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ORIGINAL ARTICLE

Quality of hurdle treated pork sausages during refrigerated (4 ± 1°C) storage

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Abstract Pork sausages developed using hurdle technology was evaluated during refrigerated storage (4 ± 1°C). Hurdles incorporated were low pH, low water activity, vacuum packaging and post package reheating. Dipping in potassium sorbate solution prior to vacuum packaging was also tried. Hurdle treatment significantly ($p < 0.05$) reduced the rate of deterioration of quality characteristics of pork sausages during storage, as indicated by TBARS and tyrosine values. Incorporation of hurdles decreased the growth of different spoilage and pathogenic microorganisms. Combination of pH, water activity, vacuum packaging and reheating inhibited the growth of yeast and molds up to 12 days, while additional dipping of sausages in 1% potassium sorbate solution prior to packaging inhibited their growth even on 30th day of storage. Incorporation of hurdles resulted in initial reduction in all the sensory attributes, but they helped to maintain these attributes for significantly longer period compared to control. Hurdle treated sausages exhibited no spoilage signs even on day 30, while the control sausages were found acceptable only up to 18 days.

Keywords Pork sausages · Hurdle technology · Potassium sorbate · Post package reheating · Refrigerated storage

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Introduction

Processed meat sector is developing slowly in India due to lack of cold chains for effective marketing, since the meat products are perishable. Processing techniques have been standardized for several meat products and most of them have limited shelf life at ambient temperature (37 ± 1°C). Studies also indicated that fermented sausages are less palatable to the consumers (Leistner 1995, Mir Salahuddin and Sharma 2003). Hence, there is imperative need to develop safe, nutritious and highly acceptable quality shelf stable meat products which can be stored/marketed without refrigerated facility.

The stability and safety of most foods is due to combined action of several preservative factors/ hurdles. As the main objective is to prevent the microbial spoilage and food poisoning, several hurdles are used minimally in optimum combination, thereby contributing for improvement in sensory qualities, safety, stability as well as saving of energy (Karthikeyan et al. 2000, Das and Radhakrishna 2001). Hurdles in foods are substances or processes inhibiting deteriorative changes. Hurdle technology (HT) is the use of 2 or more hurdles, to improve the microbial stability and the sensory quality of foods as well as their nutritional and economic properties (Leistner et al. 1980, Grijspaardtvink 1994). The HT concept had been used in many traditional foods especially in developing countries over centuries (Leistner 2000).

In view of above reports, a study was undertaken to develop safe and well acceptable pork sausages using hurdle technology /combined processes, for better distribution and marketing.

Materials and methods

Lean pork and fat (back fat) were obtained from crossbred barrows (75% Landrace × 25% Desi) (60–70 kg live weight) slaughtered as per standard procedure at the

experimental abattoir of Livestock Products Technology Division, Indian Veterinary Research Institute, Izatnagar. Meat (about 3 kg in each batch) and fat were obtained from ham portion of the carcass within 0.5 h of slaughter and deboning was done in the processing plant after conditioning in a refrigerator at 4 ± 1°C for about 16 h. Additional back fat was collected from loin portion, if required. Skin, fat and meat were separated manually. Meat was cut into about 3 cm size 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. Ground meat and fat were packaged in LDPE bags and kept frozen (–18 ± 1°C) till subsequent use. Frozen meat and fat were thawed at 4 ± 1°C for 16 h before use.

