials, and other modifications which can result in cell death (Mackey et al., 1994). In this study, all treatments inhibited microbial

growth during storage at day 3, indicating that 300 MPa HP in combination with olive oil and soy sauce improve meat safety. On the other hand, under certain circumstances, the reduction of pathogens may not be sufficient for assurance of meat safety after treatment at 300 MPa. These varied results suggest that further research is required to be certain of increasing food safety at 300 MPa pressure.

Sensory evaluation

According to sensory evaluation based on preference tests of Korean test panels, compared to the non-pressurized control (0.1 MPa) the OO 300 MPa was the only treatment that had a significantly higher willingness to buy (Table 8). This can be a function of the specific combination of small and relative differences in the sensory traits, though not significant, in conjunction with a significant increase in fat content of the OO samples, along with significantly reduced cooking loss and pH.

The SO and SS 300MPa treatments had elevated surface color and aroma scores compared to control (0.1 MPa) treatment. The only other significant difference found from the sensory analysis was the improvement in flavor score for the OO 300 MPa treatment compared to the pressurized control (300 MPa).

It has been reported that HP treatment affects many sensory characteristics of meat. Kruk et al. (2011) demonstrated that HP treatment affected flavor, juiciness

Table 7. Growth of pathogens (log(CFU/g)) in inoculated chicken breast meat treated with olive oil and/or soy sauce and treated by HP at 300 MPa

Microorganisms	Treatment ¹	Storage period (day)				SEM ²
		0	3	7	14	
<i>Escherichia coli</i> KCTC 1682	0.1 MPa	8.45 ^{ax}	7.98 ^{ay}	7.84 ^{ay}	8.01 ^{ay}	0.16
	300 MPa	6.76 ^{bx}	5.39 ^{by}	5.97 ^{cx}	6.88 ^{bx}	0.17
	SS+300 MPa	5.78 ^{bcy}	5.17 ^{bz}	5.81 ^{cy}	6.39 ^{cx}	0.13
	OO+300 MPa	6.11 ^{bx}	5.24 ^{by}	6.17 ^{bx}	6.49 ^{cx}	0.22
	SO+300 MPa	5.48 ^{cy}	5.33 ^{by}	6.19 ^{bx}	6.45 ^{cx}	0.16
	SEM ³	0.20	0.21	0.15	0.11	
<i>Salmonella typhimurium</i> KCTC 1925	0.1 MPa	6.17 ^{bx}	6.74 ^{ax}	6.69 ^{ax}	6.84 ^{ax}	0.35
	300 MPa	5.53 ^{cx}	5.26 ^{bx}	5.06 ^{by}	5.38 ^{cx}	0.26
	SS+300 MPa	5.50 ^{cx}	4.60 ^{bz}	4.95 ^{byz}	5.85 ^{bxy}	0.35
	OO+300 MPa	6.33 ^{bx}	4.81 ^{bz}	5.14 ^{by}	5.80 ^{bxy}	0.36
	SO+300 MPa	6.70 ^{ax}	5.47 ^{by}	5.54 ^{by}	6.20 ^{abx}	0.29
	SEM ³	0.16	0.45	0.33	0.38	
<i>Listeria monocytogenes</i> KCTC 3569	0.1 MPa	7.35 ^{aw}	6.08 ^{ay}	5.63 ^{az}	6.92 ^{ax}	0.11
	300 MPa	4.13 ^{cy}	4.38 ^{bxy}	4.40 ^{cxy}	4.89 ^{cx}	0.31
	SS+300 MPa	5.58 ^{bx}	5.60 ^{ax}	5.13 ^{bx}	5.65 ^{bx}	0.27
	OO+300 MPa	4.54 ^{cy}	4.43 ^{by}	5.85 ^{ax}	5.48 ^{bx}	0.312
	SO+300 MPa	5.48 ^{bx}	5.70 ^{ax}	5.58 ^{ax}	5.69 ^{bx}	0.21
	SEM ³	0.27	0.22	0.19	0.30	

^{a-c} Within microorganism, different letters in the same column indicate a significant difference (p<0.05).

^{w-z} Different letters in the same row indicate a significant difference (p<0.05).

¹ 0.1 MPa = Chicken breast without any treatment; 300 MPa = HP processed at 300 MPa; SS+300 MPa = HP processed with soy sauce (10%, w/w); OO+300 MPa = HP processed with olive oil (10%, w/w); SO+300 MPa = HP processed with soy sauce (5%, w/w) and olive oil (5%, w/w).

² Standard error of the means (n = 12). ³ Standard error of the means (n = 15).

