

Quality Changes of Pork in Relation to Packaging Conditions During Chilled Storage in Households

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Abstract

Proper storage of left-over meat in a household refrigerator is important for extending its shelf-life and assuring its safety until it is next used. Various fresh meat packaging methods were examined to determine their effects on the quality characteristics of pork loins during household storage at 5°C. The packaging methods include 1) wrapping in a polyethylene pouch (WP), 2) keeping in an air-tight plastic container (CP), and 3) using a household vacuum packaging machine (VP). The fastest increase in total aerobic bacteria during storage occurred in the WP samples, followed by the CP and VP samples. The count of *Pseudomonas* spp. was found to be lowest in the VP, and then the CP and WP samples. *Enterobacteriaceae* grew fastest in the WP samples, followed by the CP and VP samples. The WP samples also incurred the most significant increase in thiobarbituric acids and volatile basic nitrogen values over the storage period, as compared to the CP and VP samples. Off-odour at 30 min after opening the package, was first notable at day 11 in WP samples, but only at day 15 in the CP and VP samples. The colour also deteriorated earlier in the WP samples than in the CP and VP samples.

Key words: pork, packaging, storage, quality

Introduction

After purchase, left-over fresh meat intended for later consumption must be properly preserved. Freezing is the best option to avoid deterioration if the meat is not to be used within several days. However, freezing and thawing results in an inevitable deterioration in odour and flavour, as well as the previously documented moisture loss and surface discolouration associated with these processes (Soyer *et al.*, 2010; Urbain, 1978).

Microbial growth, lipid oxidation, discolouration, and increase of evaporative weight loss or purge loss are the main quality deteriorating factors for fresh meat in chilled storage (Hotchkiss, 1994; Lee and Yoon, 2001a, 2001b; Lee *et al.*, 2004). Storage conditions such as temperature, relative humidity, packaging method and materials, and illumination greatly affect the quality of chilled fresh meat (Djenanea *et al.*, 2003; Lee *et al.*, 2004; Lee, 2010). Humidity control is limited, at best, in domestic refrigerators. A relative humidity of 80-90% is required for optimum results during storage, and at least 60% during dis-

play (Moerman, 1972). However, the relative humidity of commercial refrigerators is often maintained below 50% (Lee *et al.*, 1998), making the shelf-life of fresh meat without properly incorporated packaging in a household refrigerator relatively short, and resulting in deterioration within a few days. So, appropriate packaging can extend shelf-life by excluding sources of additional microbial contamination and reducing evaporation during chilled storage.

In a domestic refrigerator, left-over fresh meat is usually stored either in a plastic bag or wrapped in cling film. Such materials are generally high in gas permeability, but low in water vapour permeability. Given the abundant oxygen within the package, the meat retains the bright red colour which appeals to consumers, but the shelf-life of aerobically stored meat is relatively short due to the development of aerobic and psychrotropic bacteria such as *Pseudomonas* spp., resulting in slime and putrefaction (Greer, 1984; Igbinedion *et al.*, 1983; Ščetar *et al.*, 2010). Alternatively, meat can be kept in air-tight containers. These are widely used today for preserving a range of foodstuffs, because of their leak proof, air-tight and liquid-tight properties and the fact that they can be stacked, cleaned and reused. Household vacuum packaging machines are also now becoming popular. In industry, vacuum packaging under refrigeration has so far been the most common way of packaging fresh meat for distribu-