Processing of shelf stable pork sausages: Different hurdles incorporated were low pH (~5.9, using lactic acid (LA, 0.5N) 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). Applications of these hurdles were initially 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 the sake of sensory attributes, because in developing shelf stable products, we wanted to begin with sausages that are almost similar to the control. Although nitrite and 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 emulsion was prepared using Seydelmann food cutter (Model K20 Ras, Stutgart, Germany) as per the procedure mentioned hereunder with 20% pork fat. About 4 kg batches were made, namely, 2600 g lean pork, 800 g pork fat, 200 g each condiments mix and refined wheat flour, 80 g each of spice mix and refined salt and 20 g each of cane sugar and sodium tripolyphosphate. Textured soy protein was added at 3% levels (over and above 100 %) in the formulation as humectant. Also, 0.015% sodium nitrite was added. Spice mix was prepared as per 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 tripolyphosphate 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. Ground pork fat was slowly incorporated while chopping, which was continued till the fat was completely dispersed in the batter (3–4 min). Spice mix and refined wheat flour were added and chopping, was continued for another 1 min to get a fine viscous emulsion. About 1 kg emulsion was separated out for processing control sausages (without any hurdles). To the remaining emulsion, textured soy protein (3%) was added as humectant (over and above 100%). pH of the treated emulsion was then adjusted to about 5.9 using LA (0.5 N) and GDL (0.1%). Meat emulsions, control followed by treated ones, were then stuffed into 25 mm diameter cellulose casings (Viskase Nojax, Viskase Co. Inc., Chicago, USA) using hydraulic sausage filler (Mainca, Model EP-25, Spain) and linked manually at about 12 cm length. Cooking was done in a steam oven without pressure till 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 (37 ± 1°C) and peeled off the casings.

Sausages made from treatment group (with hurdles) were divided into 2 treatments (T I and T II). Sausages from T II were 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 tried as a separate hurdle to reduce the possible growth of yeast and mold during ambient temperature storage). Sausages from all the 3 groups (control, T I and T II) were then vacuum packaged in laminates of Nylon/ LDPE bags using Rochermatic packaging machine (Model VM 195, Osnabruck, Germany) in such a way that each packet contained 7-8 sausages. Vacuum packaged sausages from T I and T II 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 the digital probe thermometer. The packets in each of the 3 groups were stored under refrigeration condition (4 ± 1°C). The drawing interval was 6 days and the experiment was repeated 3 times.

Analytical procedures: pH was determined using a digital pH meter (Elico, Model LI 127, India). The procedure of Tarladgis et al. (1960) was followed to estimate the TBARS number as mg of malonaldehyde per kg of sample. The procedure of Strange et al. (1977) was followed to determine the tyrosine value. The methods described by Koniecko (1979) were followed for measuring free fatty acids and titratable acidity. Free fatty acids (FFA) percent was calculated using following formula: FFA (%) = (0.1 × ml of 0.1 N alcoholic KOH × 0.282 / weight of sample (g) × 100. Titratable acidity was expressed as ml of 0.01N NaOH/g sample required to neutralize the filtrate as suggested by Feng-Sheng (2000).

Microbiological evaluation: Total plate counts, psychrotrophic counts, coliforms, anaerobic, *Lactobacillus*, *Staphyloccus aureus* and yeasts and moulds of shelf stable pork sausages were determined as per the methods described by ICMSF (1996). Ready made media from Hi-Media Laboratories (P) Ltd, Mumbai, were used for the enumeration of different microbes.

Sensory evaluation: A descriptive 8-point scale (Keeton 1983) was followed with modifications where 8=excellent and 1=extremely poor. The trained panel (7 members) consisted of scientists and post-graduate students of Division of Livestock Products Technology, IVRI, Izatnagar.

Pork sausages, vacuum packaged in laminates of Nylon/LDPE bags and held at ambient temperature (37 ± 1°C) were drawn at 3 days interval. Samples were warmed (40–45°C) using microwave oven (LG Electronics India (P) Ltd., Mumbai) for 1 min and served to the panelists. The panelists evaluated the samples for appearance, flavour, juiciness, texture, binding and overall acceptability using a standard score sheet.

Statistical analysis: The experiments were replicated three times and the data generated for different quality characteristics were analyzed using randomized block design. The data were subjected to analysis of variance (2 way ANOVA), least significant difference, paired t-test (Snedecor and Cochran 1995) and Duncan's multiple range test (Steel and Torris 1981) for comparing the means to find the effects between treatments, storage periods and their interaction for various parameters. The smallest difference needed for two means to be significantly different ($p < 0.05$) is reported.

Results and discussion

Physico-chemical characteristics: pH of the hurdle treated sausages was significantly lower ($p < 0.01$), which could be attributed to the incorporation of LA and GDL (Table 1). pH of the control sausages increased throughout the storage period and reached to about 6.6 on 24th day of storage, when they were found spoiled. Similar findings were also reported in vacuum packaged buffalo meat nuggets (Sahoo and Anjaneyulu 1997), in beef chuck (Lee and Yoon 2001) and in pork (Livingston et al. 2004) during refrigerated storage. The sausages dipped in 1% K-sorbate solution had slightly lower pH compared to undipped samples (treatment I) during storage, which could be due to their lower initial pH.

