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Effect of hot-boned pork on the quality of hurdle treated pork sausages during ambient temperature (37 ± 1 °C) storage

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Abstract

The study was aimed at evaluating the suitability of hot-boned pork and pork fat for processing shelf-stable pork sausages using hurdle technology and the different hurdles incorporated were low pH, low water activity, dipping in potassium sorbate solution, vacuum-packaging and post-package reheating. Emulsion stability and cooking yield did not Izatnagardiffer significantly among hot- and cold-processed sausages. Despite the same emulsion pH, the sausages from hot-boned pork had significantly higher fat content. Colour and texture profiles of pork sausages were significantly ($P < 0.05$) influenced by hot processing. During storage at ambient temperature (37 ± 1 °C), various physico-chemical characteristics, namely pH, TBARS and tyrosine values, of hot- and cold-processed sausages, did not differ. Hot-processing markedly increased the total plate counts of the sausages, but a significant difference was absent for anaerobic counts between treatments at any particular storage interval. Cold-processed sausages had the higher lactobacillus counts throughout the storage period. Sensory evaluation revealed that hurdle-treated pork sausages from hot-boned pork were equally suitable as those from cold-boned pork up to day 6 at ambient temperature.

Keywords: Hot boning; Hurdle treatment; Shelf-stable; Ambient temperature; Pork sausages

1. Introduction

Hot-boned meat is from the carcass before the chilling process and may include pre-rigor meat, as well as meat that has entered the onset of rigor. Hot processing, which includes the whole spectrum of technological processes from hot boning to processed meat, manufactured from pre rigor meat, have been studied in detail (Claus & Sorheim, 2006). Hot processing of meat offers several economical advantages which result from reduction of weight loss during chilling (about 1.5%), reduction of drip loss during storage of vacuum-packaged cuts by 0.1–0.6%, reduction in cooler space by 50–55%, savings of refrigeration energy by 40–50%, quicker turnover of meat at plant, reducing capital cost for buildings, higher final yield of products manufactured from hot-boned meat, savings on labour by 20% and savings on transport costs (Pisula & Tyburcy, 1996). The major problems associated with hot processing of meat are increased shape distortion of hot-boned cuts, need for careful synchronizing of the slaughter, boning and processing operations, requirements of higher standards of hygiene and high investment costs for construction of purpose-built existing plants, new equipment and training of staff.

Hot-boned meat offers numerous advantages in the production of comminuted meat products, attributed to higher muscle pH, higher protein solubility (Bentley, Reagan, & Miller, 1988) and increased emulsifying capacity (Claus & Sorheim, 2006). Due to higher pH and ATP level, dissociation of actomyosin and better solubility of myofibrillar proteins, functional properties of hot-boned meat are superior to those of cold-boned meat (Pisula & Tyburcy, 1996). Hot-processing resulted in higher fat retention during

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cooking than did cold-processing of ground beef and the patties made from hot-boned beef had higher cooking yield and more desirable pink/red colour (Berry, Bigner-George, & Eastridge, 1999) which might be associated with its higher ultimate pH and lower met-myoglobin content, respectively. Studies of Bentley et al. (1988) showed that, not only hot-boned meat but also hot-boned fat could increase the final yield of luncheon loaves.

Therefore, it is well understood that the superior functional properties of hot-boned meat are mostly due to its higher pH and protein solubility. However, in the present study, we adjusted the pH of emulsion made from both hot- and cold-boned meat to about 5.90 in order to adjust the pH hurdle in the final products. Our objective was to find out whether hot-boned pork and fat can be effectively utilized for processing shelf-stable pork sausages (SSPS) without adversely affecting different quality parameters, in order to save the expenses of refrigeration energy and cooler space requirement which are of importance in developing countries, where electricity is a major problem. In the case of positive results, we could also expect a substantial reduction in processing time from slaughter to final product development.

2. Materials and methods

2.1. Lean pork and pork fat

Both hams (4–5 kg each) from the same pig were obtained from crossbred barrows (75% Landrace × 25% Desi) (60–70 kg live weight) slaughtered by the standard procedure at the experimental abattoir of Livestock Products Technology Division, Indian Veterinary Research Institute, Izatnagar. Additional back fat was obtained from the loin portion. One of the two hams was hot boned to separate the skin, fat and meat. Hot-boned meat was cut into cubes of about 3 cm and ground using 13 mm, followed by 8 mm, plates in a Seydelmann meat grinder (Model WD 114, Stutgart, Germany). Fat was ground using 13 mm, followed by 3 mm, plates in the same grinder. They were used for making emulsion within 1 h after reaching the laboratory (total 1.5 h after slaughter). The other ham, kept for conditioning in a refrigerator at 4 ± 1 °C for about 16 h, was cold-boned on the next day. Meat and fat were ground and used for making meat emulsion.

