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Sensory Quality of Pork

Influences of Rearing System, Feed, Genotype, and Sex

BY

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ABSTRACT

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Hampshire crosses of different genotype and sex were used to investigate the effects of rearing system, feed and handling on sensory quality, consumer preference and cooking loss. A selected and trained panel carried out descriptive tests. Two preference tests were carried out by, in each case, 200 consumers.

The genotype had a major effect on sensory quality in all four studies irrespective of rearing system, feed and sex. In three of the four studies pork from RN^{-} carriers scored higher for juiciness, tenderness, acidulous taste and meat taste intensity.

Sex showed contradictory effects on sensory quality, while rearing system and feed had minor effects on sensory properties of pork.

Hams (*M. biceps femoris*) from pigs reared outdoors scored lower for juiciness and acidulous taste than hams from pigs reared indoors. Loins from pigs organically reared (KRAV) scored lower for juiciness and higher for crumbliness than ones from pigs conventionally reared.

Loins (*M. longissimus dorsi*) aged four days from conventionally fed pigs were juicier than ones from silage-fed pigs. When loins were aged eight days there was no difference in juiciness, while acidulous taste became weaker and tenderness and meat taste intensity increased.

In the case of loins stored frozen one year, those from silage-fed pigs scored higher for acidulous taste and off-flavour than those from conventionally fed pigs.
Cooking, thawing and total loss data showed minor and contradictory differences between genotypes, sexes, rearing systems and feeding regimes.

Organically and conventionally produced loins were equally liked and loins from RN^{-}-carrier pigs were preferred to loins from non-carriers.

Key words: Sensory analysis, rearing system, genotype, sex, feed, pig, food quality, taste, muscle.

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ORIGINAL PUBLICATIONS

The present thesis is based on the papers listed below, referred to by their Roman numerals. Some additional unpublished results are also included.

I **Effects of red clover silage and ageing time on sensory characteristics and cooking losses of loin *(M. longissimus dorsi)* from Hampshire crosses with and without the RN^{-} allele.**
Johansson, L., Lundström, K., Jonsäll, A. & Lundh, T. *Food Quality and Preference* 10 (1999) 299-303.

II **Effects of red clover silage and RN genotype on sensory quality of prolonged frozen stored pork *(M. longissimus dorsi).***
Jonsäll, A., Johansson, L. & Lundström, K. *Food Quality and Preference* 11 (2000) 371-376.

III **Sensory quality and cooking loss of ham muscle *(M. biceps femoris)* from pigs reared indoors and outdoors.**
Jonsäll, A., Johansson, L. & Lundström, K. *In press, Meat Science*.

IV **Rearing system less important than genotype for sensory quality of loin muscle**
Jonsäll, A., Johansson, L. Lundström, K. H Andersson, A. K Nilsen & Risvik E. *Submitted for publication in Food Quality and Preference.*

SAMMANFATTNING

Kött från Hampshirekorsningar av olika genotyp och kön användes för att undersöka effekterna av olika uppfödningssystem, foder och hantering (mörning, fryslagring och tillagning) på den sensoriska kvaliteten, konsumenters preferens och tillagningssvinn. Undersökningsmaterialet var kotlettrad från gris i tre studier och skinka i en av studierna. Samtliga sensoriska analyser genomfördes som beskrivande test (profilbedömning) av en utvald och tränad extern panel. Två preferenstest genomfördes av 200 konsumenter i varje test vid en stormarknad utanför Uppsala. Det ena preferenstestet undersökte preferens för griskött av olika genotyp (RN^{-}/rn^{+} och rn^{+}/rn^{+}) och det andra KRAV-producerat kontra konventionellt producerat griskött.

RN genotypen hade stor effekt på den sensoriska kvaliteten oavsett uppfödningssystem, fodersammansättning och kön. I tre av de fyra undersökningarna var köttet från grisar av RN genotyp saftigare, mörare, syrligare och hade mer köttsmak.

Det var liten sensorisk skillnad på kött från kastrater och sogrisar.

Skinka (*M. biceps femoris*) från utegrisar var mindre saftig och syrlig än skinka från innegrisar. Kotlettrad från KRAV-grisar var mindre saftig och smuligare i konsistensen.

Kotlettrad (*M. longissimus dorsi*) som mörats fyra dagar från konventionellt utfodrade grisar var saftigare än kotlettrad från grisar som utfodrats med en fodertillsatts av rödklöverensilage. När mörningstiden ökades från fyra till åtta dagar, blev köttet mindre syrligt men mörare med kraftigare köttsmak.

Kött, fryslagrat ett år, från grisar som fått rödklöverensilage blev syrligare och fick avvikande smak.