Hurdle treated samples showed significantly higher TBARS values on the day of processing compared to control (Table 1). However, the rate of increase in TBARS values was significantly lower in hurdle treated sausages during storage. It was also observed that dipping of pork sausages in 1% potassium sorbate solution prior to packaging slightly decreased TBARS values. The results clearly indicate that factors such as low pH and a_w, vacuum packaging, post package reheating and potassium sorbate dipping significantly reduced the rate of lipid oxidation in pork sausages during refrigerated storage. Porcella et al. (2001) in vacuum packaged chorizos, Modi et al. (2003) in buffalo meat burgers and Das et al. (2006) in goat meat patties

Table 1 Effect of hurdle treatment on the physico-chemical parameters of pork sausages during refrigerated storage (4 ± 1°C)

	Storage period (days)					
	0	6	12	18	24	30*
pH						
Control	6.4 ± 0.08^{d1}	6.4 ± 0.05^{c1}	6.5 ± 0.05^{b1}	6.5 ± 0.05^{b1}	6.6 ± 0.05^{a1}	SP
I	6.1 ± 0.05^{b2}	6.1 ± 0.08^{a2}	6.1 ± 0.08^{a2}	6.1 ± 0.05^{b2}	6.1 ± 0.05^{a2}	6.1 ± 0.09^{a1}
II	6.1 ± 0.08^{b3}	6.1 ± 0.05^{b3}	6.1 ± 0.05^{b3}	6.1 ± 0.05^{b3}	6.1 ± 0.08^{ab3}	6.1 ± 0.05^{a2}
TBARS value, mg malonaldehyde/kg						
Control	0.075 ± 0.01^{e1}	0.101 ± 0.01^{d1}	0.135 ± 0.05^{c1}	0.203 ± 0.08^{b1}	0.285 ± 0.05^{a1}	SP
I	0.093 ± 0.01^{d2}	0.095 ± 0.08^{cd2}	0.09 ± 0.05^{c2}	0.140 ± 0.05^{b2}	0.143 ± 0.08^{b2}	0.175 ± 0.08^{a}
II	0.090 ± 0.05^{d2}	0.091 ± 0.08^{d2}	0.093 ± 0.05^{d2}	0.131 ± 0.08^{c2}	0.146 ± 0.08^{b2}	0.169 ± 0.08^{a}
Tyrosine value, mg/g						
Control	0.303 ± 0.01^{e2}	0.350 ± 0.08^{d1}	0.403 ± 0.01^{c1}	0.450 ± 0.02^{b1}	0.513 ± 0.05^{a1}	SP
I	0.323 ± 0.01^{d1}	0.330 ± 0.01^{c2}	0.363 ± 0.05^{b2}	0.367 ± 0.05^{b2}	0.377 ± 0.01^{a2}	0.380 ± 0.05^{a1}
II	0.320 ± 0.03^{d1}	0.325 ± 0.08^{d2}	0.351 ± 0.01^{c3}	0.363 ± 0.05^{b2}	0.370 ± 0.01^{a3}	0.373 ± 0.05^{a2}
Titratable acidity, ml 0.01N NaOH/g						
Control	0.9 ± 0.02^{a2}	0.9 ± 0.08^{a2}	0.9 ± 0.05^{a3}	0.9 ± 0.05^{a3}	0.7 ± 0.08^{b3}	SP
I	1.3 ± 0.05^{1}	1.3 ± 0.08^{1}	1.3 ± 0.08^{2}	1.3 ± 0.08^{2}	1.3 ± 0.08^{2}	1.2 ± 0.10^{2}
II	1.3 ± 0.02^{ab1}	1.3 ± 0.08^{ab1}	1.3 ± 0.08^{ab1}	1.3 ± 0.08^{a1}	1.3 ± 0.08^{a1}	1.3 ± 0.08^{bc1}
Free fatty acids, %						
Control	0.093^{a1}	0.133^{b1}	0.184^{c1}	0.203^{d1}	0.255^{e1}	
I	0.1^{a1}	0.103^{a2}	0.117^{b2}	0.147^{c2}	0.173^{d2}	0.186^{e1}
II	0.102^{a1}	0.104^{a2}	0.117^{b2}	0.146^{c2}	0.175^{d2}	0.183^{d1}

