The effect of pale, soft and exudative (PSE) pork and fat grading on physico-chemical characteristics of low fat bacon.

by

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Abstract

The effect of pale, soft and exudative (PSE) pork and fat grading on physico-chemical characteristics of low fat bacon

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The pale, soft and exudative (PSE) pork condition is known to cause sensory defects in pork and pork products. Meat products made from PSE pork are known to be less tender, more pale and watery. Excessive fat in pork may also reduce the desire of consumers to purchase a product, but a lack of fat may lead to other sensory defects. Due to problems encountered by a local, low fat bacon producer, the research was done in an effort to acquire a better understanding of the effect of PSE pork and backfat thickness on the sensory quality of packaged low fat bacon. It is the aim of this study to find out the effectiveness of 1, the use of PSE classification based on early post mortem pH and 2, fat grading as means to predict the suitability of raw pork loins for low fat bacon processing.

Thirty carcasses were selected based on pH_{38min} measurements on *M. longissmus dorsi* (loin) and back fat thicknesses. Only carcasses with back fat grades P (≤ 12mm fat, n=14) and O (13-17 mm fat, n=16) were selected. pH_{38min} of ≤ 5.9 (n=15) was considered PSE carcasses while carcasses of pH_{38min} value > 5.9 (n=15) were considered normal.

Colour measurements (hunter lab ***L a b***), drip loss, fat content and brine uptake were determined on raw pork loins while % free fluid, colour (***L a b***) and sensory evaluation with a trained panel (degree of redness, colour distribution, fat marbling, fat thickness, wateriness and overall consistency) were done on packaged, uncooked, low fat bacon.

It was found that bacon made from PSE carcasses were lighter and less red, had more free fluid than that of the normal carcasses, possibly due to protein denaturation and subsequent lowering of water holding capacity (WHC) and higher free fluid in the package, although there was no difference in % brine uptake. The sensory panel could only find a significant difference in the degree of redness between bacon made from PSE and normal carcasses. The backfat thickness of loins had no effect on the ***L a b*** readings but positively influenced the degree of redness as determined by the sensory panel. For reasons not determined, bacon made from carcasses with thicker backfat had lower marbling effect as perceived by the sensory panel. L_{pork} (darkness) was found to be significantly related to a_{pork} (degree of redness) and a_{bacon} but not to the evenness of distribution of bacon colour, L_{bacon} and b_{bacon} (yellowness). a_{pork} was significantly related to L_{bacon}, a_{bacon} and degree of redness but not to b_{bacon} and evenness of distribution of bacon colour.

It was concluded that the use of PSE pork for low fat bacon manufacture resulted in a difference in the degree of redness of packaged bacon measured by human perception.

Low fat bacon made from PSE pork had higher drip losses compared to bacon manufactured from normal pork possibely due to protein denaturation. Higher % free fluid was subsequently measured in packaged low fat bacon. The losses in fluid from the use of PSE pork can also have a serious effect on the yield of the bacon manufacturing process and should be avoided or the PSE pork must be treated before further processing.

As far as a human perception's point of view is concerned, the use of grade O pork for low fat bacon manufacturing should not be a problem for as long as they are trimmed properly but the lost of yield due to trimming must be considered. From an economic point of view, the exclusive use of grade P carcasses can reduce the weight loss due to trimming and is recommended.

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1 Introduction

The problems of pale soft and exudative (PSE) pork (Garrido, Prdauye, Banon, Lopez & Laencina, 1995; Offer *et al.* according to Van Oeckel, Warnants, & Boucqué, (1999) and a high fat content (Rathje & Ho, 1987) can be very negative factors in bacon manufacturing.

With the aim of producing low fat bacon, it is preferable to use pork meat from pigs that produce lean muscle. However, certain high yielding breeds, for example, pigs containing Hampshire genes, are known to be prone to stress, resulting in PSE meat and the loss of functional properties of muscle proteins (McKeith *et al.* according to Bertram, Petersen & Andersen, 2000). PSE is a condition characterised by muscle having a very light, soft and watery appearance and an open structure. PSE is due to rapid post mortem glycolysis and a fast pH drop which cause the denaturation and precipitation of sarcoplasmic proteins (Pearson, 1987). PSE meats usually have low functional properties for processing, resulting in lower yield and/or poor product quality (van Laack *et al.* according to Bertram *et al.*, 2000).

There has also been a growing concern about the healthiness of consuming animal products as animal fat is high in saturated fatty acids and high proportion of saturated fatty acids in the diet is believed to increase the chance of colon, breast and prostate cancer (Chizzolini, Zanardi, Dorigoni & Ghidini, 1999; Weisburger, 2000). There is also a concern about coronary heart problems associated with a high ratio of saturated to unsaturated fatty acids in the human diet (Weisburger, 2000). In answer to concerns of the public, low fat meat products have been produced but this is not without problems. A lack of fat is also linked to a lower amount of marbling and since marbling is positively associated with juiciness of pork meat (Brewer, Zhu & McKeith, 2001), bacon manufactured from very lean carcasses may be dry.

Low fat bacon is a specialized product that demands a premium price. Consumers who are willing to pay a higher price for such a product would usually demand consistent quality. In order to control low fat bacon quality (or even any bacon quality for that matter), some kind of monitoring steps have to be set up. The determination of

early post mortem pH, colour measurement and fat thickness are some of the commonly used methods to determine pork quality (Cassens, 2000). At an early stage, these methods offer fast and nondestructive determinations of suitability of raw material for processing. The problem is that it is not clear whether or not early post mortem pH and back fat thickness relate to pork quality and ultimately, the final bacon quality. Few studies have been done on the relation between these attributes mentioned above and the sensory qualities of low fat bacon.

A local cured meat manufacturer has experienced quality defects associated with the PSE condition and fat grading in its low fat bacon line despite the fact that quality tests based on PSE and back fat grading were done. It is the aim of this study to find out the effectiveness of the use of PSE classification based on early post mortem pH and fat grading as means to predict the suitability of raw pork loins for low fat bacon processing.

2 Literature Review

2.1 The problems associated with raw pork meat for bacon processing

The sensory quality of bacon can be greatly affected by variations in the pork (Maw, Fowler, Hamilton & Petchey, 2001). However, raw material control of the incoming pork is not easily done. The biggest problem a bacon processor has to deal with, is that the major ingredient of bacon processing, namely pork, is from a biological origin and many factors, as summarized in Fig. 1 can influence the quality of pork and ultimately the bacon produced from different pigs.