Table 8. Sensory evaluation of chicken breast meat with added olive oil and/or soy sauce and treated by HP at 300 MPa

Sensory parameter	0.1 MPa	300 MPa	OO+300 MPa	SO+300 MPa	SS+300 MPa	SEM ¹
Surface color	3.10 ^b	3.08 ^b	2.50 ^b	4.40 ^a	4.83 ^a	0.37
Aroma	3.90 ^b	3.88 ^b	3.83 ^b	5.70 ^a	5.56 ^a	0.52
Tenderness	6.87 ^a	6.02 ^a	5.72 ^a	6.37 ^a	6.15 ^a	1.12
Juiciness	6.67 ^a	6.55 ^a	6.74 ^a	6.02 ^a	7.07 ^a	0.57
Chewiness	6.00 ^a	6.00 ^a	6.20 ^a	6.37 ^a	6.94 ^a	0.62
Flavor	5.20 ^{ab}	4.92 ^b	6.06 ^a	5.36 ^{ab}	5.06 ^b	0.45
Overall acceptance	5.13 ^a	5.07 ^a	6.06 ^a	5.42 ^a	5.26 ^a	0.55
Willingness to buy	4.15 ^b	4.08 ^b	5.42 ^a	4.74 ^{ab}	4.68 ^{ab}	0.52

^{ab} Different letters in the same row indicate a significant difference ($p < 0.05$).

¹ 0.1 MPa = Chicken breast without any treatment; 300 MPa = HP processed at 300 MPa; SS+300 MPa = HP processed with soy sauce (10%, w/w); OO+300 MPa = HP processed with olive oil (10%, w/w); SO+300 MPa = HP processed with soy sauce (5%, w/w) and olive oil (5%, w/w).

¹ Standard error of the means ($n = 75$).

and aroma pleasantness of chicken breast fillet. Rivas-Canedo et al. (2008) showed that pressurization of minced beef and chicken breast using HP at 400 MPa significantly changed the levels of some volatile compounds, some alcohols and aldehydes were decreased whereas other compounds were more abundant.

It was demonstrated that the use of HP to retain and enhance chicken meat safety can add further value by including olive oil, with or without other ingredients prior to vacuum packaging.

CONCLUSION

The present study demonstrates that HP with addition of soy sauce and/or olive oil (SO+300, SS+300) is an effective technology in improving chemical, health and sensory qualities of chicken breast meat as well as its safety. This technology provides a method to produce value added chicken meat product that is beneficial for health discerning consumers.

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REFERENCES

- Aaslyng, M. D., C. Bejerholm, P. Ertbjerg, H. C. Bertram, and H. J. Anderson. 2003. Cooking loss and juiciness of pork in relation to raw meat quality and cooking procedure. *Food Qual. Prefer.* 14:277-288.
- Angsupanich, K. and D. A. Ledward. 1998. High pressure treatment effects on cod (*Gadus morhua*) muscle. *Food Chem.* 63:39-50.
- AOAC. 1990. Official methods of analysis 15th revised ed. Association of Official Analytical Chemists. Washington, DC, USA
- Alterkruse, S. E., N. J. Stern, P. I. Fields, and D. I. Swerdlow. 1999. *Campylobacter jejuni*-an emerging foodborne pathogen. *Emerg. Infect. Dis.* 5:28-35.
- Alvarado, C. and S. McKee. 2007. Marination to improve functional properties and safety of poultry meat. *J. Appl. Poult. Res.* 16:113-120.
- Anang, D. M., G. Rusul, J. Bakar, and F. H. Ling. 2007. Effects of lactic acid and lauricidin on the survival of *Listeria monocytogenes*, *Salmonella enteritidis*, and *Escherichia coli* O157:H7 in chicken breast stored at 4°C. *Food Control* 18:961-969.
- Ansorena, D. and I. Astiasarán. 2004. Effect of storage and packaging on fatty acid composition and oxidation in dry fermented sausages made with added olive oil and antioxidants. *Meat Sci.* 67:237-244.
- Aparicio, R., L. Roda, M. A. Albo, and F. Gutierrez. 1999. Effect of various compounds on virgin olive oil stability measured by rancimat. *J. Agric. Food Chem.* 47:4150-4155.
- Bourne, M. C. 1978. Texture profile analysis. *Food Technol.* 33: 62-66.
- Carlez, A., T. Veciana-Nogues, and J. C. Chefel. 1995. Changes in colour and myoglobin of minced beef meat due to high pressure processing. *LWT-Food Sci. Technol.* 28:528-538.
- Chambers, E. and J. R. Bowers. 1993. Consumer perception of sensory qualities in muscle foods. *Food Technol. J.* 47:118-120.
- Cheah, P. B. and D. A. Ledward. 1996. High pressure effects on lipid oxidation in minced pork. *Meat Sci.* 43:123-134.
- Conway, E. J. 1950. Microdiffusion and volumetric error 3rd ed. Crosby Lockwood and Son Ltd. London, UK.
- Crehana, C. M., D. J. Troya, and D. J. Buckley. 2000. Effects of salt level and high hydrostatic pressure processing on frankfurters formulated with 1.5 and 2.5% salt. *Meat Sci.* 55:123-130.
- Egan, H., R. S. Kirk, and R. Sawyer. 1981. Pearson's chemical analysis of foods. 8th ed. Longman Scientific and Technol. UK.
- Fernandez-Gines, J. M., J. Fernandez-Lopez, E. Sayas-Barbera, and J. A. Perez-Alvarez. 2005. Meat products as functional foods: A review. *J. Food Sci.* 70:R37-R43.
- Folch, J., M. Less, and G. M. Sloane-Stabley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* 226:497-509.
- Garriga, M., N. Grèbol, M. T. Aymerich, J. M. Monfort, and M. Hugas. 2004. Microbial inactivation after high-pressure processing at 600 MPa in commercial meat products over its