n = 9; SP = Spoiled, Control = No hurdles, Treatment I = Hurdles + Reheating to 90°C, Treatment II = Hurdles + Reheating to 90°C + 1% potassium sorbate dipping

Means with different superscripts (letters in the same row and numbers in the same column) indicate significant difference ($p < 0.05$).

*Data in the same column on day 30 was analyzed by paired *t*-test

reported a progressive increase in lipid oxidation during refrigerated storage.

Tyrosine value, an index of degree of autolytic and bacterial proteolysis occurring in meat and meat products, was significantly higher ($p < 0.01$) for hurdle treated sausages on the day of processing (Table 1). However, the rate of increase in tyrosine value was markedly lower in hurdle treated sausages during the entire storage period. Moreover, potassium sorbate dipping prior to packaging slightly reduced the tyrosine value of the products during storage. Sahoo and Anjaneyulu (1997) in buffalo meat nuggets and Eyas Ahamed et al. (2007) in enrobed buffalo meat cutlets also observed a linear increase in tyrosine value during refrigerated storage, but the rate of increase was higher compared to the present results for hurdle treated sausages.

FFA content also increased during storage, but the increase was significantly lower in hurdle treated samples compared to control (Table 1). The slightly higher FFA content in hurdle treated samples on the day of processing could be attributed to the release of more FFA during post package reheating. Similarly, Modi et al. (2003) in buffalo meat burgers and Das et al. (2006) in goat meat patties reported increase in FFA content with the advancement of refrigerated storage, however, the lower values observed in the present study compared to those reported by others, may be attributed to the presence of hurdles in our product.

Table 2 Effect of hurdle treatment on microbiological counts (log cfu/g) of pork sausages during refrigerated storage (4 ± 1°C)

	Storage period, days					
	0	6	12	18	24	30*
Total plate count						
Control	4.23 ± 0.08^{e1}	4.4 ± 0.01^{d1}	4.6 ± 0.10^{c1}	5.3 ± 0.21^{b1}	6.1 ± 0.03^{a1}	SP
I	3.2 ± 0.03^{f2}	3.3 ± 0.02^{e2}	3.6 ± 0.01^{d2}	4.0 ± 0.04^{c2}	4.3 ± 0.06^{b2}	4.9 ± 0.03^{a1}
II	3.2 ± 0.03^{e2}	3.3 ± 0.01^{e2}	3.5 ± 0.06^{d2}	4.0 ± 0.04^{c2}	4.3 ± 0.02^{b2}	4.8 ± 0.06^{a2}
Psychrotropic count						
Control	ND	ND	2.6 ± 0.09^{c}	3.7 ± 0.05^{b}	4.6 ± 0.2^{a1}	SP
I	ND	ND	ND	ND	1.7 ± 0.0^{2}	2.2 ± 0.11
II	ND	ND	ND	ND	1.6 ± 0.1^{2}	2.1 ± 0.18
Coliform count						
Control	1.8 ± 0.06	1.4 ± 0.08	ND	ND	1.6 ± 0.13	SP
I	ND	ND	ND	1.4 ± 0.08	ND	1.6 ± 0.13
II	ND	ND	1.6 ± 0.05	ND	ND	1.4 ± 0.08
Total anaerobic count						
Control	2.3 ± 0.04^{e1}	2.3 ± 0.05^{d1}	2.6 ± 0.04^{c1}	3.1 ± 0.03^{b1}	3.2 ± 0.02^{a1}	SP
I	1.3 ± 0.13^{e2}	1.4 ± 0.08^{e2}	1.4 ± 0.13^{d2}	1.7 ± 0.17^{c2}	2.1 ± 0.05^{b2}	2.5 ± 0.06^{a}
II	1.3 ± 0.08^{f2}	1.4 ± 0.17^{e2}	1.5 ± 0.02^{d2}	1.7 ± 0.08^{c2}	2.1 ± 0.03^{b2}	2.6 ± 0.05^{a}
***Lactobacillus* count**						
Control	1.8 ± 0.03^{b1}	1.8 ± 0.10^{b1}	1.8 ± 0.13^{b1}	1.9 ± 0.08^{ab1}	1.9 ± 0.14^{a1}	SP
I	1.1 ± 0.02^{c2}	1.2 ± 0.13^{c2}	1.2 ± 0.18^{bc2}	1.2 ± 0.05^{bc2}	1.3 ± 0.02^{b2}	1.4 ± 0.03^{a}
II	1.1 ± 0.09^{d2}	1.1 ± 0.09^{cd2}	1.2 ± 0.02^{bc2}	1.2 ± 0.10^{b2}	1.3 ± 0.04^{b2}	1.4 ± 0.14^{a}
***Staphylococcus aureus* count**						
Control	2.1 ± 0.03^{c}	2.1 ± 0.03^{c}	2.2 ± 0.03^{c}	2.2 ± 0.14^{b}	2.5 ± 0.15^{a1}	SP
I	ND	ND	ND	1.3 ± 0.25^{c}	1.7 ± 0.13^{b2}	1.9 ± 0.09^{a1}
II	ND	ND	ND	ND	1.4 ± 0.07^{b3}	1.8 ± 0.02^{a2}
Yeast and mold count						
Control	ND	1.4 ± 0.08^{d}	1.6 ± 0.14^{c}	1.8 ± 0.13^{b}	2.0 ± 0.12^{a}	SP
I	ND	ND	ND	1.3 ± 0.05^{c}	1.6 ± 0.13^{b}	1.7 ± 0.31^{a}
II	ND	ND	ND	ND	ND	ND