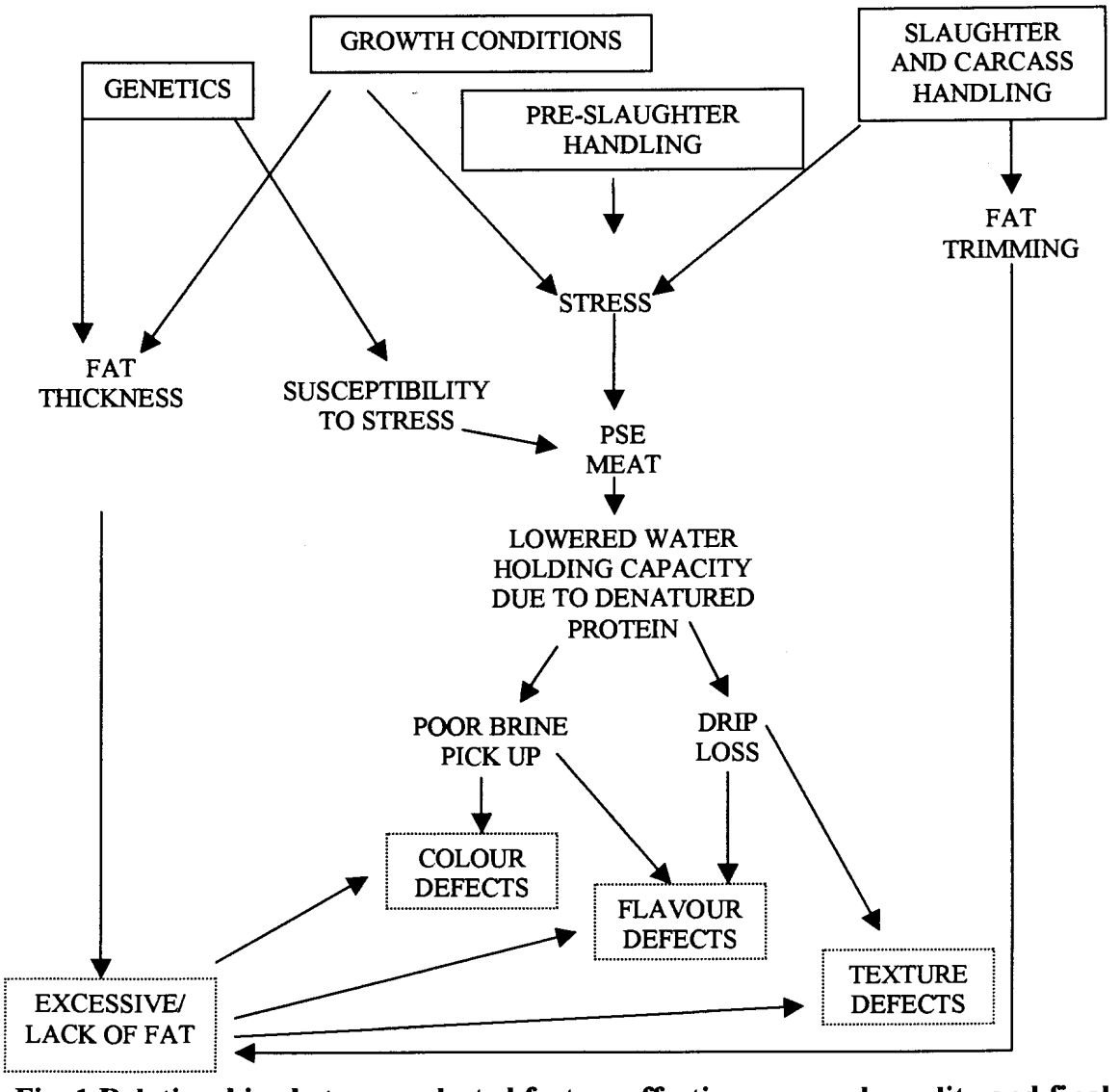


Fig. 1 Relationships between selected factors affecting raw pork quality and final product defects in bacon

2.1.1 Genetic factors

From a commercial point of view, it is always better to have breeds of pigs that produce higher yields of lean meat so that there is a higher profit. Pigs of selected desired characteristics are potentially available due to breeding schemes and/or genetic modification. There is, however, a problem with some high yielding breeds. Reports by Lahucky, Christian, Kovac, Stalder & Bauerova (1997) and Fàbrega, Manteca, Font, Gispert, Carrión, Velarde, Ruiz-de-la-Torre & Diestre (2002), suggested that pigs with heterozygote genes gave a higher yield of lean meat but lower meat quality.

According to Fisher, Mellett & Hoffman (2000a), pigs of genotypes known to be halothane sensitive have less fat, larger eye muscles but have a higher drip loss and inferior reflectance reading than halothane negative types. The findings of Channon, Payne & Warner (2000) were that muscles from halothane positive pigs had lower sarcoplasmic and myofibrillar protein solubility which impacts negatively on meat quality. Contrary to this, Van Oeckel, Warnants, Boucqué, Delputte & Depuydt (2001) failed to observe differences in meat quality between halothane positive and halothane negative pigs and Jeremiah, Gibson, Gibson, Ball, Aker & Fortin (1999) claimed that there were no differences in palatabililty between halothane positive and normal pork even though there was a difference in measurable drip loss. Bertram *et al* (2000) reported that there were still incidents of PSE pork and low water holding capacity in Denmark after halothane genes have been removed by breeding schemes suggesting that genetics was not the only factor affecting the quality of pork products.

2.1.2 Growth conditions and pre-slaughter handling

The handling of pigs have always been a concern. First of all, there is a concern about animal welfare and this is a concern of the governments all over the world. However, the treatment of the animals also carries a commercial concern. It has been shown that pigs that have been well treated usually produce pork of better quality. Maw *et al* (2001) found that even small factors such as floor construction, group size and dust

level will affect pork quality. Rosenvold, Lærke, Jensen, Karlsson, Lundström & Andersen (2002) found that the use of vitamin E in the diet delayed the rate of post mortem pH drop thus reducing the chances of PSE pork (see section 2.1.3 on glycolysis). Excessive heat in summer can also affect meat quality by impacting on the ability of the sarcoplasmic reticulum to control Ca^{2+} concentration in muscle (Küchenmeister, Kuhn & Ender, 2000), resulting in rapid pH drop. Before slaughtering, the pigs should be allowed to rest sufficiently. The increased lairage time can reduce the chance of PSE caused by stress although excessive lairage time may also cause incidents of dark firm and dry (DFD) meat (Aaslyng & Barton-Gade, 2001) which, due to the higher pH, has high water holding capacity resulting in a dark colour which is not attractive.

Different stunning methods can also affect meat quality differently, CO_2 stunning can produce reduced pH decline, less blemishes and less ecchymosis in porcine carcases (Channon, Payne & Warner, 2002). Velarde, Gispert, Faucitano, Manteca & Diestre (2000) found that CO_2 stunning produced less PSE meat resulting in more tender meat while electric stunning caused more bone fracture due to excessive muscle contraction and haemorrhages in connective tissues.

2.1.3 Post mortem changes and PSE condition

In muscle, adenosine triphosphate (ATP) is needed to provide energy (Pearson, 1987):

$$\text{ATP} + \text{stimuli} \longrightarrow \text{Adenosine Diphosphate (ADP)} + P_i + \text{Energy}$$

Before a pig is slaughtered, when oxygen is available, ATP needed for muscle functioning is produced by oxidative phosphorylation via the Krebs cycle or beta oxidation of fatty acids yielding CO_2 and water. After the pig is slaughtered, the circulation system ceases to function and the muscles are in an anaerobic environment. Anaerobically, ATP is produced by degradation of glucose (which is derived from breakdown of muscle glycogen) to lactic acid by means of glycolysis Pearson, 1987):

$$\text{Glucose} + 2\ \text{ADP} + 2\ \text{Pi} \rightleftharpoons 2\ \text{Lactate} + 2\ H_2O + 2\ \text{ATP}$$

or conversion of creatine phosphate (CP) and ADP to creatine and ATP (Pearson, 1987):

$$\text{ADP} + \text{CP} \xrightleftharpoons[\text{Phosphocreatine kinase}]{} \text{ATP} + \text{Creatine}$$

The function of CP is to furnish bonds to rephosphorylate ADP to form ATP (Pearson, 1987). According to Henckel, Karlsson, Jensen, Oksbjerg & Petersen (2002), the amount of CP will determine the time taken before glycogen degradation commences as creatine phosphate is used up before glycogen degradation starts thereby delaying the rate of pH decrease caused by lactic acid production. They also stated that muscles of stressed animals rely more on ATP from anaerobic sources therefore reducing the amount of creatine phosphate and that glycogen levels of stressed animals is higher while the creatine phosphate level is lower.

The research of Klont, Brocks & Eikelenboom (1998) suggested that the muscles of halothane positive pigs have an increased content of glycogen depleted myosin heavy chain IIA and IIB fibres, a larger mean fibre area and a reduced capillary density. They also noted that type IIA and IIB fibres have higher anaerobic glycogen utilisation capacity than type I fibres and that if type IIB is more than 30%, DFD condition can arise. Depreux, Grant & Gerrard (2002) had reported a similar finding, suggesting that muscle pH was negatively correlated to myosin heavy chain IIB content.

Many authors suggested that there is a difference between enzymatic reactions involved in normal and PSE meat. Schwaghele, Haschke, Honikel & Krausss (1996) found that there are different isoforms of kinase in PSE and normal meat arising from phosphorylation-dephosphorylation events. Although the two isoforms do not differ in the rate of ADP utilisation, kinase in PSE meat is able to continue functioning at lower pH producing more pyruvate and lactate that further reduce the pH. Schwaghele, Lopez Buesa & Honikel (1996) also found the glycogen phosphorylase of PSE and normal pork to be different but doubted that the difference has to do with the triggering of the PSE syndrome. Allison, Bates, Booren, Johnson, and Doumit

(2002) however, failed to observe the relation between pyruvate kinase capacity and pH drop although they did find a correlation between phosphofructo kinase content and drip loss.

The rapid decline of pH post mortem can induce the PSE condition. PSE meat usually has a lighter colour and lower water holding capacity. Early researchers in the 1960s, for example, Lawrie *et al.* according to Bendall & Wismer-Pederson (1962), have found that the rapid lowering of pH combined with carcasses temperature is related to "Watery Pork" and suggested that it had to do with the denaturation and aggregation of fibrillar proteins. Bendall & Swatland (1988) found that the miofibrillar protein is not denaturated at lower pH but is rather bound by a layer of denaturated sarcoplasmic protein if the pH drops too fast when the carcasses are still warm and the wateriness can also be caused by the approaching of the isoelectric point. On the other hand, Bowker, Wynveen, Grant & Gerrard (1999) stated that post mortem pH and temperature alone could not explain all aspects of pork meat quality. Enfält, Lundstrom, & Engstrand (1993) suggested that the low pH is not only caused by the rapid decline of pH but also the accumulation of lactate before slaughter.