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tion, in order to maximize shelf-life (Jayasingh *et al.*, 2001). Unfortunately, consumers have tendency to dislike the purple-red colour of vacuum packaged meat. But despite this, vacuum packaged meat can preserve colour far longer than the aerobically stored meat, and the colour can bloom when the meat is exposed to air (Lagerstedt *et al.*, 2011). The demand for vacuum packaged meat, especially in pork, is increasing not only in the wholesale market, but also in the retail market. Actually, the purple-red colour might be receding as a limitation when evaluating the freshness and quality of meat, as domestic consumers get used to packing meat themselves. People have recognised that vacuum packaging is an effective way of increasing the tenderness and safety of fresh meat (Voges *et al.*, 2007; Wezemael *et al.*, 2011). However, to date, the extension of the shelf-life of fresh meat by using a household vacuum packaging machine has not yet been proven. Besides, the effect can be varied depending on various factors, such as the gas permeability of the film, vacuum level, gas composition and amounts in the pack and storage conditions, apart from the intrinsic factors of meat (Bohnsack and Höpke, 1982; Hess *et al.*, 1980; Igbiniedion *et al.*, 1983; Lee, 2010; Lee and Yoon, 2001a, 2001b; Seideman *et al.*, 1976). Therefore, this study was carried out to compare the effects of different kinds of common packaging methods for storing fresh chilled meat in households on the various quality characteristics of pork loin.

Materials and Methods

Samples and treatment

A total of 15 crossbred sows (Landrace × Yorkshire × Durock) were selected at a commercial slaughter house. Their average live weight was 103.2 ± 2.5 kg. Both sides of loin (*M. longissimus dorsi*) were removed by sanitary sampling methods from pigs, 24 h postmortem, in 'A grade' according to the Korean carcass classification system. Loin samples weighed approximately 3.5 kg per piece and pH values of sample meats ranged between 5.6 and 5.8. Transported to the laboratory in ice boxes, the samples then had the exterior fat trimmed off and were cut into 114 lengths of 6 cm in total. One slice of sample weighed an average of 300 g. They were put on the table covered with a plastic pouch that had been previously turned inside out and disinfected with 70% ethanol solution for 10 min. Then, in order to minimize the deviation of microbial contamination among samples, samples were sufficiently rubbed with inherent microorganisms by hand wearing sterile plastic gloves, and mixed for ensuring random allocation of samples.

The packaging methods incorporated in this experiment were as follows; (1) wrapping with household high density polyethylene (HDPE) pouch (WP), 10.5 μm (Lotte Aluminum Co., Korea), (2) keeping in an air-tight container made of polypropylene (CP) ($L \times W \times H = 110 \text{ cm} \times 78 \text{ cm} \times 69 \text{ cm}$, approximately 2 mm thick, Lock & Lock Co., Korea), and (3) using a household vacuum packaging machine (VP) (VP-3000, Rollpack Co., Korea). The oxygen permeance value of the HDPE pouch was 22,829 $\text{cc}/\text{m}^2\text{-day}$ at 23°C. The specification for the film used for the vacuum packaged samples was a 7-layer coextruded film composed of polyamide and linear low density polyethylene with an oxygen permeance value of 46.2 $\text{cm}^3/\text{m}^2/\text{day}/\text{atm}$ at 23°C.

One piece of pork sample was put into the packaging film or container. In case of WP treatment, the bag was folded around the meat and then rolled up twice after putting the meat sample inside. The samples were then stored in a low temperature incubator (BI-1000M, Jeio Tech., Korea) at $5 \pm 1^\circ\text{C}$ and were allocated intervals for testing (0, 3, 5, 8, 11, 15, and 19 d).

On the day of testing, the samples were conditioned for 30 min at room temperature. This experiment was replicated and the mean values were obtained from six measurements on three separate samples at each day, except for purge loss measurement which was determined on 6 samples of each treatment.

Microbial analysis

On the appropriate day of storage, to determine the microbial colony counts, packages were hygienically opened and two 10 cm^2 (approximately 5 mm thick) sections were excised from both sides of the meat surface in the VP and WP samples and from the upper side of the CP sample which was not in contact with the container. Each section was placed in 90 ml of sterile 0.85% peptone in a Stomacher bag and homogenized in a Stomacher (Stomacher 80, Seward Medical, UK) for 2 min. Serial dilutions were spread on pre-poured and dried agar plates with a sterile Drigalski spatula. The counts of total aerobes (Standard-1 agar, Merck, Germany), lactic acid bacteria (MRS agar, Merck, Germany), *Pseudomonas* spp. (GSP agar, Merck, Germany) and *Enterobacteriaceae* (DHL agar, Merck, Germany) were enumerated during the storage period. The methods of sample selection, inoculation and incubation were followed as described by Lee and Yoon (2001a).