- shelf life. *Innov. Food Sci. Emerg. Technol.* 5:451-457.
- González, M. and M. L. Hänninen. 2011. Reduction of *Campylobacter jejuni* counts on chicken meat treated with different seasonings. *Food Control* 22:1785-1789.
- Jayasena, D. D., D. U. Ahn, K. C. Nam, and C. Jo. 2013. Flavor chemistry of chicken meat: A review. *Asian Australas. J. Anim. Sci.* 26:732-742.
- Jin, S. K., I. S. Kim, K. H. Hah, H. J. Lyou, K. H. Park, and J. R. Lee. 2005. Quality characteristics of vacuum packaged fermented pork with soy sauce, red pepper and soybean paste seasoning during storage. *J. Anim. Sci. Technol.* 47:825-836.
- Jung, S., H. Yun, H. J. Kim, J. S. Ham, I. S. Kim, M. Lee, and C. Jo. 2012a. Inactivation efficiency of *Escherichia coli* and *Listeria monocytogenes* in ground pork by combination of natural food ingredients and high pressure processing. *Korean J. Food Sci. An.* 32:1-5.
- Jung, Y., S. Jung, H. J. Lee, M. Kang, S. K. Lee, Y. J. Kim, and C. Jo. 2012b. Effect of high pressure after the addition of vegetable oil on the safety and quality of beef loin. *Korean J. Food Sci. An.* 32:68-76.
- Kim, E. J., S. Y. Hwang, and J. Y. Son. 2009. Physiological activities of sesame, black sesame, perilla and olive oil extracts. *J. Korean Soc. Food Sci. Nutr.* 38:280-286.
- Kim, Y. J., E. J. Lee, N. H. Lee, Y. H. Kim, and K. Yamamoto. 2007. Effects of hydrostatic pressure treatment on the physicochemical, morphological, and textural properties of bovine *semitendinosus* muscle. *Food Sci. Biotechnol.* 16:49-54.
- Kondjoyan, A. and S. Portanguen. 2008. Effect of superheated steam on the inactivation of *Listeria innocua* surface-inoculated onto chicken skin. *J. Food Eng.* 87:162-171.
- Kruk, Z. A., H. Yun, D. L. Rutley, E. J. Lee, Y. J. Kim, and C. Jo. 2011. The effect of high pressure on microbial population, meat quality and sensory characteristics of chicken breast fillet. *Food Control* 22:6-12.
- López-López, I., S. Cofrades, V. Cañeque, M. T. Díaz, O. López, and F. Jiménez-Colmenero. 2011. Effect of cooking on the chemical composition of low-salt, low-fat Wakame/olive oil added beef patties with special reference to fatty acid content. *Meat Sci.* 89:27-34.
- Lurueña-Martínez, M. A., A. M. Vivar-Quintana, and I. Revilla. 2004. Effect of locust bean/xanthan gum addition and replacement of pork fat with olive oil on the quality characteristics of low-fat frankfurters. *Meat Sci.* 68:383-389.
- Ma, H. J. and D. A. Ledward. 2004. High pressure/thermal treatment effects on the texture of beef muscle. *Meat Sci.* 68:347-355.
- Mackey, B. M., K. Forestière, N. S. Isaacs, R. Stenning, and B. Brooker. 1994. The effect of high hydrostatic pressure on *Salmonella thompson* and *Listeria monocytogenes* examined by electron microscopy. *Lett. Appl. Microbiol.* 19:429-432.
- Mahmoud, K. A. and H. M. Badr. 2011. Quality characteristics of gamma irradiated beef burger formulated with partial replacement of beef fat with olive oil and wheat bran fibers. *Food Nutr. Sci.* 2:656-666.
- Malicki, A., Z. Sysak, and S. Bruzewicz. 2005. Pressurization effect on *Salmonella* sp. within the fish meal. *Bull. Vet. Inst. Puławy* 49:215-217.