Brewer, Zhu, Bidner, Meisinger & McKeith (2001) found that the low pH will cause the failure of metmyoglobin reductase to form oxymyoglobin and renders the meat more brown in colour. Joo, Kauffman, Kim & Park (1999) stated that PSE meat had more precipitated sarcoplasmic proteins and precipated creatine kinase, triose phosphate isomerase and mykinase were only found in PSE meat. The precipitated proteins can mask the red colour of sarcoplasmic protein and hence the meat appears more pale (Goldspink *et al* according to Joo *et al*, 1999). They also found that the solubility of myofibrillar and sarcoplasmic proteins were lower in PSE meat. Findings of Torley, D'Arcy & Trout (2000) also indicated that lowered functional protein contents were linked to lowered muscle pH and further stated that the rapid drop of pH reduced the tenderisation effects of m-calpain as it is likely to be activated before the pH drops from 6.2 to 6.0. Torley, D'Arcy & Trout (2000) also suggested that the effect of salt to increase water holding capacity is minimal in PSE meat as the partly denatured sarcoplasmic protein prevented the actomyosin from being split. The protein denaturation combined with the lowered protein solubility can result in the

loss of membrane integrity and hence the merging of extracellular and intracellular fluids (Oliver, Gispert & Diestre, 1988) resulting in drip loss. The free fluid in meat can cause the increase of light scattering of muscle and hence the more pale appearance (Lindahl, Lundström & Tornberg, 2001).

2.1.4 Fat content

It is not easy to produce a low fat product that has the same sensory qualities as that of the full fat counterparts. The change of fat content will change the taste perception of meat as fat hastens the perception of saltiness and fatty after taste in bacon and ham (Jeremiah, Ball, Uttaro & Gibson, 1996). According to Fernandez, Monin, Talmant, Mourot & Lebret (1999), up to 3.5% of intramuscular fat will improve the taste and textural perception of pork. They also found that if the backfat of loin is trimmed off, the presence of intramuscular fat will reduce the desire of consumers to purchase pork possibly due to the fattiness but if the back fat layer is present, the effect of intramuscular fat on consumer preference is minimal. The removal of fat layer can also result in the lack of fat soluble, aromatic compounds, Coutron-Gambotti, Gandemer, Rousset, Maestrin & Casabianca (1998) found that salt reacts with lipids to produce volatiles in dry cured ham. The reduction in fat also causes a safety concern in some meat products as water is usually needed to make up for the weight losses after the fat has been removed and therefore if all else are being equal, the water activity is increased (Jiménez Colmenero, 2000). For example, *Listeria monocytogenes*, species known to cause high mortality, can be found in cooked bacon and even a higher amount can be found in sliced bacon due to contamination (Uyttendaele, De Troy & Debevere 1999). Therefore a combination of different hurdles is usually needed to ensure safety in reduced fat products (Juncher, Vestergaard, Søltoft-Jensen, Weber, Bertelsen & Skibsted, 2000).

2.2 Curing

Curing is a step where the meat is subjected to treatment of a mixture of curing agents. Nitrite/nitrate and salt (NaCl) are the most commonly used agents in both dry curing and brine curing while the addition of organic acids such as lactic acid and

sorbic acid are more exclusively found in brine curing. It is known that the reduced functional properties of PSE pork may hamper the sensory properties of cured products but little research has been done on the relation between PSE condition and bacon sensory qualities. Halothane pigs are known to be stress prone and can be determined by actual halothane testing or DNA testing for known halothane positive trails. According to Nanni Costa, Lo Fiego, Dall'Olio, Davoli & Russo (1999), halothane carrier (Nn) pigs produce meat with faster post mortem pH drop, causing defects and lowered water holding capacity. This result is higher fluid loss and salt content during dry curing in ham production. On the other hand, García-Garrido, Quiles-Zafra, Tapiador & Luque de Castro (1999) found that the increase in water content (which is associated with non-PSE muscles) in ham can cause textural problems. Fernandez, Gilbert & Vendeuvre (2002) found that the yield of cured-cooked ham made from Nn pork to be significantly lower that that of the non-halothane carrier (NN) pork; the texture is also tougher and less smooth although they did no observe a difference in colour (redness).

2.2.1 Nitrite and nitrate in brine

Nitrate, a reducing agent, is not toxic to bacterial growth itself but many bacteria will produce nitrite from nitrate (fig. 2)during anaerobic respiration by reductase reactions with some bacteria having more than one type of nitrate reductase (Wolf, Emig, Gruenenwald & Hammes, 1990).

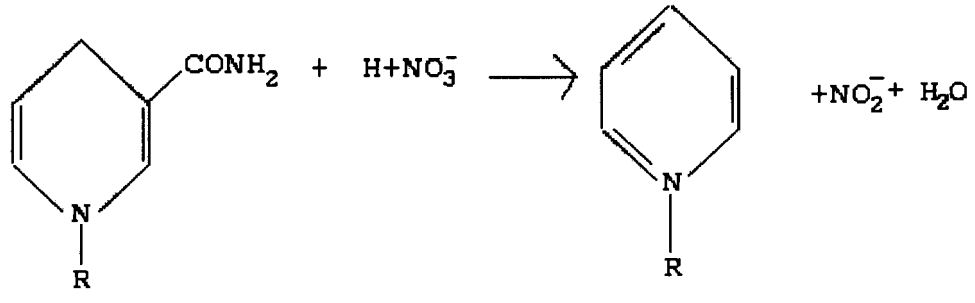


Fig. 2 Reduction of nitrate to nitrite (Kyzlink, 1990)

There are several theories on the action of nitrite against bacterial growth. Since decades ago, it has been speculated that nitrite reacts with the S-H bonds of protein and the redox and hydrolytic enzymes which are dependent on the activities of S-H

bonding (Hochster & Quastel, 1963). Tompkin *et al*, according to Cammack, Joannou, Cui, Martinez, Maraj & Hughes (1999) suggested that nitric oxide, formed via nitrous acid from nitrite, reacts with the bacterial iron-sulfur proteins which are important in energy metabolism of both aerobic and anaerobic bacteria and thus are likely targets for the bacteriostatic action of nitrite, nitric oxide and related compounds.

As far as sensory quality is concerned, when nitrite reacts with myoglobin (Mb), it oxidizes it to ferric metmyglobin (red). Metmyglobin then forms a complex with nitrite which, on reduction, yields a red NO-myglobin (NO-myoglobin) (Tomoda, Murakami & Shibuya, 1997). Taira, Miik & Riesz (1997), suggested that Mb-NO is an end product of the reaction pathway involving Mb, H_2O_2 and hydroxylamine (HA). If heat denatures the NOMb complex, a protein linkage co-ordination site in NOMb can be broken and replaced by a second NO (Karmas, 1982). NO_2 also prevents oxidation by stabilising myoglobin radicals as hypervalent ferrylmygoblin (MbFe(IV)=O) and perferrylmyoglobin ($^{+}$MbFe(IV=0) are powerful pro-oxidants formed by reaction of MbFe(II)O_2 and MbFe(III) with H_2O_2 (Kröger-Ohlsen & Skibsted, 2000). Fig. 3 shows the general pathway of myoglobin changes.

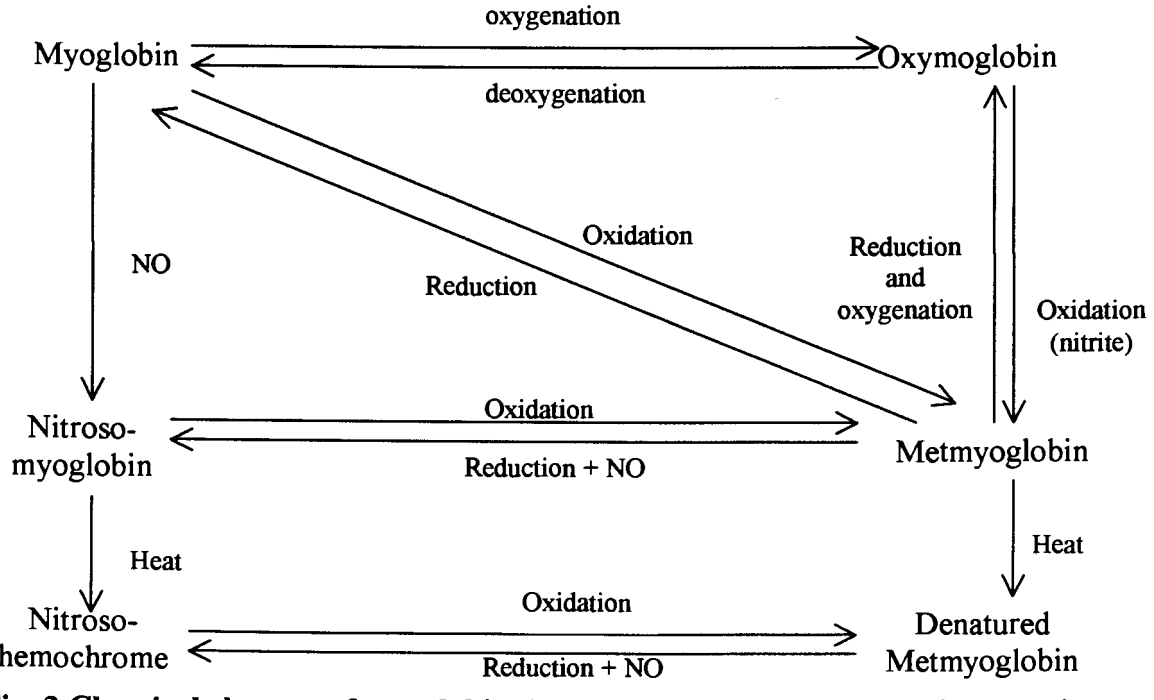


Fig. 3 Chemical changes of myoglobin that may occur during the curing reaction (Wilson, 1960)

2.2.2 Salt

The most noted change that salts (usually in the form of NaCl) can impose is the ability to reduce the water activity of the system (Loureiro, 2000). On the other hand, the addition of salt is also important for the sensory qualities of bacon.