Tillagnings-, tinings- och totalsvinn påverkades i liten grad av genotyp, kön, uppfödningssystem och foder.

De flesta konsumenterna föredrog kött av RN genotyp, men det fanns ingen signifikant skillnad i preferens mellan KRAV-producerat och konventionellt producerat griskött.

CONTENTS

INTRODUCTION

The consumer has become more concerned about the origin of meat and the circumstances under which meat is produced both when it comes to effects on the environment and when it comes to the ethical aspects of animal welfare. How animals are reared and treated until slaughter is part of animal welfare, and the interest in animal welfare has led to discussions of how ethical today's animal rearing systems are in respect to animals' natural behaviour and needs. Today there are several rearing systems with organic profiles aiming to produce meat of high quality in an environmentally sustainable way, and among Swedish consumers a large section call for organically produced meat. A consequence of the great demand for organically produced meat is that the producers are not yet able to produce large enough quantities.

The consumer demands could also be based on several other factors such as an actual perception of food from a sensory point of view, the consumer's physiological state, short-term food habits and long-term food culture (Köster, 1996). An early Swedish study (Holm and Drake, 1989) indicated that price and taste were the main concerns when it came to the consumers' choice of meat, and a Swedish report (SOU 1994:112) showed that the consumers' requirement regarding beef was firstly freshness and secondly good flavour. A recent study about consumer preferences showed that taste is the most important quality criterion for the consumer (Magnusson et al., 2000).

Consumer preference, however, can be influenced by both sensory qualities and information on how a food product is produced. Both sensory properties and information on growing system affected the consumer preference regarding tomatoes and the preference increased when the consumers were informed that the tomatoes were organically produced (Johansson et al., 1999).

With a change in production conditions such as the rearing system for pigs, the meat quality might be affected. The term meat quality probably does not have the same meaning for a producer as it has for a consumer not involved in food production. Meat quality can be defined in many ways, Jul and Zéuthen (1981) define it for instance as "the total degree of satisfaction that a meat gives consumers". The prime goal of the meat producers should therefore be to satisfy the consumer.

Meat quality extends over chemical, nutritional, technological and sensory parameters which can be affected both by several internal and external factors (Figure 1). Among the internal factors are counted e.g. genotype and sex. Among the external factors are counted e.g. rearing system, feed, and handling of the meat such as ageing, frozen storage and cooking.

Sensory properties are closely related to the internal factors of genotype and sex and could be affected by external factors. The effects on sensory characteristics of pork could be subjected to sensory analysis as regards colour, texture (e.g. juiciness and tenderness) and flavour (meat taste intensity, acidulous taste).

As regards meat quality, Risvik (1994) stated that the main sensory descriptors for the perception of whole meat in relation to preferences are tenderness, juiciness and absence of off-flavour.

The per capita consumption of meat in Sweden was 72.3 kg in 1998, and most of it was pork (SJV, 1999). Pork consumption increased rapidly during the 90s up to 1999 when the consumption of pork was 35.9 kg per person and year (SJV, 1999). The market for organically produced pork has since 1993 increased steadily and the demand for more organically producers has increased. Today's consumption of organic produced pork is about 0.5-0.6% of the total pork consumption, which is about 200 g per person and year (Ekokött, 2000).

In a large Swedish interdisciplinary research programme called FOOD 21 (FOOD 21, 2000) the aim is to find interdisciplinary solutions for a more sustainable food production without negative food quality changes for the consumer.

This thesis is a part of FOOD 21, concentrating on the sensory quality of pork produced in different rearing systems. Organic rearing systems aim at a sustainable food production (Gustafsson-Fahlbeck, 1998); and when there is a change in production conditions such as the rearing systems for pigs, the meat quality might be affected and therefore it is important to investigate the production at certain key-points to ascertain on the one hand if organically produced pork has a different sensory profile than conventionally produced, and on the other hand if such a difference established by a selected sensory trained panel will be of importance to the consumer.