n=9; SP = Spoiled

Control = No hurdles. ND: Not detected, T I, T II: See Table 1.

Means with different superscripts (letters in the same row and numbers in the same column) indicate significant difference ($p<0.05$)

*Data in the same column on day 30 was analyzed by paired t-test

Hurdle treatment increased the titratable acidity (TA) of the sausages, which could be due to the presence of LA and GDL in their formulation (Table 1). Titratable acidity decreased up to day 12 in control but increased slightly on day 18 before further declining on day 24. However, TA of hurdle treated sausages remained almost same up to day 12, then showed a slight increase on day 18 but decreased thereafter. Throughout the storage period, the sausages dipped in 1% potassium sorbate solution (T II) exhibited slightly higher TA than their undipped counter parts (T I). The reduction in TA observed during storage could be attributed to an increase in pH of the sausages as a result of increased microbial proliferation. The LA produced by increased lactobacillus organisms might have caused an elevated TA on day 18 of storage. The accumulation of bacterial metabolites as a result of increased spoilage organisms might have resulted in further reduction of TA towards the end of storage period. However, Rajani et al. (2006) observed a linear decrease in TA in chicken emulsions stored under refrigeration conditions with the advancement of storage period.

Microbiological characteristics: A significant reduction (about 1 log cfu/g) in TPC was observed in hurdle treated sausages on the day of processing compared to control (Table 2). This initial reduction could mostly be attributed to the post package reheating. Dipping of sausages in 1% potassium sorbate solution prior to packaging further decreased the TPC. A significant ($p < 0.01$) linear increase in TPC was found in all the samples during storage. However, it is evident from the results that incorporation of hurdles significantly reduced the rate of multiplication of these organisms during storage.