2.2. Processing of shelf-stable pork sausages

Different hurdles incorporated were low pH (~5.90, using lactic acid (LA-0.5 N) and glucono-delta-lactone (GDL-0.1%)), low water activity (~0.93, using textured soy protein-3%), dipping in 1% potassium sorbate, vacuum-packaging and post-package reheating (90 °C). These hurdles were standardized in the laboratory by conducting a series of preliminary trials (data not shown). In most of the preliminary trials, shelf-life was considerably sacrificed for sensory attributes, because the objective was to begin with sausages that were as similar as possible to the control. Nitrite and sodium chloride (NaCl) are normally considered as hurdles, but in this study the term 'hurdle' refers to product hurdles other than nitrite and NaCl. The reason for selecting mild pH and a_w hurdles was that the sour and dried products are least relished by Indians.

Meat emulsions made from hot boned (within 1.5 h of slaughter) and cold-boned (next day of slaughter) pork were processed into sausages like the procedure mentioned hereunder. About 4 kg batches were made, namely, 2600 g lean pork, 800 g pork fat, 200 g condiments mix and refined wheat flour each, 80 g of spice mix and refined salt each and 20 g cane sugar and sodium tripoly phosphate each. Textured soy protein was added at 3% level (over and above 100 %) in the formulation as humectant. Also, sodium nitrite was added at 0.015%. Spice mix was prepared as for the formulation developed in the laboratory. Onion and garlic were used in the ratio 3:1 as condiments. To the ground lean pork, salt, sugar, sodium nitrite and sodium tripoly phosphate were added and chopped for about 2 min. Condiments mix was then added and chopped again for 2 min (water/ice flakes were not added, to reduce the water activity in the sausages). Textured soy protein (3%) was then added and the chopping continued for a further 0.5 min. Ground pork fat was slowly incorporated while chopping which was continued until the fat was completely dispersed in the batter (3–4 min). Spice mix and refined wheat flour were added and chopping was continued for a further 1 min to get a fine viscous emulsion. pH of the emulsion was adjusted to about 5.90 using lactic acid (0.5 N) and GDL (0.1%). The temperature of the emulsion varied from 10 to 12 °C. To evaluate the quality of meat emulsion, pH and emulsion stability were determined. Meat emulsions were then stuffed into 25 mm diameter cellulose casings (Viskase Nojax, Viskase Co. Inc., Chicago, USA) using a hydraulic sausage filler (Mainca, Model EP-25, Spain) and linked manually at about 12 cm intervals. Cooking was done in a steam oven without pressure until the internal temperature reached 75 °C, as recorded by a digital probe thermometer (Model CT-809, Century Instruments (P) Ltd., Chandigarh). The sausages were cooled to room temperature and peeled off the casings.

Sausages were then dipped in 1% warm (60–70 °C) potassium sorbate solution in filtered water and allowed to dry at room temperature (about 15 min) in a closed chamber in the processing plant (potassium sorbate dipping was performed to minimize the yeast and mold growth). Sausages were then vacuum-packaged in laminates of Nylon/LDPE bags, using a Rochermatic packaging machine (Model VM 195, Osnabruck, Germany) in such a way that each packet contained 7–8 sausages. Vacuum-packaged sausages were reheated to an internal temperature of 90 °C and were then allowed to cool to room temperature. The internal temperature of the sausages was monitored continuously, using a digital probe thermometer (Model CT-809, Century Instruments (P) Ltd., Chandigarh). One packet from each group was used for evaluation of physico-chemical, microbiological and

sensory attributes on the day of processing. The remaining packets (6 packets for each group) were stored at ambient temperature (37 ± 1 °C) in an incubator whose temperature was pre-set at 37 ± 1 °C. One packet from each group was drawn at 3 day intervals to evaluate their keeping quality at ambient temperature. The experiment was repeated three times.