Torley *et al* (2000) noted that salt will reduce cooking loss in bacon due to the increase in ionic strength but this effect is minimal on PSE meat due to protein denaturation. However, salt can also cause defects in cured meat products. Coutron-Gambotti *et al* (1999) found that salt can be a pro-oxidant which oxidises volatiles in ham but failed to observe an expected increase in polyunsaturated fatty acid contents. Medy-ski, Pospiech & Knia (2000) reported a problem with salt addition in bacon causing white liquid exudates when bacon is cooked due to the denaturation of low molecular weight sarcoplamic proteins at high salt %. They also stated that during injection into pork blocks, the denaturation of proteins could also be seen in areas where salt content is initially high, therefore explaining the reason for the "tiger stripping effect" in some bacon. Tiger stripping happens when the meat around the site of brine injection is denatured and becomes lighter in colour due to the initially high concentration of salt. They suggested that the problem was made worse when a rapid curing did not increase the water holding capacity enough to hold the brine and the fact that the excess liquid was held by the vacuum pack.

3 Objectives

The main objective of this study was to determine the effect of PSE pork meat and fat grading on selected quality parameters of low fat bacon by:

Measuring fat content of raw loins after fat trimming;
Measuring the colour values (***L a b***) of PSE and normal pork before and after processing into bacon;
Measuring the water holding capacity of the raw pork, the brine uptake of the bacon during curing and drip loss of the bacon after processing and packaging and
Quantifying the appearance characteristics of the processed bacon using a trained descriptive sensory panel.

3.1 Hypotheses

It is expected that the early post mortem pH of the raw pork will have an influence on the raw pork quality. Due to the reduced chance of protein denaturation, the pork meat and finished low fat bacon samples with a higher initial pH should be more red, darker and have better water binding capacity and less watery surface appearance . Also, the brine uptake should be higher.

It is expected that the darkness and redness of bacon will be positively correlated with the darkness and redness of bacon and negatively related with the wateriness since darkness and redness of pork suggest a high initial pH and the lack of protein denaturation in the pork muscle.

Bacon made from O grade carcasses should have more marbling perception than that of the grade P's.

4 Materials and methods

4.1 Experimental design

The experiment was designed to include raw pork quality evaluation and the evaluation of packaged low fat bacon. Fig. 4 shows the experimental design.

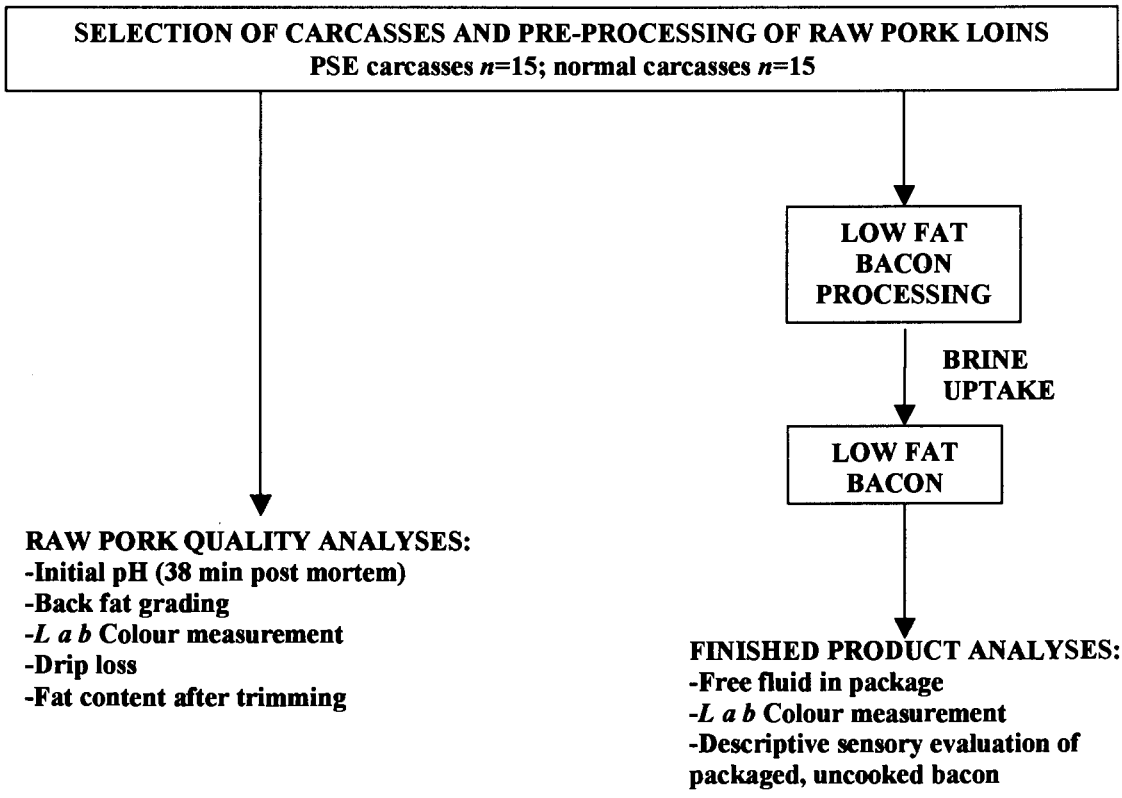


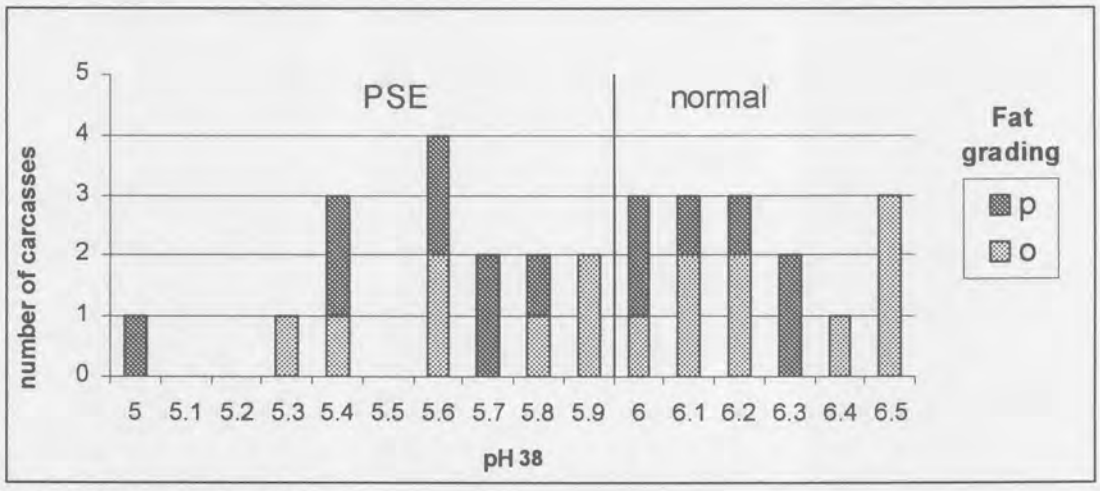
Fig. 4 Experimental Design to determine the effect of PSE and fat grading on physico-chemical characteristics of low fat bacon

4.2 Selection of Carcasses

Thirty pork carcasses were chosen from the slaughter line of a commercial abattoir in Olifantsfontein, Midrand. Ten carcasses were chosen per day, once a week over three weeks. All pigs were stunned by means of electrically charged tongs (210 V, 1.3 Amp) placed over the head of the animals. After the pigs were stuck, bled and dressed, the carcasses went to the online grading station. The carcasses were graded on their fat thickness with a Hennessey grading probe and only carcass grades P (less

or equal to 12 mm fat) and O (13-17 mm fat) (South African Meat Industry Company, 2000) were considered for further selection.

The pH was measured in the *M. longissimus dorsi*, between the 2nd and 3rd rib and 45 mm from the center line ±38 min after stunning at an online pH station with a Russell pH meter which was calibrated by suing buffer solution of pH 4 and 7. Carcasses with pH_{38} of ≤5.9 were considered to be PSE carcasses while carcasses of pH_{38min} value >5.9 were considered to be normal carcasses. To ensure a variation of carcasses of different initial pH, on each selection day, at least 4 and not more than 6 PSE carcasses were selected and normal carcasses made up for the rest of the 10 carcasses. 14 P grade and 16 O grade carcasses were chosen. Fig. 5 shows the fat grading and pH of the 30 carcasses chosen.