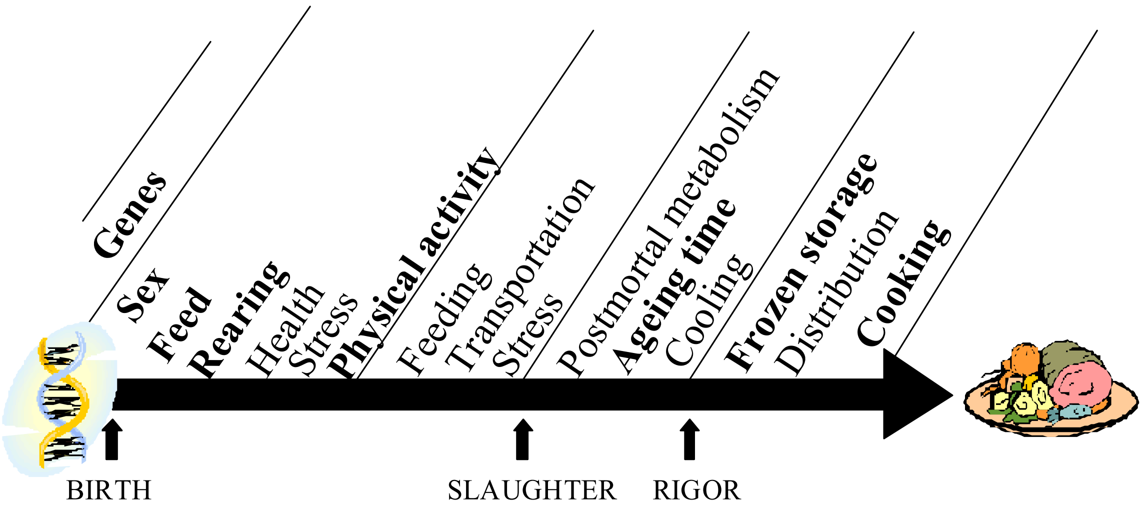

Figure 1. *Parameters affecting meat quality with special emphasis on variables (bold) investigated in this thesis.*
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Sensory Analysis

Application

Sensory evaluation has been defined as "a scientific method used to evoke, measure, analyse, and interpret those responses to products as perceived through the sense of sight, smell, touch, taste and hearing" (Stone and Sidel, 1993).

Sensory analysis is a useful tool when evaluating the eating quality of foods and is nowadays frequently used both within the food industry and research. Sensory analysis can be used in quality control (of e.g. raw material, process and product), product development (copying competing products, product improvement) and shelf life evaluation (Sensorisk Studiegruppe, 1997). The methodology offers a broad variety of tests and the type of test to be used depends on what type of information is expected. There are international standards concerning sensory analysis which constitute general guidelines (ISO, 6658, 1985), and more detailed guidelines for different test procedures (ISO for each test below). The test methods can be divided into *discrimination* tests and *descriptive* tests which are analytical, and *affective* tests which are hedonic (Figure 2).

The discrimination tests encompass e.g. triangular (ISO, 4120, 1983), duo-trio (ISO, 10399, 1991), paired comparison (ISO, 5495, 1983) and ranking (ISO, 8587, 1988) tests (Figure 2). Each one of them answers the question "Is there a difference between samples?" The pair comparison and the ranking test can also answer the question whether there is a difference between samples as regards a specific attribute. In these tests two or more samples can be evaluated at the same time. They are easy and relatively cheap to perform and evaluate but their outcome is limited. The panel should constitute 5 to 20 members. The sensory data are tested by a hypothesis test (ISO, 6658, 1985). These tests are useful in pilot studies, when the food industry wants to check whether a new ingredient or new process makes a significant sensory difference to the product.

The descriptive tests encompass profile methods, quantitative-descriptive analysis and free-choice profiling (Figure 2). They describe not only the differences between several samples but also the degree of difference for each attribute constituting the profile. Several samples can be evaluated and replicated during the same session. The descriptive panel consists of a minimum of 5 selected and trained members, ("in the section Material and Method, External panel recruitment"), which can be recruited internally within the establishment or externally (ISO 8586-1, 1993).

The requirements regarding test room and equipment for descriptive analysis are described in ISO, 8598 (1988).

Descriptive tests have been the most frequently used method in this thesis. An essential part of descriptive analysis is the training of the panel (ISO 8586-1, 1993). How this is carried out is seldom discussed in detail in scientific publications using sensory analysis as a method. Examples of how the descriptive panel training can be performed are presented in the section on "Material and Method, Sensory assessments".

The sensory data from the descriptive tests can be statistically analysed by different advanced methods. For example analysis of variance performed in SAS (1995) using procedures MIXED and GLM and Principal Component Analysis (PCA; Unscrambler, 1986-1999) to study effects of different factors (Studies I-IV), and PanelCheck (1998) to evaluate the performance of the panel (Study IV).

The affective tests, often called consumer or preference tests describe the consumers' subjective liking for a product. The recommended number of consumers is at least thirty, but if possible one, two hundred or more (ISO 5495: 1983), depending on how many subgroups (for example gender, age) one wants to collect information from. There are different types of consumer test (Lawless and Heymann, 1999) and they sometimes include a form with qualitative questions. How the data are to be statistically analysed depends on what kind of test has been performed.