2.3. Analytical procedures

pH was measured using a digital pH meter (Elico, Model LI 127, India). The weight of sausages was recorded before and after initial cooking and the yield was calculated (cooking yield = weight of cooked sausages/weight of raw sausages × 100) and expressed as a percentage. The procedure of Kondaiah, Anjaneyulu, Sharma, Rao, and Joshi (1985) was followed to measure the emulsion stability. Moisture, fat and protein contents of the sausages were determined by standard procedures (AOAC, 1995). The procedure of Tarladgis, Watts, Younathan, and Dugan (1960) was followed to estimate the TBARS number as mg of malonaldehyde per kg of sample. The water activity (a_w) of the sausages was measured by a Pa_w kit water activity meter (Decagon, Devices, USA). The procedure of Strange, Bendedict, Smith, and Swift (1977) was followed to determine the tyrosine value. The methods described by Koniecko (1979) were followed for measuring free fatty acids and titratable acidity. Titratable acidity was expressed as ml of 0.01 N NaOH/g sample required to neutralize the filtrate, as suggested by Feng-Sheng Wang (2000).

2.4. Accelerated TBARS

This is a measure of potential protection against lipid oxidation by the addition of hurdles to the meat products. In this method, lipid oxidation was accelerated by temperature (50 °C) and the addition of $FeSO_4$. The procedure described by Juncher et al. (2000) was followed.

2.5. Lovibond tintometer colour units

The colour of the cooked pork sausages was measured using a Lovibond tintometer (Model F, Greenwich, UK). Samples, from three different places, of sausages were taken in the sample holder and secured against the viewing aperture. The sample colour was matched by adjusting red (a) and yellow (b) units, while keeping the blue units fixed at 2.0. The corresponding colour units were recorded. The hue and chroma values were determined by using the formula, $(\tan^{-1})^{b\backslash a}$ (Little, 1975) and $(a^2 + b^2)^{1/2}$ (Froehlich, Gullet, & Usborne, 1983) respectively, where a = red units, b = yellow units.

2.6. Texture profile analysis

Texture profile analysis (TPA) of pork sausages was conducted by the procedure described earlier (Bourne, 1978) using a Stable Microsystems Texturometer (Stable Microsystems Ltd. Surrey, UK) model TA-XT_2 texture analyzer attached to a software, texture expert. Uniform sized pieces (1.5 cm^3) were used as the test samples. They were placed on platform in a fixture and compressed to 50% of their original height at a cross head speed of 50 mm/s through a two cycle sequence, using 25 kg load cell.

The texturometer was also used to measure shear force and work of shearing, using a Warner–Bratzler blade. Uniform sized samples (1 $cm^{3)}$ were radially sheared with a V-shaped blade attached to plunger at 50 mm/min crosshead speed.

2.7. Microbiological evaluation

All the microbiological parameters of shelf-stable pork sausages were determined by the methods described by ICMSF (1996). Ready-made media from Hi-Media Laboratories (P) Ltd., Mumbai, were used for the enumeration of different microbes. Duplicate plates were prepared and the counts were expressed as colony-forming units (cfu) per gramme. Preparation of samples and serial dilution of pork sausages were done near the flame in a horizontal laminar flow apparatus (Model YSI-188, Yarco Sales (P) Ltd., New Delhi) which was pre-sterilized by ultraviolet irradiation, observing all possible aseptic precautions. About 10 g of sample were aseptically weighed and transferred to a sterile mortar and homogenized for 2 min using a sterile pestle, while adding 90 ml of 0.1% sterile peptone water to make 10^{-1} dilution. Sterile peptone water (0.1%) was used as diluent for making further dilutions. One milliliter of 10^{-1} dilution was mixed with 9 ml of 0.1% peptone water to obtain a 10^{-2} dilution and so on.

The plates (M 091) for mesophilic counts were incubated at 37 ± 1 °C for 48 h and plates showing 30–300 colonies were counted. Coliform count was detected by using Violet Red Bile Agar (M 049 A). The number of red–purple colonies with about 0.5 mm diameter surrounded by a zone of precipitated bile was counted. Anaerobic (anaerobic agar, M228), lactobacilli (MRS Agar, M6411) and *Staphyloccus aureus* (Baired Parker agar, M 1140) counts were also measured. Potato dextrose agar (M 096) was used to enumerate yeast and mold counts. The plates were incubated at 25 ± 1 °C for 5 days. Black, white, red or greenish-black coloured colonies appearing on the plates were counted. Colonies judged to be borderline cases were also counted.