Physico-chemical measurements

pH was measured using a combined glass electrode

(720A, Orion, USA). Changes in the thiobarbituric acid (TBA) value were used to assess lipid oxidation (Witte *et al.*, 1970). Absorbance was read at 538 nm, and malonaldehyde concentration in the meat was determined. The TBA value was expressed as mg malonaldehyde per kg of meat. The volatile basic nitrogen (VBN) test used the microdiffusion technique of Conway (1958) to determine proteolytic degradation. Purge loss was calculated by the weight differences of samples between the day they were packed and the storage day.

Sensory evaluation

A trained, 10-member sensory panel evaluated meat samples by using a 5-point hedonic scale with 0.5 intervals for discolouration (5 = none; 1 = total), overall appearance (5 = most desirable; 1 = least desirable) and off-odour (5 = none; 1 = extremely abundant). Overall appearance was evaluated immediately after opening the pack for the quality characteristics in outer shape of samples such as the amount of purge loss, sliminess, and solidity of muscular tissue etc. Surface off-odour and discolouration were assessed 30 min after the pack was opened.

Panelists were trained for evaluating the quality change of fresh chilled pork during storage. The pork samples for sensory evaluation were presented to the panelists after putting in polypropylene trays identified with three-digit random numbers. The samples were positioned under a three-wavelength lamp with 1,200 lux. The shelf-life criteria assumed that rejection would occur when the sensory attributes declined below 3.0.

Statistical analysis

All data were analyzed using Statistical Analysis System (SAS/STAT, USA). Duncan's multiple range test was used to compare means and significance was established at $p < 0.05$.

Results and Discussion

Table 1 shows the changes in the total plate count (TPC), the counts of lactic acid bacteria, *Pseudomonas* spp. and *Enterobacteriaceae* of the pork samples over the 19 d of storage at 5°C. The initial count of the TPC was 3.17 Log CFU/cm². A lag phase was shown until day 3 followed by a steady increase throughout the storage period. The increase of TPC was fastest in the WP samples, followed by the CP and the VP samples during storage. From day 3, the TPC in the WP sample began to show a significantly higher level than in the other treatments ($p < 0.05$). Until the 8th day, the TPCs in the CP and VP samples sustained similar levels with 5.26 and 5.29 Log CFU/cm², respectively. However, from the 11th day of storage, the TPC of the CP samples increased more significantly than the VP samples ($p < 0.05$).

After 11 d, the TPCs in the WP, CP and VP samples increased to 7.93, 6.61, and 6.1 Log CFU/cm², respectively. According to Egan and Grau (1981), a TPC of 6 Log CFU/cm² is regarded as the early spoilage level and distinct off-odour is noticeable when it reaches to about 8 Log CFU/cm² in aerobic storage of meat. Therefore, the TPC levels of the WP samples after 11 d rendered them inedible.

Table 1. Changes in bacterial counts (Log CFU/cm²) of total aerobes, lactic acid bacteria, *Pseudomonas* spp., and *Enterobacteriaceae* of fresh pork packaged in a high density polyethylene pouch, an air-tight container, and under vacuum during storage at 5°C