- Master, A. M., D. Stegeman, J. Kals, and P. V. Bartels. 2000. Effects of high pressure on colour and texture of fish. *High Press. Res.* 19:109-115.
- Mor-Mur, M. and J. Yuste. 2003. High pressure processing applied to cooked sausage manufacture: physical properties and sensory analysis. *Meat Sci.* 65:1187-1191.
- Ohashi, E., M. Okamoto, A. Ozawa, and T. Fujita. 1991. Characterization of common squid using several freshness indicators. *J. Food Sci.* 56:161-163.
- Ramirez-Suarez, J. C. and M. T. Morrisey. 2006. Effect of high pressure processing (HPP) on shelf life of albacore tuna (*Thunnus alalunga*) minced muscle. *Innov. Food Sci. Emerg. Technol.* 7:19-27.
- Rastogi, N. K., K. S. M. S. Raghavaro, V. M. M. Balasubramaniam, K. Niranjana, and D. Knorr. 2007. Opportunities and challenges in high pressure processing of foods. *Crit. Rev. Food Sci. Nutr.* 47:69-112.
- Rivas-Canedo, A., E. Fernandez-Garcia, and M. Nunez. 2008. Volatile compounds in fresh meats subjected to high pressure processing: effect of the packaging material. *Meat Sci.* 81:321-328.
- Rodrigo, S., A. Adesiyun, Z. Asgarali, and W. Swanston. 2005. Prevalence of *Campylobacter* spp. on chickens from selected retail processors in Trinidad. *Food Microbiol.* 22:125-131.
- Serra, X., N. Grèbol, M. D. Guàrdia, L. Guerrero, P. Gou, P. Masoliver, M. Gassiot, C. Sárraga, J. A. Monfort, and J. Arnau. 2007. High pressure applied to frozen ham at different process stages. Effect on the sensory attributes and on the colour characteristics of dry-cured ham. *Meat Sci.* 75:21-28.
- Styles, M. F., D. G. Hoover, and D. F. Farkas. 1991. Response of *Listeria monocytogenes* and *Vibrio parahaemolyticus* to hydrostatic pressure. *J. Food Sci.* 56:1404-1407.
- Sun, X. D. and R. A. Holly. 2010. High hydrostatic pressure effects on the texture of meat and meat products. *J. Food Sci.* 75:R17-R23.
- Suzuki, A., M. Watanabe, K. Iwamura, Y. Ikeuchi, and M. Saito. 1990. Effects of high pressure treatment on the ultrastructure and myofibrillar protein of beef skeletal muscle. *Agric. Biol. Chem.* 54:3085-3091.
- Weiss, J., M. Gibis, V. Schuh, and H. Salminen. 2010. Advances in ingredient and processing systems for meat and meat products. *Meat Sci.* 86:196-213.
- Wiggers, S. B., M. V. Kroger-Ohlsen, and L. H. Skibsted. 2004. Lipid oxidation in high pressure processed chicken breast during chill storage and subsequent heat treatment: effect of working pressure, packaging atmosphere and storage time. *Eur. Food Res. Technol.* 219:167-170.
- Yagiz, Y., H. G. Kristinsson, M. O. Balaban, B. A. Welt, M. Ralat, and M. R. Marshall. 2009. Effect of high pressure processing and cooking treatment on the quality of Atlantic salmon. *Food Chem.* 116:828-835.
- Yamanaka, H. and M. Matsumoto. 1989. Simultaneous determination of polyamines in red meat fishes by high performance liquid chromatography and evaluation of freshness. *J. Food Hyg. Soc. Jap.* 30:396-400.
- Zhang, H. and G. S. Mittal. 2008. Effects of high-pressure processing (HPP) on bacterial spores: an overview. *Food Rev. Int.* 24:330-351.
- Zhang, W., S. Xiao, H. Samaraweera, E. J. Lee, and D. U. Ahn. 2010. Improving functional value of meat products. *Meat Sci.* 86:15-31.