2.8. Sensory evaluation

Standard sensory evaluation, using an 8-point descriptive scale (Keeton, 1983), was followed with modifications where 8 = excellent and 1 = extremely poor. The experienced panel (7 members) consisted of scientists and postgraduate students of the Division of Livestock Products Technology, IVRI, Izatnagar. The panellists were trained

and well acquainted with different sensory attributes during their postgraduate/doctoral programme. They were briefly appraised of the nature of the experiment without disclosing the identity of samples. The sausages were not subjected to sensory evaluation on the day that they were found spoiled, but different physico-chemical and microbiological parameters were determined. The acceptable/unacceptable distinction was made mostly on the basis of flavour changes detected at the time of opening of the packets. The colour changes and amount of sliminess developed were also considered. Pork sausages, vacuum packaged in laminates of Nylon/LDPE bags and held at ambient temperature (37 ± 1 °C), were withdrawn at 3 day intervals. Samples were warmed (40–45 °C) using a microwave oven (LG Electronics India (P) Ltd., Mumbai) for 1 min and served to the panellists. The panellists evaluated the samples for appearance, flavour, juiciness, texture, binding and overall acceptability using a standard score sheet. Sensory evaluations were conducted between 3.30 and 4 pm and filtered tap water was provided to the panellists for rinsing their mouths between evaluations of different samples.

2.9. Statistical analysis

At least three replicate measurements were made and the data generated for different quality characteristics were compiled and analyzed using a randomized block design at the Institute's computer centre. The data were subjected to analysis of variance (one way ANOVA), least significant difference, paired *t*-test (Snedecor & Cochran, 1995) and Duncan's multiple range test (Steel & Torris, 1981) for comparing the means to find the effects between treatments, storage periods and their interaction for various parameters in different experiments. The smallest difference ($D_{5\%}$) for two means to be significantly different ($P < 0.05$) is reported.

3. Results and discussion

3.1. Physico-chemical characteristics of SSPS processed from hot- and cold-boned pork and fat

Temperatures of hot- and cold-boned meat at the time of processing were 36.20 and 4.27 °C, respectively (Table 1). As expected, hot-boned meat had significantly higher ($P < 0.01$) pH than had cold-boned meat (6.80 vs. 5.60). However, after the adjustment of the pH hurdle (using LA and GDL), the emulsions prepared from both hot- and cold-boned pork and fat showed similar pH values (~5.90). The emulsion stability and cooking yield did not differ significantly ($P > 0.05$) among hot- and cold-boned treatments. However, it is well established that hot-boned meat generally results in higher processing yields than does

Table 1
Effect of hot-boned pork and fat on the quality characteristics of SSPS

Parameter	Hot-boned	Cold-boned	*t*-value
Physico-chemical characteristics			
Meat temperature at processing (°C)	36.20 ± 0.03	4.27 ± 0.06	362.09**
Meat pH at processing	6.80 ± 0.08	5.60 ± 0.02	52.37**
Emulsion pH	5.94 ± 0.06	5.93 ± 0.06	0.253
Emulsion stability (%)	93.02 ± 0.09	92.85 ± 0.26	0.563
Cooking yield (%)#	94.39 ± 0.02	94.36 ± 0.03	0.359
Product pH	6.12 ± 0.06	6.11 ± 0.06	1.00
Moisture (%)	56.45 ± 0.09	56.39 ± 0.09	1.10
Protein (%)	18.7 ± 0.03	18.6 ± 0.05	0.627
Fat (%)	18.73 ± 0.03	18.41 ± 0.02	3.72*
Water activity	0.93 ± 0.00	0.93 ± 0.00	0.00
Shear force (*N*)	11.18 ± 0.06	11.65 ± 0.08	3.62 *
Work of shearing (Ns)	39.15 ± 0.22	40.67 ± 0.26	3.61*
Instrumental colour scores			
Redness (a)	4.23 ± 0.02	3.77 ± 0.02	16.00**
Yellowness (b)	4.33 ± 0.02	4.07 ± 0.02	6.05**
Hue	45.57 ± 0.12	47.20 ± 0.31	17.08**
Chroma	6.05 ± 0.02	5.55 ± 0.02	8.25**
Texture profiles			
Hardness (N/cm^2)	35.05 ± 0.15	36.41 ± 0.08	9.69**
Adhesiveness (Ns)	−0.011 ± 0.02	−0.013 ± 0.07	2.31*
Springiness (cm)	0.883 ± 0.03	0.859 ± 0.02	2.84*
Cohesiveness (Ratio)	0.407 ± 0.01	0.413 ± 0.01	3.21*
Gumminess (N/cm^2)	15.01 ± 0.06	14.26 ± 0.05	18.23**
Chewiness (N/cm)	13.25 ± 0.09	12.25 ± 0.05	28.64**
Fracturability (N)	0.341 ± 0.03	0.324 ± 0.01	3.72*