Grade P : less or equal to 12mm fat
Grade O : 13-17mm fat

Fig. 5 The distribution of the 30 carcasses chosen according to backfat grading and pH_{38} values for classification as PSE or normal

After each carcass had been selected, a number was assigned and an alcohol sterilized, water/oil proof number tag was attached onto the leg of the carcass by means of an alcohol sterilized cable tie.

The chosen carcasses were rapidly chilled in a blast cooling tunnel at -25°C and then chilled to ± 4°C in a chilling room.

4.3 Pre-processing of loins and sampling of raw loins

About 24h after the pigs were slaughtered, the chosen carcasses were cut to obtain the loins for low fat bacon processing. The loins were deboned and the back fat hand trimmed to a thickness of ≤10 mm. The trimmed loins were then labeled with alcohol sterilized tags secured with cable ties, placed into plastic bags and crates and transported for ± 30 km under chilled conditions at 4°C to a bacon processing plant in Germiston, Johannesburg.

A sample slice of about 150g and ± 70 mm thick was removed, perpendicularly to the grain with a knife from each loin from the shoulder side and packed in a numbered, laminated polyethylene vacuum bag and kept chilled at ± 4°C until it was perpendicularly subdivided, with subcutaneous fat layer intact, into smaller pieces for colour, drip loss and fat content determinations.

4.4 Raw meat quality assessment

4.4.1 Colour measurement

The colour measurement of the raw pork was done on the same day as the raw loin sampling. The samples were kept chilled at ± 4 °C until 30 min before the measurement when sample of about 100g were removed from each loin and exposed to the atmosphere at room temperature of ± 21 °C to allow for blooming. For colour measurements, a Minolta Colorimeter was used for determination of hunter lab ***L a b*** values. ***L*** is the value corresponding to the degree of lightness/darkness, ***a*** value for greenness/redness and ***b*** for yellowness/blueness. A white tile was used to calibrate the Colorimeter. Each loin sample was measured 3 times at 3 different positions and care was taken not to measure the fat layers of the samples.

4.4.2 Drip loss of pork

Two samples were analyzed per carcass. Water holding capacity of the raw pork loins was measured using the method proposed by Honikel (1998). Each weighed sample of

80-100 g slice was suspended by a thread and sealed in a laminated polyethylene bag (10 cm X 15cm). Care was taken so that the meat did not touch the bag. The samples were removed from the bags and weighed again after 24 hour, 2 days and 7 days at 1 to 5°C. Drip loss was expressed as % loss of initial weight.

4.4.3 Fat content after trimming

4.4.3.1 Preparation for test

The preparation of samples was done according to AOAC Official Method 983.18 (Cunnif, 1995). Samples were rapidly passed 3 times through a mincer with plate openings of 3mm. One deviation to the AOAC method was that when analysis was not done soon after the preparation, the samples were kept at –20 °C to prevent decomposition and then thawed prior to the analyses. Two samples were analyzed per carcass.

4.4.3.2 Moisture determination

AOAC Official Method 950.46 (Cunnif, 1995) was used to determinate the moisture content of the samples. Approximately 2 g sample was added to a pre-weighed, dry metal tin and the content weighed. The tin was then placed into an oven for 16 h to 18 h at 100 to 102 °C, cooled in a desiccator and weighed. The loss in weight was reported as moisture content.

4.4.3.3 Fat determination

AOAC Official Method 960.39 (Cunnif, 1995) was used except for the drying method where freeze drying replaced the prescribed oven drying. Flat bottomed Soxhlet flasks were cleaned, labelled and dried in an oven at 100°C overnight. The flasks were cooled in the desiccator and their weights were measured and recorded. Each sample of 2 g material was weighed on a filter paper. The sample was wrapped and pushed into a numbered thimble and the thimble in turn placed into the extraction unit and 375 ml of petroleum ether was then added to the Soxhlet flask. The extraction took a total of 16 h at a rate of 2 to 3 drops/s. After the extraction, the flasks were heated on

a hot water bath to evaporate most of the petroleum ether followed by incubation in an oven at 100 °C for 30 min to allow all traces of petroleum ether to evaporate. The flasks were then cooled in a desiccator and weighed. The amount of extracted fat was reported as % fat on dry basis. The % fat was expressed as:

$$\% \text{ fat} = \frac{(100 - \% \text{ moisture}) \text{ X } \% \text{ fat on dry basis}}{100}$$

4.5 Processing of loins into low fat bacon

The selected loins were processed into low fat bacon 2 days after slaughtering. All loins were individually weighed before brine injection. The loins were cured by means of brine injection with a Fomaco multiple needle injector at a calibrated 13% brine uptake. The brine contained 12.3 % salt, 7.0 % spice and 1.7 % curing salts. The loins were again weighed after brine injection and any increase in mass was reported as % brine uptake:

$$\%\text{Brine uptake} = \frac{\text{Mass}_{\text{after injection}} - \text{Mass}_{\text{before injection}}}{\text{Mass}_{\text{before injection}}} \text{ X } 100$$

The bacons were hung on smoke sticks for liquid smoke spraying. The smoking was followed by cooking at 55 °C until a core temperature of 37 °C was reached. The bacon was then frozen in a freezer at –26 °C. All bacon samples were kept frozen until 24 h before slicing at this time the bacon samples were moved to a tempering room where the temperature of the bacon was increased up to a minimum of –4 °C. A commercial slicing machine was used and the thickness was set to 2.5-3 mm. The sliced low fat bacon was then vacuum packed in laminated polyethylene vacuum bags with ±250 g of bacon in each bag. The bags were then labeled with a number corresponding to the numbers given to the carcass loins.

4.6 Bacon quality assessment

4.6.1 Colour measurement

The packaged bacon samples were kept chilled at ± 4 °C until the measurement. The

L a b values were measured the same way as in 4.4.1 except that the measurement was done on bacon samples with the packages still intact.

4.6.2 Free fluid in package

For the determination of free fluid in the package, one pack of bacon from each loin was analyzed. Each pack was weighed with the package intact, then the bacon was removed and hung over the opened package for 1 min using a pair of tongs. Afterwards, the package was weighed again. The remaining fluid inside the package was removed, the package cleaned with petroleum ether and then placed in an oven at 70°C for 15min followed by weighting. The % free fluid was expressed as follows:

$$\% \text{ Free Fluid} = \frac{\text{Mass whole content} - \text{Mass bacon}}{\text{Mass whole content}} \times 100$$

4.6.3 Sensory evaluation of packaged bacon

A descriptive sensory test was done with a trained panel of 9 panellists to evaluate the appearance of the packaged product.

4.6.3.1 Selection of panel

An orientation session was held to inform potential candidates what was expected from them and to make sure that the candidates were not colour blind. Each candidate was given a set of 15 test tubes filled with coloured dye solutions. There were 5 samples of each colour red, yellow and green at different colour intensities. Each sample was marked with an unique 3 digit number. Each candidate was then asked to fill in a form as shown in Fig. 6.

NAME
STUDENT NUMBER
DATE

There are 15 test tubes, with 5 tubes of 3 different colours, red, green and yellow at different intensity, please identify the samples of different intensities by filling the number corresponding to the samples in the columns below:

Hint: it is easier to place a piece of blank paper behind the samples.

RED	GREEN	YELLOW	
			MOST INTENSE
			LEAST INTENSE

Fig. 6 Form for colour blindness test

Only the candidates with full marks were considered for further tests. The candidates who passed the colour test were asked how frequently they consumed low fat bacon. Candidates who consumed low fat bacon less than twice every three weeks were eliminated from the panel.

4.6.3.2 Training of the panel

The panel participated in two one hour training/discussion sessions The panel were shown bacon samples that were obtained from commercial sources. The samples had different intensities of redness, fat layer thicknesses and darkness. The panel was asked to come up with terms to describe the sensory properties of the products inside the packages. The final agreed terms are listed in Table 1:

Table 1 The terms used for descriptive sensory evaluation of low fat bacon samples

Degree of redness	The degree of redness in the sample
Colour distribution	Evenness of the redness in the sample
Fat Marbling	Degree to which intramuscular fat is present
Thickness of Fat	Physical thickness of the fat layer on bacon
Wateriness	The amount of visible fluid inside the pack not bound to muscle
Overall Consistency	The amount of variation between the slices of the bacon in the same pack

The format of the evaluation form (Fig. 7) was set up and shown to the panel. There was a two hour session when the exact testing procedures were explained to the panellists and any uncertainties clarified.

Name

Date

Time

Here is a sample of bacon, please look at it and/or feel it if you wish (But DO NOT open the sachet) and then fill in the scores by marking with an X according to the scales of different attributes.