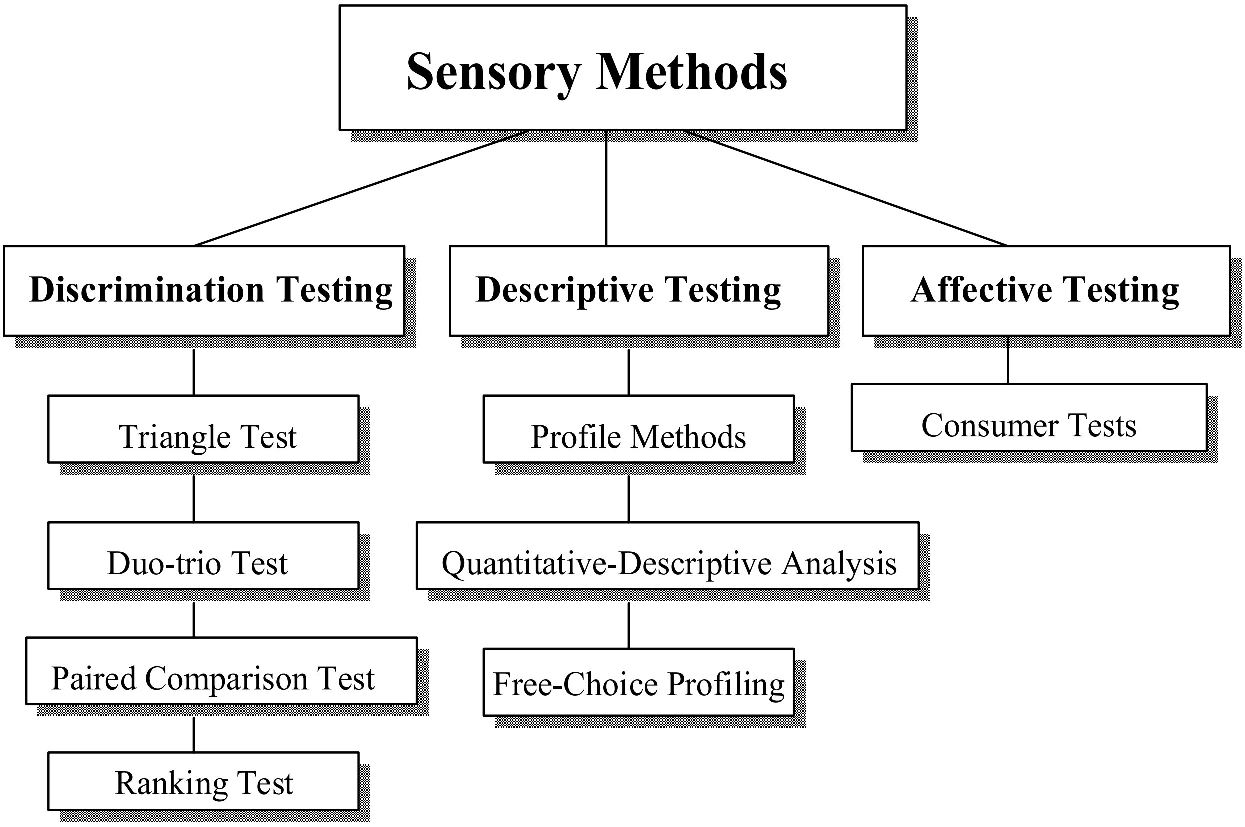

Figure 2. *Overview of sensory methods.*

Panellist performance

As a selected and trained panel is used as an instrumental tool in descriptive analysis it is necessary to evaluate the skill of each assessor on a regular basis. To control the data in sensory studies is an important task, because a panel of humans has a natural variation in the generation of data that can be influenced by the mood or motivation of each assessor. Therefore the training of the panel has to be done properly to minimise error variance and keep a high sensitivity (Lawless and Heymann, 1999). A requirement is that the relationship found between samples and for each attribute is likely to be real, and not an uncontrolled variation in the data (Lawless and Heymann, 1999). It is also a requirement that there be good reliability, in other words we want to get the same results when the test is repeated.

In this thesis panellist performance has been checked routinely in each study, firstly during the training sessions by going through each assessor's assessments for all attributes and secondly by using statistical methods to estimate the F-values, root MSE values standard range of variation.

The newly designed software "PanelCheck" (1998), described by Næs (1998), can be used to check the panel member performance. This program provides a visual summary of the results by isolating for example MSE and p-values from ANOVA and other summary statistics. These values can then be presented in different types of graphical plots. The eggshell plot (Study IV; Figure 2) shows each assessor's ability to rank the samples in relation to the consensus (mean) ranking for each attribute, the MSE plot (Study IV; Figure 4) shows each assessor's ability to repeat the assessments, and the F-value plot (Study IV; Figure 3) shows the assessor's ability to detect differences between samples.

An assessor can be excluded from the panel on the grounds that she/he cannot repeat her/his assessments and/or cannot discriminate between samples. Also during training these tests can elucidate the need for more training sessions for all panel members or specific training for an individual.