$n = 9$; #$n = 3$.
* $P < 0.05$.
** $P < 0.01$.

cold-boned meat (Boles & Swan, 1996; Claus & Sorheim, 2006; Gariepy et al., 1994) due to its higher pH. It is obvious that the incorporation of the pH hurdle in the products resulted in the lower emulsion stability and cooking yield observed in sausages made from hot-boned pork and fat. Proximate analysis revealed slightly higher moisture and protein contents and a significantly higher ($P < 0.05$) fat percent in sausages made from hot-boned meat (Table 1). The increase in fat, despite the same emulsion pH, could be attributed to the better binding properties resulting from increased solubility and thus extractability of actin and myosin in hot-boned meat (Sadler & Swan, 1997). This may be expected because permanent cross bridges between actin and myosin would not have formed in hot-boned meat at the time of processing and muscles will be in a more relaxed state due to their still higher ATP level. Berry et al. (1999) reported higher moisture and fat retentions in cooked patties made from hot-processed beef. But, Claus and Sorheim (2006) observed lower percentages of moisture and protein and higher fat in patties made from pre-rigor beef. Water activity was the same for sausages made from hot- and cold-boned meat.

Accelerated TBARS value, a measure of potential protection against lipid oxidation by the addition of hurdles to the meat products, was significantly higher ($P < 0.05$) for hot-processed sausages (Fig. 1). This may be attributed to the post-package reheating of the sausages that could have resulted in release of more non-heme iron (Verma, Paranjape, & Ledward, 1985), which catalytically increased the lipid oxidation in products, as measured in terms of malonaldehyde production. Shear force and work of shearing were significantly lower ($P < 0.05$) for hot-processed sausages (Table 1). Similarly, hot processing of beef muscle for patties resulted in greater softness (Berry et al., 1999). Moreover, hot processing has been recognized as a processing technology capable of generating tenderness improvement in meat and meat products (Claus, Jordan, Eigel, Marriott, & Shaw, 1998; Van Lacck & Smulders, 1990; Williams, Johnson, & Regan, 1994).

Processing of pork sausages from hot-boned pork and fat resulted in significant increase ($P < 0.01$) in their Lovibond tintometer redness (*a*-values), yellowness (*b*-values) and chroma, which determine the intensity of colour but

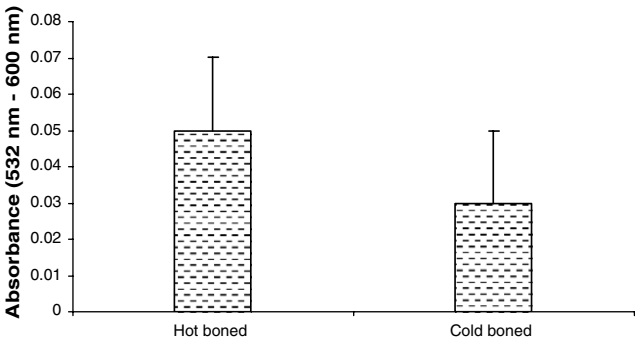

Fig. 1. Effect of hot-boned pork and fat on accelerated TBARS values of SSPS.

significantly decreased the hue angle (Table 1). Several authors have reported an increase in redness due to hot processing as observed in our study, which appears to be associated with its lower met-myoglobin content (Sadler & Swan, 1997) due to its more intensive respiratory action (Pisula & Tyburcy, 1996). Mendenhall (1989) reported that patties from pre-rigor ground beef had more redness but lower yellowness/lightness. The difference in our results (i.e. increase in yellowness) from those of Mendenhall (1989) might be attributed to the incorporation of hot fat in the formulation.

Sausages containing hot-boned pork and fat had significantly lower ($P < 0.01$) hardness (Table 1). It is reported that pre-rigor ground meat had higher protein solubility (Claus & Sorheim, 2006). Therefore, the increased solubilization that occurred in hot-boned pork could have resulted in decrease in the hardness of sausages. The observations for *W–B* shear force and cohesiveness also support this finding. The improved springiness in hot-processed sausages may be attributed to the increased elasticity as a result of better fat binding. Gumminess and chewiness were also significantly higher for hot-processed sausages. It was reported that hot-boned pre-blends produce softer frankfurters with more springiness and chewiness than do cold-boned pre-blends (Choi, Kastner, & Kropf, 1987; Claus & Sorheim, 2006).