Microorganisms	Packaging	Storage time (d)						
		0	3	5	8	11	15	19
Total aerobes	WP ¹⁾	3.17 ^a	4.14 ^{bA}	5.37 ^{cA}	6.80 ^{dA}	7.93 ^{eA}	9.32 ^{fA}	-
	CP ²⁾	3.17 ^a	3.40 ^{aB}	4.25 ^{bB}	5.29 ^{cB}	6.61 ^{dB}	8.25 ^{eB}	9.13 ^{fA}
	VP ³⁾	3.17 ^a	3.40 ^{abB}	4.19 ^{bB}	5.26 ^{cB}	6.10 ^{cC}	6.16 ^{cC}	7.46 ^{eB}
Lactic acid bacteria	WP	2.18 ^a	3.58 ^{bA}	3.97 ^{cA}	4.51 ^{deA}	5.94 ^{eA}	6.21 ^{fA}	-
	CP	2.18 ^a	2.80 ^{abB}	3.70 ^{bcAB}	4.40 ^{dA}	4.36 ^{dB}	5.46 ^{eB}	6.33 ^{fA}
	VP	2.18 ^a	2.16 ^{aC}	3.25 ^{bB}	3.77 ^{cB}	4.29 ^{dB}	4.75 ^{deC}	6.22 ^{fA}
<i>Pseudomonas</i> spp.	WP	<2.00	3.71 ^{aA}	5.21 ^{dA}	6.58 ^{eA}	7.31 ^{fA}	8.21 ^{gA}	-
	CP	<2.00	2.84 ^{aB}	3.72 ^{bB}	5.30 ^{dB}	6.50 ^{eA}	6.20 ^{eB}	6.30 ^{eA}
	VP	<2.00	2.33 ^{aC}	3.60 ^{bB}	4.41 ^{cC}	4.70 ^{cC}	5.10 ^{dC}	5.21 ^{dB}
<i>Enterobacteriaceae</i>	WP	<2.00	3.19 ^{bA}	3.64 ^{cA}	4.73 ^{dA}	7.21 ^{eA}	8.19 ^{fA}	-
	CP	<2.00	2.00 ^{aB}	2.72 ^{bB}	4.74 ^{dA}	6.17 ^{fB}	7.28 ^{gB}	7.78 ^{ghA}
	VP	<2.00	2.16 ^{aB}	2.00 ^{aC}	2.81 ^{bB}	3.89 ^{cC}	4.90 ^{dC}	5.27 ^{eB}

¹⁾WP: Wrapping with a HDPE pouch, ²⁾CP: Putting in an air-tight container, ³⁾VP: Vacuum packaging.

^{A-C}Means with the same superscripts in the same column at the same storage time and microorganism type are not significantly different at $p < 0.05$.

^{a-h}Means with the same superscripts in the same microorganism type are not significantly different at $p < 0.05$.

The TPC of the VP samples reached 6.16 Log CFU/cm² after 15 d and then increased to 7.46 Log CFU/cm² after 19 d, whereas in the CP samples TPC exceeded 8.0 Log CFU/cm² at day 15. Young *et al.* (1999) reported that the shelf-life of refrigerated vacuum packed pork was 3 wk. However, the shelf-life of vacuum packed fresh meat can vary depending upon the gas permeability of film, vacuum grade under the same storage temperature, initial bacterial load level, and the size of meat cut (Jeremiah, 2001; Koch *et al.*, 2009; Labadie, 1999; Lee, 1985; Seideman *et al.*, 1976).

In the VP samples, lactic acid bacteria dominated the flora with longer storage time, its growth encouraged by the oxygen-depleted condition in the evacuated package. A steady increase of lactic acid bacteria concomitant growth with *Pseudomonas* spp. during storage time was observed also in aerobically preserved samples like WP and CP. Similar results were reported by other researchers (Hess *et al.*, 1980; Pierson *et al.*, 1970), where lactic acid bacteria were one of the dominant microflora in aerobically stored meat samples. The count of lactic acid bacteria in the VP samples exceeded that of *Pseudomonas* spp. and *Enterobacteriaceae* after 19 d. Lactic acid bacteria showed higher counts in the WP samples than in the VP and CP samples at the end of storage. Huffman *et al.* (1975) and Silliker and Wolfe (1980) reported that the growth of aerobic bacteria is suppressed while that of lactic acid bacteria is pronounced when the meat is stored in an evacuated state. However, in our experiment, the counts of lactic acid bacteria in the VP samples at day 15 and 19 were 4.75 and 6.22 Log CFU/cm², respectively. The relatively low count of lactic acid bacteria in the VP samples until day 15 (< 6 Log CFU/cm²) might be attributed either to the insufficient low vacuum grade in the household vacuum packaging machine or to the microenvironment in the package being unfavourable for the growth of lactic acid bacteria.