Internal Factors Affecting Pork Quality

Genotype

In the middle of the 1980´s a new pig gene was defined, the RN¯ gene (Naveau, 1986; Le Roy et al., 1990). It is a major gene and occurs frequently in the Swedish Hampshire breeds. Approximately 60% of Swedish Hampshire crosses carry this gene (I. Velander, pers. comm.). Previous studies have shown that the Hampshire pigs causes a high glycogen content in glycolytic muscles (Sayre et al., 1963; Kastenschmidt et al., 1968; Essen-Gustavsson and Fjelkner-Modig, 1985; Monin and Sellier,1985). It was later established that this was caused by the RN¯ allele (Le Roy et al., 1990; Fernandez et al., 1992). The RN¯ allele was found to have low protein content (Monin et al., 1992; Estrade et al., 1993; Enfält et al., 1997a; Johansson et al., 2000), low ultimate pH and a large cooking loss (Lundström et al., 1996). Estrade et al. (1992) found that the glycogen accumulates in the sarcoplasm of the white muscle myofibres.

The high glycogen content in glycolytic muscles affects several sensory characteristics of the loin muscle, causing the loin muscle from carriers score higher for acidulous taste (Lundström et al., 1996; Lundström et al., 1998), flavour and smell intensity (Lundström et al., 1996) and juiciness (Lundström et al., 1998) than that from non-carriers. From a sensory point of view the characteristics of fresh pork from RN¯ carriers are positive, with tender, juicy, acidulous meat with high meat taste intensity. From a technological point of view the characteristics of pork from RN¯ carriers are negative: low protein content and high cooking loss.

The name RN¯ originates from the French "Rendement Napole" which means decreased Napole yield. Napole yield is a standard method used to estimate the technological yield of the processed French type of cured-cooked ham (Naveau et al, 1985). This method proved to correlate closely with the actual yield of processed ham and also with the glycolytic potential of the muscle (Fernandez et al, 1991).

External Factors Affecting Pork Quality

Rearing

Most of the Swedish slaughter pig producers are today rearing their pigs in conventional systems, usually in large stocks with indoor rearing in pens lined with straw and relatively small areas for the pigs to move around in. The pigs are fed conventional pellet feed based on cereals with protein supplements (Study IV; Table 1).

A small number of pork producers are rearing their pigs in organic systems. Those farmers are producing their pig feed without chemical fertilisers and pesticides. The main differences between organic and conventional rearing systems are the methods used for feed production, and how outdoor-rearing is applied, health care is carried out and diseases are treated. The organic rearing system is intended to minimise the use of non-replenishable resources and to work in a recycling way on each farm and more towards a sustainable rearing system. The organic pig producer has to produce as much as possible of the pig feed on his own farm and therefore the number of animals will be limited. This results in smaller farms (Gustafsson-Fahlbeck, 1998).

Most organic producers in Sweden are organised in KRAV, a member organisation of the International Federation of Organic Agriculture Movement (IFOAM) which is a global organisation for farmers, scientists, educators and certifiers. The KRAV label is there to signal to consumers that the product has been produced by a certified farmer in accordance with KRAV´s standards (KRAV, 2000). These standards cover animal rearing (breeding, buying, labelling, documentation), animal environment (birth, outdoor rearing, pasture, indoor period and exercise area), feed (self-distribution, feed intake, process, animal feed, roughage), health and medical treatment (medicine, qualifying period and treatment). For pigs, the KRAV regulations specify among other things that sows should have a hut of their own when they are close to giving birth and that the rearing system should be integrated, implying that both sow and suckling-pigs should be in the same production unit. The animals should also be able to practise their natural behavioural pattern, including for example rooting in the mud, living in a herd and being active in food-search behaviour (KRAV, 2000).

A big difference between organic and conventional rearing of pigs is the option to stay outdoors. Warriss et al. (1983) and Barton-Gade and Blaabjerg (1989) stated that pigs reared outdoors were calmer and easier to handle. In conventional production most of the pigs are kept indoors in pens and they have no opportunity to perform their natural food-search behaviour. The type of rearing system could affect quality parameters of meat. Sather et al. (1997) for example reported that free-range pigs had heavier butts and loins, lighter bellies, and a greater yield of dissected lean meat. Also Enfält et al. (1997b) reported that outdoor-reared Hampshire crosses had leaner carcasses. Pigs reared outdoors in fields are exposed to several external factors like weather conditions such as rain and temperature fluctuations and also have other feed components available, which can influence the sensory quality of pork.

Another aspect of outdoor rearing of pigs is the health of the pigs. Lindsjö (1997) investigated 40 Swedish pig herds (22 organic and 18 conventional) reared outdoors. No difference was found between the average of the organic herds and that of the conventional herds concerning disease records at slaughter, but there was a difference in disease records between the different organic herds.