3.2. Effect of hot-boned pork and fat on the quality of SSPS during ambient temperature storage (37 ± 1 °C)

3.2.1. Physico-chemical characteristics

pH of sausages processed from hot- and cold-boned pork and fat increased significantly ($P < 0.01$) throughout the storage period, except on day 6, but no significant effect was observed between the treatments at any of the particular storage interval (Table 2). The significantly lower ($P < 0.01$) pH of sausages on day 6 might be attributed to the growth of lactic acid-producing bacteria in the products. It was reported that organic acids, mainly lactic acid, are formed in vacuum packaged sausages during storage as a result of carbohydrate fermentation, and these decrease the pH (Incze, 1992). Even though lactobacillus count further increased on day 9, the substantial increase in spoilage flora, especially TPC, could have nullified their effect. As with our findings, Cross and Tennet (1981) did not observe differences in pH between hot- and cold-processed ground beef; however, Berry et al. (1999) reported that pH values were higher in hot-processed patties than in cold-processed ones.

Hot-processed sausages exhibited significantly higher TBARS values up to the 3rd day, but the difference was insignificant ($P > 0.05$) on days 6 and 9 (Table 2). Rhee, Keeton, Ziprin, Leu, and Bohac (1988) and Pisula and Tyburcy (1996) also reported that pre-cooked pork and beef products from hot-boned meat were more susceptible to lipid oxidation and warmed-over flavour development. However, Torres, Pearson, Gray, Booren,

Table 2
Effect of hot-boned pork and fat on the physico-chemical and microbiological characteristics of SSPS during ambient temperature storage (37 ± 1 °C)

Treatment/parameter	Storage period (days)			
	0	3	6	9
Physico-chemical characteristics				
pH				
Hot-boned	6.12 ± 0.02^{d}	6.24 ± 0.02^{b}	6.17 ± 0.02^{c}	6.27 ± 0.02^{a}
Cold-boned	6.11 ± 0.02^{d}	6.23 ± 0.01^{b}	6.17 ± 0.02^{c}	6.27 ± 0.05^{a}
t-Value	1.00	1.31	0.00	0.00
TBARS value (mg malonaldehyde/kg)				
Hot-boned	0.08 ± 0.05^{d}	0.16 ± 0.05^{c}	0.23 ± 0.01^{b}	0.32 ± 0.03^{a}
Cold-boned	0.07 ± 0.01^{d}	0.15 ± 0.05^{c}	0.22 ± 0.02^{b}	0.32 ± 0.02^{a}
t-Value	2.86*	4.23**	0.318	1.606
Tyrosine value (mg/g)				
Hot-boned	0.36 ± 0.03^{d}	0.45 ± 0.02^{c}	0.54 ± 0.02^{b}	0.65 ± 0.03^{a}
Cold-boned	0.35 ± 0.05^{d}	0.44 ± 0.01^{c}	0.53 ± 0.03^{b}	0.64 ± 0.03^{a}
t-Value	1.25	2.64*	0.918	0.562
Titratable acidity (ml 0.01 N NaOH/g)				
Hot-boned	1.25 ± 0.03^{a}	1.12 ± 0.02^{c}	1.18 ± 0.02^{b}	1.02 ± 0.03^{d}
Cold-boned	1.25 ± 0.04^{a}	1.12 ± 0.03^{c}	1.19 ± 0.03^{b}	1.03 ± 0.03^{d}
t-Value	0.00	0.00	1.21	2.00
Microbiological characteristics				
Total plate count (log cfu/g)				
Hot-boned	3.52 ± 0.08^{d}	4.16 ± 0.07^{c}	4.48 ± 0.06^{b}	5.91 ± 0.09^{a}
Cold-boned	3.28 ± 0.07^{d}	3.85 ± 0.06^{c}	4.34 ± 0.09^{b}	5.86 ± 0.10^{a}
t-Value	8.715**	28.670**	6.576**	1.543
Total anaerobic count (log cfu/g)				
Hot-boned	1.42 ± 0.09^{d}	1.64 ± 0.04^{c}	2.07 ± 0.07^{b}	3.06 ± 0.11^{a}
Cold-boned	1.41 ± 0.08^{d}	1.67 ± 0.03^{c}	2.08 ± 0.07^{b}	3.02 ± 0.10^{a}
t-Value	1.26	1.512	0.378	1.00
Lactobacillus count (log cfu/g)				
Hot-boned	1.15 ± 0.03^{d}	1.26 ± 0.03^{c}	1.36 ± 0.03^{b}	1.52 ± 0.04^{a}
Cold-boned	1.17 ± 0.06^{d}	1.34 ± 0.02^{c}	1.43 ± 0.04^{b}	1.57 ± 0.04^{a}
t-Value	0.611	4.00**	22.00**	1.85
Staphylococcus aureus count (log cfu/g)				
Hot-boned	ND	ND	ND	1.63 ± 0.13
Cold-boned	ND	ND	1.65 ± 0.04	1.85 ± 0.03
t-Value	–	–	–	3.957*