The effectiveness of vacuum packaging depends upon the proximity of the packaging film to product surfaces, since oxygen can accumulate in the voids of packages and also oxygen containing atmospheres can develop along with the permeation of gas into the package during storage. In vacuum packaged meat, the efficiency of evacuation affects greatly the residual oxygen volume in the vacuities of the package and the quality of packaged meat (Gill, 1996). Normally, 0.3-3% air is contained in the vacuum package (Sanjeev and Ramesh, 2006). Therefore, it is desirable so to reduce the void volume by packaging the meat as tightly as possible to the film so that the oxida-

tion takes place minimally and the oxygen ingress can be consumed by the meat (Jeremiah, 2001). However, it is likely a household vacuum packaging machine would not achieve as efficient a vacuum as an industrial machine, because of its pump's lower evacuation capacity.

In the WP and CP samples, *Pseudomonas* spp. and *Enterobacteriaceae* were the dominant flora. It appeared that the high-oxygen environment might favour the growth of aerobic *Pseudomonas* spp. mostly in the WP samples which were packaged in oxygen permeable film, and then moderately in the CP samples where there was oxygen ingress. *Pseudomonas* spp., typical putrefactive aerobes, are frequently detected at a level of 2-5 Log CFU/cm² in fresh meat, and produce off-odour and slime when the count exceeds 7-8 Log CFU/cm² (Blixt and Borch, 2002; Gill and Harrison, 1989; Ingram, 1962; Lee, 1985; Lee *et al.*, 2004). The count of *Pseudomonas* spp. was found to be lowest in the VP, then the CP and WP samples. In the WP samples, the count exceeded 7.31 Log CFU/cm² at day 11. In vacuum packaged meat, the growth of *Pseudomonas* spp. is suppressed by various factors including low oxygen and high carbon dioxide content in the package, organic acid and antibiotics produced by lactic acid bacteria (Hurst and Collins-Thompson, 1979; Sutherland *et al.*, 1975). Implementing a higher vacuum resulted in a significant reduction of the growth of *Pseudomonas* spp. and *Enterobacteriaceae* on vacuum packaged pork due to the deficiency of oxygen in the package compared to conventional vacuum packaging (Bohnsack and Höpke, 1982). It has been reported that the growth of other flora is suppressed when the count of lactic acid bacteria exceeds 6 Log CFU/cm² (Lee and Yoon, 2001a). Based on this fact, the growth of *Pseudomonas* spp. in the VP samples seemed not to be restrained by lactic acid bacteria by the end of the storage period.

Enterobacteriaceae represent the gram negative and facultative anaerobes including *Salmonella*, *Klebsiella*, *E. coli*, *Enterobacter*, *Citrobacter*, *Proteus*, and *Serratia* spp., which are of importance as fecal indicator microorganisms and the predominant species associated with poisoning infections in meat (Al-Mutairi, 2011; Jay, 1992). The *Enterobacteriaceae* count was initially below 2 Log CFU/cm² and reached 4.9, 8.19, and 7.28 Log CFU/cm² after 15 d in the VP, WP, and CP samples, respectively. It grew fastest in the WP samples, followed by the CP and VP samples. Under a condition of diminished-oxygen, as in the VP samples, the growth of *Enterobacteriaceae* seemed to be less pronounced than in the WP and CP samples.

A high *Enterobacteriaceae* count in fresh meat indicates

unhygienic handling, so a low count is required for the sake of the hygiene and safety of consumers (Lasta *et al.*, 1992; Stiles and Ng, 1981). In most countries, *Enterobacteriaceae* is not generally regulated in raw meat. However, according to Irish guidelines, set out by the Food Safety Authority of Ireland (FSAI), *Enterobacteriaceae* numbers in three of five raw meat samples should be less than 5 Log CFU/g (Crowley *et al.*, 2005). In this regard, the VP samples sustained the most hygienic and safe quality among the three different packaging samples during chilled storage. It also showed that the vacuum condition favoured the rapid growth of lactic acid bacteria which resulted in the suppression of the growth of *Enterobacteriaceae*.