Feed

One very important part in reaching a sustainable pork production is to produce organic pig feed. If it is possible to exchange cereals for red clover silage, with high levels of unsaturated fatty acids (Johansson et al., 2000) in pig feed it could be of both environmental, nutritional and technological significance. From an environmental point of view it would be beneficial if pigs could eat grass products because humans do not consume these and less cereal products would be used for pig feed. From a nutritional point of view a high level of unsaturated fatty acids in pork meat would be beneficial for humans because the unsaturated fatty acids reduce the incidence of coronary heart disease (e.g. Grundy 1986; Kuhnlein 1991) and can thus be positively perceived by the consumer. However this change in fatty acid composition can also affect the pork technological quality, (fat being softer an thereby introducing handling problems) and sensory quality (an increased risk for off-flavour and off-odour in frozen stored pork). When fresh meat with a high level of unsaturated fatty acids is exposed to oxygen, oxidation of lipids may occur and affect the eating quality. Ahn et al. (1996) stated that vacuum packaging of meat soon after cooking prevents lipid oxidation and retain the eating quality.

To meet the need of society for safe and nutritious food in a sustainable agricultural system, alternative feed components have been tried. Several studies have focused on manipulating the diet of the pigs by including different admixtures of components with high levels of unsaturated fatty acids. In general there are increased relative levels of polyunsaturated fatty acids when pigs are administered feed admixed with highly unsaturated components such as cereal admixed with soya-, fish- or rape-seed-flour, tallow with soya-oil, sunflower-oil, canola-oil and peanuts (e.g. St. John et al., 1987; West and Myer, 1987; Morgan, 1992; Myer et al. 1992). None of these feeds had any sensory effect on loin, while Ahn et al. (1996) found a decrease in sensory preference for loin from pigs fed a high amount of α-linolenic acid (Flax seed) compared with loins from pigs fed the control diet. Rhee et al. (1990) found that an inclusion of high-oleic sunflower oil in pig feed gave a more tender and juicy loin than loin from pigs fed a control diet.

Danielsen et al.(1999) found that pigs fed a high amount (100%) of conventional feed gave a less tender meat with less acidulous taste and bite resistance than meat from pigs fed a low amount (70%) of conventional feed. Both groups had access to roughage *ad libitum*. When the lower amount of conventional feed was administered to the pigs the intake of roughage increased (Danielsen et al., 1999).

Handling

Ageing. After slaughter the muscles have limited sources of energy and oxygen, lactic acid accumulates and pH falls. When pH falls and the temperature is still high protein starts to denature. The enzymatic proteolysis increases the level of free amino acids, the decomposition of ATP (adenosine triphosphate) and IMP (5'-inosine monophoshate) increases ribose and ribose-5-phosphate, and the glycogenolysis increases glucose and fructose. These compounds are the most important aroma precursors in meat (MacLeod, 1986). Maga (1994) defined the fifth basic taste, umami, as "the taste properties resulting from the natural occurrence of compounds such as MSG (*monosodium* glutamate) and certain 5'-nucleotides such as IMP and GMP (5'-guanosine monophosphate)". These types of compounds increased in aged meat. Bauer (1983) clearly demonstrated that glutamic acid was affected by ageing the meat. He aged beef and pork 4 and 7 days and found that the longer-aged meat had significantly higher levels of glutamic acid that contributed to the meat taste. Kato and Nishimura (1986) found that ageing significantly affected the umami taste in pork.

Frozen storage. The Swedish Frozen Food Institute recommended frozen storage at −18ºC for a maximum of 6 months in the case of lean pork and a maximum of 4 months in the case of lean pork with a fat rind (Lyberg, 1975). Frozen storage of meat is a good method for preservation. Factors which influence the quality of frozen meat are freezing rate, length of frozen storage and storage conditions such as temperature, humidity and packaging materials (Hedrick et al., 1994). Several investigations have studied the influence of frozen storage and thawing on tenderness, with contradictory results. Law et al. (1967) and Smith et al. (1969) found that tenderness was unaffected by freezing, frozen storage and thawing. Jakobsson and Bengtsson (1973) and Roberts et al. (1976) found that freezing, frozen storage and thawing affected tenderness, while others found slight negative tenderisation effects (Jeremiah, 1980; Jeremiah et al., 1990).