$n = 9$; ND = Not detected.
Means with different superscripts in the same row indicate significant difference.
* $P < 0.05$.
** $P < 0.01$.

and Shimokomaki (1988) did not observe any significant difference in TBARS values for the pre and post-rigor ground beef samples during storage. Results of the present study indicated that, even though the hot-processing accelerates the lipid oxidation in SSPS, the TBARS values were still below the threshold level of 0.50–1.0 mg malonaldehyde/kg (Tarladgis et al., 1960), even on day 9.

Tyrosine value, a measure of degree of autolytic and bacterial proteolysis occurring in meat and meat products, was slightly higher for hot-processed sausages throughout the storage period and a significant difference ($P < 0.05$) was observed on day 3 (Table 2). Tyrosine value has been regarded as a good general index of meat protein breakdown (Pearson, 1968) and could prove useful for the assessment of spoilage in meat (Lawrie, 1998). Therefore, the slightly higher tyrosine values observed for hot-processed sausages could be attributed to their significantly higher total plate counts (Table 2), which might include proteolytic organisms.

Hot-processed sausages had slightly higher FFA contents throughout the storage period, but a significant difference was absent at any particular interval from the cold processed ones (Fig. 2). This increase in FFA with storage might be attributed to the lipolytic activities of their increased microbial load (Greene & Cumuze, 1982). Significant difference was also absent, for titratable acidity, between hot- and cold-processed sausages at any particular storage interval. However, it decreased significantly with increase of storage period in both treatments except on day 6. The lactic acid produced by increased lactobacillus organisms (Table 2) might be attributed to an increase in titratable acidity on day 6, while the further reduction in

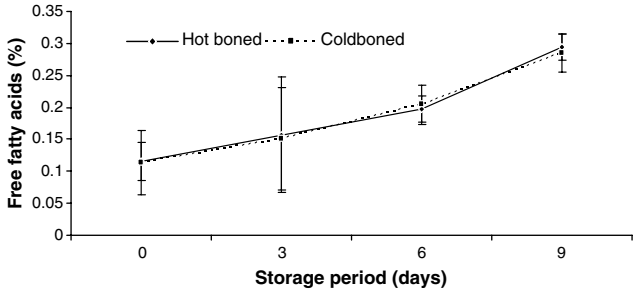

Fig. 2. Effect of hot-boned pork and fat on the free fatty acid content of SSPS during ambient temperature storage (37 ± 1 °C).

titratable acidity on day 9 could be due to accumulation of more bacterial metabolites as a result of substantial increase in TPC on that day, which might have nullified the effect of increased lactobacillus counts. Moreover, the present findings confirm an inverse relationship between titratable acidity and pH.

3.2.2. Microbiological characteristics

Hot-processing markedly increased the TPC of the sausages and the difference from cold-processed sausages was significant up to day 6 (Table 2). No significant difference was observed for anaerobic counts between treatments at any particular storage interval, but the counts increased significantly ($P < 0.01$) in both the treatments with the advancement of storage period and reached about 3 log cfu/g on day 9. However, cold-processed samples had higher lactobacillus counts throughout the storage and this was significant ($P < 0.01$) on days 3 and 6. *Staphyloccus aureus* were detected from day 6 onwards in cold-processed sausages, while only on day 9 in hot-processed samples. The presence of different hurdles in the sausages could have prevented their growth during the initial storage period. Coliforms and yeast and molds were not detected in any of the samples during the entire storage period. It was reported that hot-boned vacuum-packaged beef had significantly higher TPC, but the overall differences disappeared after a few days of storage (Reichel, Phillips, Jones, & Gill, 1991). Also, Sadler and Swan (1997) and Van Lacck and Smulders (1990) found that the boning method had no effect on mesophilic, psychrotrophic and salt-tolerant counts in freshly ground meat, while Pisula and Tyburcy (1996) reported that enterobacteriacea and lactic acid bacteria were more numerous in cold-boned meat than in hot-boned meat.