Psychrotrophs were not detected in any of the samples up to 6th day, but appeared in control on day 12 and increased thereafter. Incorporation of hurdles inhibited their growth/appearance up to 18th day. More importantly, hurdle

Table 3 Effect of hurdle treatment on the sensory attributes* of pork sausages during refrigerated storage (4 ± 1°C)

Treatment/Parameter	Storage period, days					
	0	6	12	18	24	30**
Appearance						
Control	7.0 ± 0.12^{a1}	7.0 ± 0.15^{a1}	6.3 ± 0.24^{b2}	6.1 ± 0.24^{c3}	SP	–
I	6.8 ± 0.24^{a2}	6.8 ± 0.15^{a2}	6.8 ± 0.24^{a1}	6.7 ± 0.12^{b2}	6.7 ± 0.12^{b}	6.4 ± 0.15^{a}
II	6.8 ± 0.15^{a2}	6.8 ± 0.12^{a2}	6.8 ± 0.12^{a1}	6.8 ± 0.16^{a1}	6.7 ± 0.15^{b}	6.4 ± 0.24^{c}
Flavour						
Control	7.2 ± 0.12^{a1}	7.0 ± 0.11^{b1}	6.7 ± 0.11^{c2}	5.7 ± 0.24^{d2}	SP	–
I	6.8 ± 0.11^{a2}	6.8 ± 0.11^{a2}	6.8 ± 0.14^{a1}	6.7 ± 0.16^{b1}	6.7 ± 0.15^{b}	6.5 ± 0.14^{c}
II	6.8 ± 0.11^{a2}	6.8 ± 0.11^{a2}	6.8 ± 0.15^{a1}	6.7 ± 0.11^{b1}	6.7 ± 0.18^{b}	6.5 ± 0.10^{c}
Juiciness						
Control	7.2 ± 0.14^{a1}	7.0 ± 0.15^{a1}	6.5 ± 0.14^{b2}	6.4 ± 0.24^{c}	SP	–
I	6.7 ± 0.11^{a2}	6.7 ± 0.16^{a2}	6.7 ± 0.20^{a1}	6.4 ± 0.21^{b}	6.3 ± 0.15^{b}	6.5 ± 0.24^{c}
II	6.7 ± 0.11^{a2}	6.7 ± 0.13^{a2}	6.7 ± 0.15^{a1}	6.4 ± 0.15^{b}	6.2 ± 0.11^{b}	6.1 ± 0.15^{c}
Texture						
Control	7.0 ± 0.10^{a1}	7.0 ± 0.15^{a1}	6.8 ± 0.15^{b}	6.0 ± 0.24^{c2}	SP	–
I	6.8 ± 0.11^{a2}	6.8 ± 0.16^{a2}	6.8 ± 0.21^{a}	6.6 ± 0.14^{b1}	6.4 ± 0.11^{c}	6.3 ± 0.09^{d}
II	6.8 ± 0.11^{a2}	6.8 ± 0.10^{a2}	6.8 ± 0.14^{a}	6.5 ± 0.10^{b1}	6.4 ± 0.19^{c}	6.2 ± 0.15^{d}
Binding						
Control	7.0 ± 0.11^{a1}	7.0 ± 0.11^{a1}	6.7 ± 0.15^{b1}	5.8 ± 0.24^{c2}	SP	–
I	6.5 ± 0.15^{a2}	6.5 ± 0.15^{a2}	6.1 ± 0.10^{b2}	6.0 ± 0.10^{c1}	6.0 ± 0.12^{c}	6.0 ± 0.19^{c}
II	6.5 ± 0.15^{a2}	6.5 ± 0.15^{a2}	6.2 ± 0.10^{b2}	6.0 ± 0.10^{c1}	6.0 ± 0.12^{c}	6.0 ± 0.19^{c}
Overall acceptability						
Control	7.0 ± 0.11^{a1}	7.0 ± 0.10^{a1}	6.3 ± 0.24^{b2}	5.7 ± 0.24^{c2}	SP	–
I	6.8 ± 0.10^{a2}	6.7 ± 0.15^{b2}	6.5 ± 0.13^{c1}	6.5 ± 0.15^{c1}	6.3 ± 0.14^{d}	6.2 ± 0.17^{e}
II	6.8 ± 0.10^{a2}	6.7 ± 0.12^{b2}	6.5 ± 0.11^{c1}	6.5 ± 0.10^{c1}	6.4 ± 0.14^{d}	6.2 ± 0.10^{e}

n=21 panalists

*Based on 8-point descriptive scale

Control = No hurdles, T I, T II: See Table 1

Means with different superscripts (letters in the same row and numbers in the same column) indicate significant difference ($p < 0.05$)

**Data in the same column on day 30 was analyzed by paired *t*-test

treatment significantly reduced the number of organisms. The absence of psychrotrophs in hurdle treated sausages for a considerably long time compared to control (18 days vs 6 days) could be attributed to a retardation of log phase as a result of reduced metabolic rate due to the presence of different hurdles. A higher initial psychrophilic count was noticed in chicken patties incorporated with liquid egg (Kalaikannan et al. 2006). Similarly, a consistent increase in psychrotrophic bacterial counts on all storage days in ground chevon during refrigerated storage was also reported (Babji et al. 2000, Verma and Sahoo 2001).