Table 2 shows the comparison of the values of pH, thiobarbituric acid (TBA), volatile basic nitrogen (VBN), and purge loss of pork loins packed in WP, CP, and VP during storage at 5°C. The pH of samples from 3 different treatments tended to decrease during the earlier part of storage and then increase with time up till day 19. The pH values were at the lowest after 3, 5-8, and 8 d in the VP, CP, and WP samples, respectively, and then increased with time up till the 19th day. The pH increase in longer storage is induced by the reaction between protein and ionic substances, the decrease of dissociated substances, and the formation of proteolytic metabolites. Its decrease on the other hand, is partly attributed to the metabolite accumulation produced by lactic acid bacteria (Demeyer *et al.*, 1979; Jaye *et al.*, 1962; Lee, 1985). Those of the WP and CP samples increased up to 6.0 at the end of the storage time, probably as a result of aerobic putrefaction.

The TBA values increased with the storage time in all the packaged samples. From the 5th day, the TBA value of the WP samples increased rapidly compared to the CP and VP samples. This indicated the faster development of lipid oxidation in the meats wrapped with oxygen permeable polyethylene compared to other treatments. However, it might have been retarded by preventing the oxygen-inlet into the container as in the CP and into the air-tight film as in the VP. The TBA value of WP at 3rd day was 0.26 mg MA/kg and exceeded 0.62 mg MA/kg after 15 d. TBA values of VP and CP samples increased to 0.33 and 0.36 mg MA/kg where the increase was slower compared than WP samples. Turner *et al.* (1954) reported that a TBA value higher than 0.46 revealed sensorial quality defects. When judging by TBA value, the lipid oxidation seemed to be retarded by the shut-off of the oxygen-inlet in the container as in CP and through the vacuum film as in VP.

Routine monitoring of meat in countries of the Far East uses VBN value, which was initially found to be 3.73 mg% and increased linearly with storage time in all samples tested. At 15 d the values reached 18.20 and 19.13 mg% in CP and VP samples, respectively. However, the level in the WP sample was 24.73 mg% at day 11 which exceeded the putrefaction criterion of 20 mg% prescribed in the Korean specification (KFDA, 2000). VBN value represents the degree of protein degradation predominantly caused by microbial growth such as putrefactive aerobic bacteria. The changes in VBN values over the storage period among the samples are well correlated with those of the counts of *Pseudomonas* spp. as shown in Table 1. The WP sample

Table 2. Changes in pH, TBA, and VBN values of fresh pork packaged in a high-density polyethylene pouch, an air-tight container, and under vacuum during storage at 5°C†

Parameter	Packaging	Storage time (d)						
		0	3	5	8	11	15	19
pH	WP ¹⁾	5.77 ^c	5.65 ^d	5.48 ^{eb}	5.44 ^{eb}	5.89 ^{ba}	6.06 ^{aa}	-
	CP ²⁾	5.77 ^c	5.70 ^d	5.64 ^{ea}	5.64 ^{ea}	5.68 ^{deb}	5.90 ^{bb}	6.06 ^{aa}
	VP ³⁾	5.77 ^a	5.62 ^c	5.63 ^{ca}	5.66 ^{bcA}	5.69 ^{bb}	5.68 ^{bb}	5.78 ^{ab}
TBA	WP	0.19 ^e	0.26 ^{da}	0.35 ^{ca}	0.31 ^{cdA}	0.41 ^{ba}	0.62 ^{aa}	-
	CP	0.19 ^d	0.20 ^{db}	0.23 ^{cb}	0.25 ^{cb}	0.32 ^{bb}	0.36 ^{ab}	0.38 ^a
	VP	0.19 ^d	0.20 ^{db}	0.23 ^{cb}	0.24 ^{cb}	0.32 ^{bb}	0.33 ^{bb}	0.37 ^a
VBN	WP	3.73 ^{ef}	7.93 ^{deA}	12.13 ^{dA}	18.67 ^{ca}	24.73 ^{ba}	40.13 ^{aa}	-
	CP	3.73 ^e	4.20 ^{eb}	5.13 ^{eb}	8.40 ^{db}	14.00 ^{cb}	19.13 ^{bb}	25.67 ^a
	VP	3.73 ^e	2.80 ^{ec}	3.73 ^{eb}	7.00 ^{db}	13.53 ^{cb}	18.20 ^{bb}	24.07 ^a
Purge loss	WP	0	7.54 ^{ad}	9.72 ^{abc}	11.12 ^{ab}	12.80 ^{aA}	13.10 ^{aA}	-
	CP	0	7.56 ^{ab}	9.28 ^{aa}	7.24 ^{bb}	9.38 ^{ba}	9.62 ^{ba}	-
	VP	0	7.65 ^B	12.39 ^{aA}	11.99 ^{aA}	12.33 ^{aA}	13.45 ^{aA}	-