Long-term frozen stored pork will eventually become rancid. The oxidation quality and shelf life of meat has been described in a recent review (Gray et al., 1996), who elucidated the role of lipid oxidation in pork flavour. Frozen storage of pork for a long period might lead to the development of off-flavours due to oxidation of the polyunsaturated fatty acids (Hertzman et al., 1988; St. Angelo, 1996). Arnkværn and Bronken Lien (1997) concluded that pig feed with an admixture of marine food waste affected the fatty acid composition of the pork fat in that the lean pork rapidly developed a rancid flavour during storage from 1 to 8 months at -20°C to -25°C. West and Myer (1987) indicated that there should be 2 or 4 months at -15º C at the most for frozen stored meat from pigs administered feed with different admixtures of highly unsaturated components. The effect on fatty acid composition of red clover silage admixed to conventional feed was analysed on the same pig material as in studies I and II. It was found that the relative levels of saturated fatty acids and monounsaturated fatty acids were lower, and the relative levels of polyunsaturated fatty acids and ω3-fatty acids were higher, in raw loins from silage-fed pigs than in those from pigs on conventional feed (Johansson et al., 2000).

Cooking loss. Results from sensory studies on pork are often contradictory. This can be explained by the differences in design of the different studies, that is, type of muscle used, cooking methods applied and choice of oven temperature and internal temperature. With high oven- and final core-temperature the cooking loss of meat will increase (Fjelkner-Modig, 1985; Simmons et al., 1985; Heymann et al., 1990). The oven temperature and the core temperature highly affect juiciness and tenderness of the meat by loss of water. Juiciness declined in the range of 60-80°C (Fjelkner-Modig, 1985; Simmons et al., 1985; Heymann et al., 1990; Wood et al.,1995) and tenderness declined drastically at final temperatures exceeding 68°C (Fjelkner-Modig, 1985). When 68°C is exceeded the loss of meat juice increases because of the longitudinal shortening of the perimysium and denaturation of the contractile myofilaments (Bailey, 1984) leading to an increase in fibres per unit of a cross-section and thereby making the meat tougher. Christensen et al. (2000) investigated the effect of cooking temperature on beef. They concluded that during cooking two separate phases of increasing meat toughness occur. The first phase arose between 40 and 50°C and the second between 60 and 80°C. Between 50 and 60°C they found a decrease in meat toughness, which indicated a decrease in breaking strength of the perimysial connective tissue as an effect of denaturation and shrinkage of collagen fibres. During the second phase toughness was enhanced by the strengthening of the myofibril components due to denaturation. There are, however, different opinions about what oven temperature and final temperature to use in pork. The desired final core temperature for pork differs between countries (Dransfield et al., 1984) and even between consumer age groups within a country. Older people prefer meat cooked to a higher temperature than younger people on account of the fact that older (traditional) people care more about meat taste while younger (modern) people care more about meat texture (Agerhem and Tornberg, 1993). Mottram (1992) states in his overview that raw meat has a blood-like taste with little or no aroma and that it is the volatile compounds formed during cooking that contribute to most of the flavours of meat. The meat flavour derives from several reactions during heating, such as pyrolysis of amino acids and peptides, caramelisation of carbohydrates, degradation of ribonucleotides, thiamin degradation, interaction of sugars with amino acids or peptides, and thermal degradation of lipids (Mottram, 1991). In all, 361 compounds have been identified in cooked pork (Mottram, 1992).

AIM

The aim of the project was to study the effects of rearing system, feed and handling on sensory quality, consumer preference and cooking loss of meat from Hampshire crosses of different genotype and sex.

The specific aims were:

To investigate the sensory quality, consumer preference and cooking loss of meat from Hampshire crosses of different genotype and sex in relation to:

I. Conventional rearing and feed with and without red clover silage and ageing

II. Conventional rearing and feed with and without silage and frozen storage of meat

III. Indoor and outdoor rearing with and without fresh pasture

IV. Organic rearing and feed compared with conventional rearing and feed

MATERIAL & METHODS

Thesis Design

This thesis consists of four articles. Hampshire crosses of different genotype and sex were used to investigate the effects of rearing, feed and handling on sensory quality, consumer preference and cooking loss.

Study I concerned effects of indoor (conventional) rearing, conventional feed with and without an admixture of red clover silage and ageing time; Study II, concerned effects of conventional rearing and feed with and without silage and frozen storage. Study III concerned effects of indoor versus outdoor rearing with and without access to fresh pasture. Study IV concerned effects of organic rearing and feed as compared with conventional rearing and feed (Figure 3).