1 Degree of redness
Not red 0 1 2 3 4 5 6 7 8 9 Extremely red

2 Distribution of Meat Colour
Not even 0 1 2 3 4 5 6 7 8 9 Extremely even

3 Wateriness
Not watery 0 1 2 3 4 5 6 7 8 9 Extremely watery

4 Thickness o Fat Layer
Not thick 0 1 2 3 4 5 6 7 8 9 Extremely thick

5 Presence of Marbling Fat in Meat
None 0 1 2 3 4 5 6 7 8 9 Extreme

6 Consistency of Bacon Slices in the Pack
Not consistent 0 1 2 3 4 5 6 7 8 9 Extremely consistent

Fig. 7 Sensory evaluation form for packaged bacon

4.6.3.3 Evaluation

A panel of 9 panellists were subdivided into groups of 3 panellists. Three packs of bacon per loin were used for the evaluation so that one pack was used per group. The samples were thawed at 4 °C for 24 h before the test. Each sample was numbered with a unique 3-digit random number. Each sample was individually placed on a tray along with an evaluation form. The order of the samples was randomized. Each panelist evaluated 10 samples per hour for 2 hours per day over 3 days. There was a 20 min break between the two one hour sessions.

The test location was the sensory evaluation area of the Department of Food Science, University of Pretoria. Fluorescent white light was used and the room temperature set to 21°C. Each panellist was separated in individual evaluation compartments. Samples where given to the panellists through individual hatch openings from the sensory preparation area.

The panellists were asked to look at each sample and complete a form (Fig. 7) to rate the samples. A scale of 0 to 9 was used, with 0 being total lack of attribute and 9 being extreme presence of attribute.

4.7 Statistical analyses

Statistica version 5 (STATSOFT Inc., 1995) was used to analyse the data obtained from raw pork quality and finished product analyses. Analysis of Variance (ANOVA) was used to determine whether significant differences existed between PSE and normal samples and the two fat grades for the physical measurements and sensory scores. Pearsons Correlation test was done on the ***L a b*** colour values of raw pork and finished products and selected sensory attributes. Cluster analysis using K-means clustering was performed on the ***L a b*** colour values of the raw pork to see whether the ***L a b*** values could effectively separate PSE and normal loins.

5 Results

5.1 Raw material analyses

The difference in pH_{38} between Grade P and O carcasses, was not found to be significant (p>0.05).

5.1.1 Colour measurement of raw pork loins

Table 2 shows the differences in ***L a b*** colour values of raw pork loins between the PSE and normal groups.

Table 2 The differences in *L a b* colour measurements between pork loins from PSE and Normal carcasses

	Loins from normal carcasses (*n*=15)	Loins from PSE Carcasses (*n*=15)	p value
L	49.80 (±2.28)	53.35 (±1.80)	<0.01
a	6.33 (±0.73)	4.89 (±0.86)	<0.01
b	5.34 (±1.23)	5.14 (±1.29)	0.68

Normal : pH38 > 5.9
PSE : pH38 ≤ 5.9
L = lightness/darkness
a = greenness/redness
b = blueness/yellowness
Standard deviation in parenthesis

There were significant differences between the ***L*** and ***a*** values of the two groups of raw pork. The group with higher pH_{38min} (normal) was found to be both redder and darker than the group of lower pH_{38min} (PSE).

Regarding the ***b*** values (yellowness/blueness), there was no significant difference between the PSE and Normal groups indicating that yellowness was not affected by differences in pH_{38min}.

When the pork loins were statistically grouped into 2 groups according to ***L a b*** values respectively (Table 3) to maximize the differences within these colour parameters using the K-means clustering method, it was found that pH_{38min} classification criteria did not totally differentiate between colour groupings effectively.

Table 3 Distribution of pork loins from PSE and normal carcasses according to K-means clustering of *L a* and *b* colour values

High *L* values (less dark)		**Low *L* values (more dark)**		***p* value**
***L*mean=53.94 (±1.24)**		***L*mean=49.51 (±1.75)**		<0.01
normal	PSE	normal	PSE	
2	12	13	3	

Low *a* values (less red)		**High *a* values (more red)**		***p* value**
***a*mean=4.83 (±0.79)**		***a*mean=6.50 (±0.52)**		<0.01
normal	PSE	normal	PSE	
2	14	13	1	

Low *b* values (less yellow)		**High *b* values (more yellow)**		***p* value**
***B*mean=4.40 (±0.62)**		***B*mean=6.50 (±0.76)**		<0.01
normal	PSE	normal	PSE	
9	9	6	6	

Normal : $pH_{38} > 5.9$

PSE : $pH_{38} \leq 5.9$

L = lightness/darkness

a = greenness/redness

b = blueness/yellowness

Standard deviation in parenthesis

While loins of both PSE and normal groups could be found in both groups of higher (lighter) and lower (darker) ***L*** values, most of the PSE samples fell in the lighter group and most normal samples were found in the darker group.

Most of the PSE loins were found in the less red (lower ***a***) group and most of the normal samples in the more red group.

There was no significant difference between the ***b*** values of the two groups, the majority of both PSE and normal carcasses were found in the less yellow group.

Table 4 shows the differences in colour of raw pork loins between the P and O grade groups after trimming.

Table 4 The differences in *L a b* colour measurements between pork loins from P and O grade carcasses

	Grade P (*n*=14)	Grade O (*n*=16)	*p* value
L	51.79 (±3.30)	51.39 (±2.16)	0.69
a	5.29 (±1.34)	5.88 (±0.71)	0.14
b	5.30 (±1.28)	5.19 (±1.25)	0.82

Grade P : less or equal to 12mm fat
Grade O : 13-17mm fat
L = lightness/darkness
a = greenness/redness
b = blueness/yellowness
Standard deviation in parenthesis

There were no significant differences between the ***L a b*** values of grades P and O carcasses.

5.1.2 Drip loss of raw pork loins

With regards to drip losses of pork loins (Table 5), the PSE group had significantly more drip loss than the Normal group while there was no significant difference between grade P and O carcasses (Table 6).

Table 5 The differences in drip loss % of normal and PSE raw pork loins over 7 days

	Normal (*n*=15)	PSE (*n*=15)	*p* value
% Drip loss Day1	0.66 (±0.18)	1.09 (±0.20)	<0.01
% Drip loss Day2	0.50 (±0.19)	0.91 (±0.15)	<0.01
% Drip loss Day7	1.52 (±0.44)	2.56 (±0.46)	<0.01
% Total drip loss	2.68	4.56	

Normal : $pH_{38} > 5.9$

PSE : $pH_{38} \leq 5.9$

Standard deviation in parenthesis

Table 6 The differences in drip loss % of Grade P and O raw pork loins over 7 days

	Grade P (*n*=14)	Grade O (*n*=16)	*p* value
% Drip loss Day1	0.91 (±0.28)	1.84 (±0.30)	0.30
% Drip loss Day2	0.76 (±0.24)	0.66 (±0.29)	0.32
% Drip loss Day7	2.17 (±0.61)	1.93 (±0.75)	0.35
% Total drip loss	3.84	4.43	

Grade P : less or equal to 12mm fat

Grade O : 13-17mm fat

Standard deviation in parenthesis

5.1.3 Fat content after trimming

There was no significant difference found between the fat content of pork loin from grade P and grade O carcasses once they were trimmed (Table 7). There was no significant difference (p>0.05, results not shown) between the fat content of normal [11.81 % (±1.51)] and PSE [10.91% (±1.83)] groups.

Table 7 The fat % of pork loins from grades P and O carcasses

	Grade P (*n*=14)	Grade O (*n*=16)	*p* value
Fat %	11.32(±1.52)	11.40(±1.9)	0.85

Grade P : less or equal to 12 mm back fat

Grade O : 13-17 mm back fat

Standard deviation in parenthesis

5.1.4 Brine uptake of pork loins

There was no significant difference in the brine uptake between the PSE and normal pork loins (table 8). The average brine uptake of both groups were muchlower than the calibrated 13% set for the brine injector. There was also a very large variation in brine uptake within the groups. There was no significant difference (p>0.05, results not shown) between the average % brine uptake of the P (10.12 % (±3.51)) and O (10.35 % (±3.60)) graded samples.

Table 8 The differences in % brine uptake of PSE and normal raw pork loins

	Normal (*n*=15)	PSE (*n*=15)	*p* value
% Brine uptake	10.70 (±3.60)	9.40 (±5.26)	0.55

Normal : $pH_{38} > 5.9$

PSE : $pH_{38} \leq 5.9$

Standard deviation in parenthesis

5.2 Bacon analyses

5.2.1 Colour measurements of bacon

Table 9 shows the differences in bacon colour between the PSE and normal samples. The ***L*** values of the bacon manufactured from normal and PSE bacon did not differ significantly. There was a significant difference between the ***a*** values of the normal group and PSE group. There was no significant difference between the two groups

where ***b*** values were concerned. The PSE bacon was found to be less red compared to normal bacon.