†Mean values of 4 determinations.

-Not measured.

^{A-D}Means with the same superscripts in the same column at the same storage time and parameter are not significantly different at $p < 0.05$.

^{a-h}Means with the same superscripts in the same parameter are not significantly different at $p < 0.05$.

¹⁻³⁾Refer to Table 1.

Table 3. Changes in sensory evaluation scores of fresh pork packaged in a high-density polyethylene pouch, an air-tight container, and under vacuum during storage at 5°C

Sensory parameter	Packaging	Storage time (d)						
		0	3	5	8	11	15	19
Discolouration	WP ¹⁾	5.00 ^a	4.72 ^{bA}	4.28 ^c	3.78 ^{dB}	2.33 ^{EB}	1.33 ^{FB}	-
	CP ²⁾	5.00 ^a	4.94 ^{aA}	4.56 ^b	4.33 ^{bA}	3.28 ^{cA}	2.44 ^{dA}	1.72 ^{EB}
	VP ³⁾	5.00 ^a	4.33 ^{bB}	4.28 ^b	3.83 ^{cB}	3.28 ^{dA}	2.72 ^{eA}	2.22 ^{fA}
Overall appearance	WP	5.00 ^a	4.44 ^{bB}	3.94 ^{cB}	3.67 ^{cB}	2.39 ^{dB}	1.33 ^{EB}	-
	CP	5.00 ^a	4.89 ^{aA}	4.39 ^{bA}	4.06 ^{cA}	3.22 ^{dA}	2.56 ^{eA}	1.72 ^{FB}
	VP	5.00 ^a	4.50 ^{bB}	4.28 ^{bA}	3.33 ^{cC}	3.00 ^{cdA}	2.67 ^{dA}	2.22 ^{eA}
Off-odour	WP	5.00 ^a	4.39 ^{bB}	3.83 ^{cA}	3.56 ^{dB}	1.72 ^{EB}	1.11 ^{FB}	-
	CP	5.00 ^a	4.83 ^{aA}	4.39 ^{bA}	4.22 ^{bA}	3.39 ^{cA}	2.39 ^{dA}	1.61 ^e
	VP	5.00 ^a	4.83 ^{aA}	4.17 ^{bAB}	3.44 ^{cB}	3.00 ^{dA}	2.39 ^{eA}	1.72 ^f

Sensory scores were evaluated by using a 5-point hedonic scale; discolouration (5 = none and 1 = total), overall appearance (5 = most desirable; 1 = least desirable), off-odour (5 = none; 1 = extremely abundant).

^{A-C}Means with the same superscripts in the same column at the same storage time and sensory parameter are not significantly different at $p < 0.05$.

^{a-h}Means with the same superscripts in the same sensory parameter are not significantly different at $p < 0.05$.

¹⁻³⁾Refer to Table 1.

from day 19 was excluded from all physico-chemical and sensory evaluation because it was so putrid.