Coliforms were detected only in control sausages during initial storage periods (0 and 6th day). The absence of coliforms in treated samples during this period could be attributed to the presence of hurdles, especially post package reheating. However, the occurrence of coliforms was occasional in all the treatments and a definite pattern was not observed. Anaerobic and lactobacillus counts were also increased during storage, but a significant increase ($p < 0.01$) was observed only towards the end of storage period. As observed for other microbial counts, the hurdle treatment significantly reduced the counts of anaerobic and lactobacillus organisms. Papadima and Bloukas (1999) also observed an increase in LAB counts during storage of traditional Greek sausages. It was reported that anaerobes and facultative anaerobes are the most important spoilage organisms in vacuum packaged refrigerated meat (Fu et al. 1992) and vacuum packaging causes a microbial shift resulting in the development of lactobacillus dominated population rather than a higher spoilage potential pseudomonas population (Kotzekidou and Bloukas 1996). However, at the counts observed in hurdle treated samples, LAB would not have been enough to cause any fermentative changes in these products during entire period of storage.

Incorporation of hurdles inhibited the growth of *Staph. aureus* up to 12th day of refrigerated storage in pork sausages. Potassium sorbate dipping further extended it up to 18 days. Even after 30 days of storage, the counts in hurdle treated samples were well below 2 log cfu/g, whereas it reached about 2.5 log cfu/g on 24th day in control sausages. Even though, the a_w was not enough to inhibit the *Staph. aureus* growth, other hurdles such as low pH and reheating might have contributed to the inhibitory effect. Similarly, a combination of pH, a_w, vacuum packaging and reheating was sufficient to inhibit the growth of yeast and molds up to 12th day, while additional dipping of sausages in 1% potassium sorbate solution prior to packaging inhibited their growth even on 30th day of storage.

Sensory attributes: Sensory evaluation of control sausages was discontinued from 24th day onwards, as they developed slight off-flavour and sliminess. Incorporation of hurdles resulted in initial reduction of all the sensory attributes, but they maintained these attributes for longer period compared to control (Table 3). The adverse effect of hurdles was more prominent on flavour, juiciness and binding attributes. From 18th day onwards, a significant reduction in different sensory attributes of hurdle treated sausages was observed. Moreover, potassium sorbate dipping had no significant effect on any of the sensory attributes of pork sausages. The significant decrease ($p < 0.01$) in appearance of hurdle treated sausages may be due to the concentration of meat pigments as a result of increased moisture and fat loss occurring in them. The increased fat loss could also have contributed to the reduced flavour scores observed in sausages containing hurdles, because it was reported that fat content of the meat products contribute significantly to their flavour (Pearson and Gillett 1997). It may also be due to increased oxidation of fat (Santamaria et al. 1992) and liberation of more free fatty acids (Branen 1979). The reduced a_W and increased fat loss may have contributed to the decrease in juiciness of the hurdle treated sausages. The lower texture scores observed in the hurdle treated sausages might be due to the increased denaturation of proteins (both meat and soy proteins) as a result of low pH and reheating. Overall acceptability of the sausages from different treatments also followed the same pattern that was observed for other sensory attributes.

Conclusion

Despite causing an initial reduction in different quality parameters of pork sausages, hurdle treatment helped to maintain these parameters for a longer period. Hurdle treatment significantly improved the microbiological characteristics of the pork sausages. Additional potassium sorbate dipping prior to packaging, helped markedly to improve the microbiological status of pork sausages, especially yeast and mold counts. Moreover, hurdle treated sausages exhibited no spoilage signs even on 30th day of storage, while the control sausages were acceptable only up to 18th day.

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