Table 9 Comparison of *L a b* colour measurements of bacon made from PSE and normal pork carcasses

	Normal (*n*=15)	PSE (*n*=15)	*p* value
L_{bacon}	44.50 (±2.44)	46.10 (±2.81)	0.07
a_{bacon}	6.22 (±0.94)	5.81 (±1.49)	<0.01
b_{bacon}	6.93 (±1.68)	7.05 (±1.63)	0.85

Normal : $pH_{38} > 5.9$

PSE : $pH_{38} \leq 5.9$

L = lightness/darkness

a = greenness/redness

b = blueness/yellowness

Standard deviation in parenthesis

Tables 10 shows the correlation between the colour values of raw pork loins and that of the bacon.

Table 10 Pearson correlations (*r*) between *L*pork, *L*bacon, *a*bacon and *b*bacon

	L_{bacon}	a_{bacon}	b_{bacon}
L_{pork}	0.17	-0.42 **	-0.1
a_{pork}	-0.36 *	0.48 **	0.08
b_{pork}	-0.05	0.11	0.08

* p value <0.05

** p value <0.01

L = lightness/darkness

a = greenness/redness

b = blueness/yellowness

There were no significant correlations (p>0.05) between L_{pork} and L_{bacon} and between L_{pork} and b_{bacon}. There was a significant negative correlation between L_{pork} and a_{bacon} suggesting that the redness of bacon was positively related to the darkness of raw pork. There was no significant correlation between a_{pork} and b_{bacon}. There was a significant negative correlation between a_{pork} and L_{bacon} and also a positive significant correlation between a_{pork} and a_{bacon} suggesting that if the pork is more red, the bacon will be more red and darker. There were no significant correlations between b_{pork} and L_{bacon}, b_{pork} and a_{bacon} and b_{pork} and b_{bacon}.

There were no significant differences in either of L_{bacon} a_{bacon} and b_{bacon} values between the P and O graded samples ($p > 0.05$, not shown).

5.2.2 Free fluid in package

On average the fluid loss from the bacon of the PSE group, was more than double of that of the Normal group (Table 11).

Table 11 The difference in % free fluid in package of bacon made from normal and PSE carcasses

	normal (n=15)	PSE (n=15)	p value
% Free fluid	1.30 (±0.70)	3.24 (±0.82)	<0.01

Normal : pH_{38} >5.9

PSE : pH_{38} ≤5.9

Standard deviation in parenthesis

There were no significant differences in % free fluid between the P [2.51 % (±1.17)] and O [2.06 % (±1.29)] graded samples ($p > 0.05$, results not shown).

5.2.3 Sensory evaluation

5.2.3.1 Effect of PSE on sensory properties of bacon

When evaluating the appearance of the bacon in the plastic packages using a sensory panel, bacon samples from normal carcasses were found to be more red than the PSE group (Table 12). There was no significant differences observed between the two groups in any of the other sensory properties.

Table 12 Comparison of the sensory properties of packaged bacon from PSE and normal pork carcasses

	normal carcasses(n=15)	PSE carcasses(n=15)	*p* value
Degree of redness 0 = not red, 9 = extremely red	6.43 (±0.52)	4.64 (±1.08)	<0.01
Distribution of meat colour 0 = not even, 9 = extremely even	5.53 (±1.24)	5.24 (±1.18)	0.35
Wateriness 0 = not watery, 9 = extremely watery	4.00 (±0.68)	4.18 (±1.04)	0.42
Thickness of fat layer 0 = not thick, 9 = extremely thick	5.20 (±1.05)	4.94 (±1.11)	0.37
Presence of marbling fat in meat 0 = none, 9 = extreme	5.08 (±0.93)	5.06 (±0.60)	0.92
Consistency of bacon slices 0 = not consistent, 9 = extremely consistent	5.76 (±0.86)	5.70 (±1.03)	0.82

Normal : $pH_{38} > 5.9$

PSE : $pH_{38} \leq 5.9$

Standard deviation in parenthesis

5.2.3.2 Relation between ***L a b*** colour values of pork loins and the appearance of bacon samples

As indicated in Table 13, both ***L***pork and ***a***pork had significant correlations with the redness of bacon meaning that if the pork was darker or more red, the sensory panel perceived the final product as more red. On the other hand, there were no significant correlations between ***L a b*** values of pork with evenness of distribution of meat colour.

Table 13 Pearson correlations (*r*) between *L a b* values of pork and degree of redness and Distribution of meat colour

	Degree of redness Scale: 0 = not red, 9 = extremely red	Evenness of distribution of meat colour Scale: 0 = not even, 9 = extremely even
L_{pork}	-0.40*	0.17
a_{pork}	0.56**	-0.06
b_{pork}	0.06	0.0

* p value < 0.05

** p value < 0.01

5.2.3.3 Effect of fat grading of pork carcasses on sensory properties of bacon

As indicated in Table 14, the bacon made from Grade P pork was perceived as more marbled and less red. No significant differences were found for evenness of colour distribution, wateriness, fat thickness and overall consistency.

Table 14 Comparison of the sensory properties of packaged bacon from Grades P and O pork

	Grade P (n=14)	Grade O (n=16)	*p* value
Degree of redness 0 = not red, 9 = extremely red	5.08 (±1.32)	6.16 (±0.81)	<0.01
Distribution of meat colour 0 = not even, 9 = extremely even	5.23 (±1.05)	5.56 (±1.33)	0.29
Wateriness 0 = not watery, 9 = extremely watery	3.88 (±0.83)	4.25 (±0.84)	0.09
Thickness of fat layer 0 = not thick, 9 = extremely thick	4.87 (±1.17)	5.28 (±0.97)	0.14
Presence of marbling fat in meat 0 = none, 9 = extreme	5.33 (±0.86)	4.85 (±0.68)	0.02
Consistency of bacon slices 0 = not consistent, 9 = extremely consistent	5.61 (±0.89)	5.84 (±0.97)	0.35

Grade P : less or equal to 12mm fat

Grade O : 13-17mm fat

Standard deviation in parenthesis

6 Discussion

6.1 Raw material analysis

Raw pork loins from the PSE group had a lighter (higher ***L***) and less red (lower ***a***) colour compared to that of the normal group while there was no significant differences in the yellowness (***b*** values). There are several possible reasons for the PSE group to be lighter. According to Brewer *et al.* (2001), the lower pH of the PSE group is closer to the isoelectric point (pI) which results in the lowering of water holding capacity. Close to pI, the decreased myofilament spacing will increase the light scattering due to the now available free water (Bendall & Swatland, 1988 according to Lindahl *et al*, 2001) without the protein even being denaturated, resulting in a paler appearance. On the other hand, Van Laack, Kauffman, Sybesma & Smulders (1994), found that water holding capacity is only responsible for about 37% of brightness (***L*** values) variation. Brewer *et al* (2001) also stated that the low pH can cause the failure of the muscle reducing system to convert metmyoglobin to the reduced form hence affecting both ***L*** and ***a*** values.

The ***a*** values of the raw pork samples seemed to increase with higher pH_{38} readings and concurred with earlier research of Warner, Kauffman & Greaser (1997) where pH was measured at different post mortem times. The ***L a b*** measurements of the work done by Warner *et al.* were somewhat different from the results of this study. This was probably due to procedural difference as the colour measurements of the two studies were done at different times after stunning. In addition, the instruments used in the two studies differed which could explain the differences in results as different instruments are known to produce different results (Brewer *et al.*, 2001). As expected, the PSE group had a lower ***a*** value than that of the normal group. PSE pork is usually associated with denaturated protein and the denaturated protein can precipitate and mask the red colour of the sarcoplasmic proteins (Goldspink & McLoughlin, 1964). As stated earlier, if the reducing system of the muscle fails due to low pH, there will be more metmyoglobin in the muscle which is more grey/brownish. Mikkelsen, Juncher & Skibsted (1999) found that the reductase activity is highest at pH 6 and the findings of Hagler *et al.* according to Mikkelsen *et al.* (1999), suggest that bovine metmyglobin reductase activities are bell shaped at different pH. Zhu & Brewer

(2002) also found that the state of myoglobin is important for colour as the absorbance of denaturated myoglobin is different from the myoglobin in its native state. Zhu & Brewer (2002) also stated that high pH would lead to better formation of oxymyogloin from metmyoglobin although once the protein is denaturated, the effect of pH is minimal. Furthermore, the integrity of globin is critical as it maintain the formation of myoglobin which prevents it from converting into its physiologically inactive form (Stryer, 1995).

The lack of differences in ***b*** values was somewhat unexpected. Lindahl *et al* (2001) suggested that ***b*** values are affected by the form of myoglobin. If there was a difference in ***a*** values due to the forms of myoglobin, the same should probably be true for the ***b*** values.

If the samples were classified according to ***L*** and ***a*** values, most PSE samples would fall into the lighter or less red group while most of the Normal samples would fall into the darker or more red group but there were some exceptions. One possible reason for the exceptions is that pH_{38min} may not be a good indicator for pork quality. Enfalt *et al.* (1993) found that in PSE carcasses, there is a rapid decline in pH of 0.2 units between 35 and 40 min and the pH would stabilize after 40 min. They also showed that there can be huge variations in initial pH drops before 45 or so minutes and one sample even had a pH increase before finally dropping again. The research of Allison *et al.* (2002) also showed that pH_{45min} had a better correlation with the ***L*** values than pH_{20min}.