Increased purge in packaging involves weight loss, nutrient loss, and colour change of meat. Excessive purge accumulation in the package is also unappealing to the consumer. The purge occurs in the spaces between the fibre bundles and the perimysial or endomysial network (Offer and Cousins, 1992). The packaging factors influencing purge loss include vacuum level, flushing, shrinking, application of CO₂ and scavenger system (Lee and Yoon 2001b; Payne *et al.*, 1998; Stiebing and Karnitzschy, 1997). Purge loss increased with storage time in all packaging methods. However, the greatest purge loss was observed in the initial 3 d of storage in all samples. At day 3, the purge loss was not significantly different among the packaging treatments. However, VP samples showed significantly higher purge loss values than the WP and CP samples at day 5 ($p < 0.05$). From day 8, the purge loss in the CP samples was significantly lower than in the WP and VP samples ($p < 0.05$). The observation that the purge loss in the VP samples was generally higher than other samples can be explained by the fact that the reduced pressure developed in the VP would accelerate the meat juice to flow out into spaces between the product and the film. Payne *et al.* (1997) reported that meat packaged in a polyethylene bag yielded a lower purge loss than vacuum packaged meat, a result inconsistent with ours. The small sample size might account for the WP purge losses in our experiment not differing significantly from those of the VP samples after 8 d.

The WP samples dropped below the minimum marketable criteria for sensory evaluation (3.0) due to discolouration after 11 d, and the CP and VP samples after 15 d.

The WP sample fell to 1.33 in colour score at day 14, indicating a pronounced discolouration. In the VP samples at day 11, the colour was purple-red immediately after opening the pack, however, the colour turned purplish red after 30 min exposure to air. The oxidative discolouration of meat pigment is accelerated with the increase of oxygen concentration in the packaging atmosphere. Therefore, this result indicates that the oxidation of myoglobin took place more rapidly in the WP samples than in the CP and VP samples.

The first off-odour was detected at day 15 in the CP and VP samples, but at day 11 in the WP sample. The off-odour detected from the WP samples was described as putrid, stuffy, stale and slightly sweet-sour. According to Sutherland *et al.* (1975), a high count of *Pseudomonas* spp. (> 6 Log CFU/cm²) is accountable to the formation of sweet-rotten odour on aerobic storage of meat. Ingram and Dainty (1971) reported that off-odour is noticed when the total colony count reaches 7 Log CFU/cm². However, the sensory quality of vacuum packaged meat is sometimes not proportional to the level of total colony count (Ingram, 1962). In the VP samples after 11 d of storage, a slight sour odour was detected immediately after opening the pack, however the sour odour disappeared after 30 min of exposure to the air. The off-odour score for the VP samples was 2.39 at day 15, which is below the marketable criteria level of 3.0 even though the total colony count remained less than 7 Log CFU/cm².

The results evaluated for the overall appearance of samples were similar as with off-odour. The time point at which the evaluation score for the overall appearance fell below 3.0 was at day 11 for the WP samples and at day 15

for CP and VP samples, respectively. These results indicated that the film wrapping of fresh meat induced the increase of the relative humidity resulting in the shortening of shelf-life (Bem and Hechelmann, 1995). In general, among the three packaging treatments, the quality preservation of pork during chilled storage, as judged by sensory scores for discolouration, overall appearance and off-odour, were worst in the WP samples.

Conclusion

Sensory testing led to the WP samples being evaluated as the worst among the packaging treatments, while the CP and VP samples showed equivalent quality and shelf-life characteristics during storage up until 19 d. Sensory defects for the VP samples included purple-red colour, accumulation of purge in the package and a slightly sour odour from the meat caused by evacuated storage. However, the VP samples showed slightly more favourable results in some physic-chemical (TBA and VBN values) and microbiological quality parameters (lower bacterial counts, particularly in *Enterobacteriaceae* count) than the CP method. WP would be the simplest and most economical storage option for fresh chilled pork in households for several days of storage. However, for longer storage, CP or VP is recommended. Further research, evaluating the effects of the evacuation level of the vacuum pump, gas permeability of the film, and the type of vacuum packaging film used, will be required to determine the potential for domestic vacuum packaging machines to extend shelf-life and optimize the quality preservation of chilled pork.

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