3.2.3. Sensory attributes

Hot-processed sausages had significantly better ($P < 0.05$) appearance on the day of processing, but were only slightly better on day 3, with no difference on day 6, from that of cold processed samples (Table 3). The bright

Table 3
Effect of hot-boned pork and fat on the sensory attributes of SSPS during ambient temperature storage (37 ± 1 °C)

Treatment/parameter	Storage period (days)		
	0	3	6
Appearance			
Hot-boned	7.00 ± 0.10^{a}	6.66 ± 0.24^{b}	6.50 ± 0.13^{c}
Cold-boned	6.83 ± 0.24^{a}	6.60 ± 0.42^{b}	6.50 ± 0.06^{c}
t-Value	3.162*	1.195	0.00
Flavour			
Hot-boned	6.87 ± 0.24^{a}	6.57 ± 0.24^{b}	6.45 ± 0.41^{c}
Cold-boned	7.00 ± 0.10^{a}	6.66 ± 0.24^{b}	6.45 ± 0.24^{c}
t-Value	2.982*	2.137*	0.00
Juiciness			
Hot-boned	7.00 ± 0.10^{a}	6.50 ± 0.15^{b}	6.50 ± 0.21^{b}
Cold-boned	700 ± 0.24^{a}	6.50 ± 0.06^{b}	6.50 ± 0.03^{b}
t-Value	0.00	0.00	0.00
Texture			
Hot-boned	6.93 ± 0.24^{a}	6.78 ± 0.24^{b}	6.53 ± 0.18^{c}
Cold-boned	7.00 ± 0.09^{a}	6.83 ± 024^{b}	6.53 ± 0.24^{c}
t-Value	1.621	1.581	0.00
Binding			
Hot-boned	6.50 ± 0.16^{a}	$6.50 \pm .10^{a}$	6.00 ± 0.24^{b}
Cold-boned	6.50 ± 0.10^{a}	6.50 ± 0.10^{a}	6.00 ± 0.24^{b}
t-Value	0.00	0.00	0.00
Overall acceptability			
Hot-boned	7.00 ± 0.24^{a}	6.67 ± 0.42^{b}	6.50 ± 0.15^{c}
Cold-boned	6.83 ± 0.24^{a}	6.67 ± 0.24^{b}	6.54 ± 0.24^{c}
t-Value	3.162*	0.00	0.872

$n = 21$; SP = Spoiled.
Means with different superscripts in the same row indicate significant differences.
* $P < 0.05$.

appearance of hot-processed sausages on the day of processing could be attributed to their lower met-myoglobin content as a result of more intensive respiratory action (Sadler & Swan, 1997). However, appearances of sausages from both treatments worsened significantly with the advancement of storage period. Flavour scores were significantly higher for cold-processed sausages up to day 3, while no difference was observed on day 6 between the treatments. The significantly lower flavour scores for hot-processed sausages may be attributed to the higher lipid oxidation observed in them. As in the case of appearance, flavour of sausages from both treatments decreased significantly with increase of storage period.

There were no significant differences for juiciness, texture and binding among hot- and cold-processed sausages at any of the storage intervals. However, as in other sensory attributes, they also decreased significantly with the advancement of storage period in both treatments. Hot-processed sausages had significantly higher overall acceptability on the day of processing, while no significant difference was observed during subsequent storage periods, compared to the cold-processed samples. This indicated that overall acceptability of the sausages on the day of processing was influenced mostly by their appearance and not by flavour. Williams et al. (1994) did not find differences in sensory characteristics of patties prepared from hot- and cold-boned ground beef. In addition, several researchers have found no significant differences among the overall acceptability of hot- and cold-processed pork (Pisula & Tyburcy, 1996; Rhee et al., 1988). Moreover, Bentley et al. (1988) reported that sensory panel evaluation scores of firmness, flavour and overall desirability for luncheon loaves exhibited no significant differences as affected by hot- or cold-pork fat.

4. Conclusions

Hurdle technology was successfully utilized to develop pork sausages which are shelf-stable up to the 6th day at ambient temperature (37 ± 1 °C). Sausages made from hot-processed pork and fat exhibited higher fat percent, desirable red colour and texture profiles. However, hot-processed sausages had higher TBARS values and total plate counts during ambient temperature storage. However, different sensory attributes of SSPS were not significantly affected by using hot-boned pork and fat in place of their cold-boned counterparts. Hot-boned lean pork and fat could effectively be used in a similar way to cold-boned pork and fat in the formulation to process SSPS.

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