The loins from the PSE group had, as expected, a higher drip loss than those of the normal group possibly due to reduced water holding capacity. The drip loss, however, was much lower than that reported in earlier research. For example, Warner *et al.* (1997) found that there was a 9.6 % drip loss in PSE and 3.4% in Red Firm Non-exudative (RFN), a condition considered to be normal, pork at the two days after slaughter. The deviation in this study from the results of Warner *et al* (1997) was most probably caused by procedural differences. The water holding capacity or drip loss analysis was only started two days after slaughtering compared to starting on the day

of slaughter as per Warner *et al* (1997). Some dripping could have occurred between slaughtering and the time when the analysis begin.

The differences in drip loss between PSE and normal groups were not as pronounced as that of the findings of Pérez, Palacio, Santolaria, Aceña, Chacón, Gascónd, Calvo, Zaragoza, Beltran & García-Belenguer (2002). According to Àngels Oliver, Gobantes, Arnau, Elvira, Riu, Grèbol & Monfort (2001), the loss of fluid is a consequence of the loss of membrane integrity and the merging of extracellular fluid and intracellular fluid but Brewer *et al* (2001) and Lindahl *et al* (2001) suggested that lowered pH may not always denature protein but sometime merely reduce the myofibril spacing due to the reaching of isoelectric points. Also, Red Soft Exudative (RSE) and Red, Firm Non-exudative (RFN) muscles (muscles with acceptable red colour but with excessive exudation), have the same protein solubility and myosin denaturation, therefore low pH denaturation is not the only reason for reduction of water holding capacity (van Laack *et al,* 1994). Irving *et al* (1990) according to van Laack *et al* (1994), found that the cause of RSE muscles' low water binding capacity was not denaturation due to rapid pH drop but rather an effect of low $pH_{ultimate}$ and it may explain the lower differences in water holding capacity when the carcasses were classified merely on pH_{38min}.

There was no significant difference in % brine uptake between the PSE and normal groups. These results seem to contradict results of Fisher, Mellett & Hoffman (2000b). They found that NN pork had 15.2 % brine gain while nn pork only had 8.9% brine gain. On the other hand, Swan & Boles (2002) did not find differences in brine retention between cured beef made from carcasses with pH_{18h} of ranging between 5.3 and 5.5 and $pH_{18h} \geq 6$.

The lack of a significant difference in brine uptake between PSE and normal groups could also be caused by the increase in functional properties due to the increase in ionic strength as a result of the addition of salt in brine (Torley *et al.*, 2000) although these authors found a large proportion of PSE myofibrils unable to swell due to denaturation. Furthermore, the large variation within groups could be caused by a lack of injection consistence of the brine injector.

There were no differences in mean fat content of the pork between the two fat grading groups P and O. The most probable reason is the fact that the samples were only analyzed after the cutting and trimming operations for the production of low fat bacon. Therefore it is logical that the fat contents of the samples would not reflect that of the original fat content of the unprocessed loins.

6.2 Final product analysis

As expected the bacon from the normal group had less free fluid than that of the PSE group, most probably due to the denaturation of protein in PSE meat or the combination of approaching of isoelectric point and reduced myofibril spacing leading to the subsequent lowering of water holding capacity. Furthermore, the lack of swelling in PSE protein is well known. Bendall & Wismer-Pederson (1962) found that both PSE and normal muscles had the lowest swelling at the isoelectric point and proteins of both muscle types had the same isoelectric point and the same ionic strength. However, PSE muscle protein had lower extractability and lower water retention.

The bacon had an Decrease in L and an increase in a and b values after processing compared to the values for the raw pork loin. The logical reason would be the formation of NO-myoglobin (which is darker and redder) in the product due to the presence of nitrite. Another possible explanation is the improvement of functional properties due to the increase in ionic strength hence the reduction of surface water, lowering the light scattering effect.

Coinciding with the results for the raw pork, there were still no differences in the b values between the PSE and normal groups, nor was there a relation between b_{pork} or b_{bacon} suggesting that b value is a poor indicator for the selection of pork with the intention to process cured products.

Interestingly, L_{pork} correlated better with a_{bacon} than L_{bacon}. One of the most important factors in the colour of meat is the reflectance which in turn largely depend on the free water content and one can speculate that water holding capacity is important and is related to L_{pork}. It is therefore possible for the loose water to cause more light scattering and since any loose water is held inside the package, there will always be a layer of water on the bacon surface which may mask the colour of the bacon. Several authors (Van Laack *et al.*, 1994; Young, Priolo, Simmons &.West, 1999; *Jeremiah et al.*, 1999) claimed that colour and water holding capacity were poorly related and colour and water holding capacity are dependent on different pre rigor events (van Laack *et al.*, 1994). Seeing that the ***L*** value is only a poor guide for water holding capacity and that the lightness/darkness of the bacon is dependent on the water holding capacity, it is very possible for the L_{pork} and L_{bacon} value to be unrelated to each other. On the other hand, if L_{pork} is related to the state of muscle protein including myoglobin, then it is quite possible for L_{pork} to be related to a_{bacon} as it is dependent on the state of protein. Goldspink & McLoughlin (1964) stated that precipitated protein can mask the red colour of the myoglobin and denaturated myoglobin may not react well with nitrite anyway. One last explanation would be the effect of nitrite. Fisher *et al.* (2000b) failed to find differences in ***L a b*** values of bacon made from NN, Nn and nn pigs and stated that the effect of nitrite in brine could overshadow the differences in pork quality.

It seemed that the sensory panel could only pick up the differences in bacon redness made from PSE and normal pork but not wateriness and evenness of colour distribution. As discussed before, bacon made from normal pork should be darker, redder and with less free water. Jeremiah *et al.* (1999) stated that that the perception of a sensory panel is mostly related to ***a*** value which seem to agree with the results of this research. Furthermore, the packaging material and free fluid may mask any other differences in the bacon which the panel could have picked up. As far as wateriness is concerned, it is possible that the panel could not pick up the difference between the free fluid in the two groups as the difference was less than 2 % of the total product mass. The package could also interfere with human perception.

The panel could only pick up the differences in the degrees of marbling between groups classified by fat grading based on measurement of back fat. The fat thickness had no effect on intra muscular fat. This is understandable, as the back fat has been trimmed especially for the processing of low fat bacon.

As for marbling, it is interesting that the sensory panel perceived the bacon made from leaner back fat grading to have more marbling which was totally contrary to what was expected. According to Fernandez *et al* (1999), it is also possible that the back fat present on the bacon affected the perception of marbling as they found that the panel ignored the intra muscular fat if the back fat is present on the pork muscle.

7 Conclusions and recommendations

The classification of normal and PSE carcasses by pH_{38min}, in general, results in low fat bacon made from the PSE group to have a lighter (higher ***L***) and less red (higher ***a***) colour but no difference in yellowness (***b***). It is, however, worth noting that there can be normal samples with light colour values close to that of the PSE samples and *vice versa*. Light coloured normal carcasses can be a potential sensory problem if early pH measurement is not used in conjunction with colour measurement.

The classification of normal and PSE carcasses by pH_{38min} results in the low fat bacon made from normal carcasses to have a more red appearance to a sensory panel but has no effect on the evenness of colour distribution, wateriness, thickness of the fat layer nor the presence of marbling. It is worth noting that although there is no difference in wateriness as perceived by a sensory panel, the drip loss and increased free fluid % can mean that there is a product weight loss and subsequently, lowering of yield.

The thicker back fat measurement (O grade) compared to P grade has no effect on colour (***L a b*** values) but is positively related to the perception of redness on low fat bacon by a sensory panel. Interestingly, the back fat thickness is negatively related to marbling scores. The back fat thickness, when trimmed to a uniform thickness had no effect on any other sensory attribute.

PSE carcasses results in lower water holding capacity in raw pork loins and more free fluid inside low fat bacon packages but for reasons not determined, there is no differences in % brine uptake between PSE and normal groups during processing.

The ***L a b*** colour values can be useful when used in conjunction with pH_{38min} but is a poor quality indicator for suitability for processing on its own. The use of pH_{38min} as criteria to chose suitable carcasses can improve the appearance of the final product in terms of redness and reduce weight losses during processing. The use of pork with $pH_{38min} > 5.9$ is recommended for bacon processing. On the other hand, the elimination of PSE pork can be an extremely costly practice therefore the normal and PSE pork should be separated and the use of processing adjuncts such as phosphate

when processing PSE meat should be considered. It is recommended that one measures the differences in the use of pH_{38} and pH_{45} as early pork quality indicators in further studies and allocates to pH measrement in the processing line accordingly.

For as long as the loins are properly trimmed, there should not be a problem using either grades P and O carcasses as far as sensory qualities are concerned. From an economic point of view, the exclusive use of grade P carcasses can reduce the weight loss due to trimming and is recommended as less fat needs to be trimmed. It is also recommended that the differences in actual losses in weight between the two groups to be measured.

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