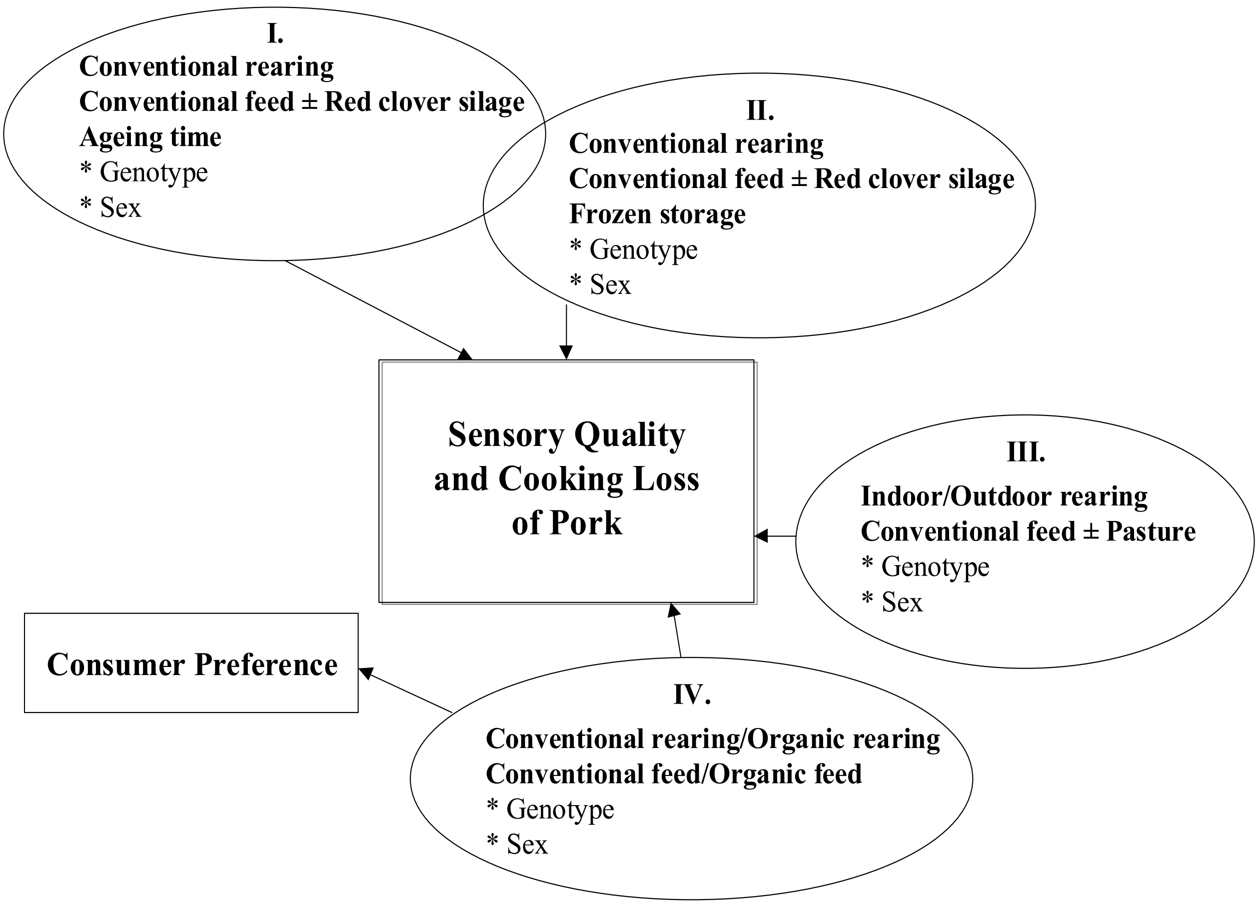

Figure 3. *Project design.*

Animals

Breed

Three-way crossbred slaughter pigs with pure-bred Hampshire breed as terminal sire and crosses between Swedish Landrace and Swedish Yorkshire dams were used in all four studies.
The animals in studies I, II and III were reared at Funbo-Lövsta Research Station and the animals in study IV were reared at Bjertorp Research Station, Swedish University of Agricultural Sciences, Uppsala, Sweden. In studies I, II and III the animals were of the same breed and the same genetic stock and the litters were split equally with regard to the different traits. In study IV the same breed was used but the pigs originated from different herds for the two traits, because of the different rearing background.

The pig material in studies I and II constituted 81 animals, 23 of which were selected for sensory analysis (Study I) and another 29 of which were selected for the sensory analysis of loins stored frozen for one year (Study II). Study III involved 120 pigs, 48 of which were selected for the sensory analysis. Study IV involved 80 animals, 40 of which were selected for the sensory analysis. An overview of the number of animals in the different studies is presented in Table 1.

Sex

The pig material in all four studies consisted of females and castrated males with and without the RN^- allele. The distribution of females and castrated males in the studies is given in Table 1.

Rearing

Indoor rearing. In studies I and II half of 9 litters were reared indoors in pens lined with straw. In study III each litter was split in two, half of them being reared indoors with 8 animals in each straw-lined pen (120 m^2). In study IV the conventionally reared pigs were indoors with 8 animals in each pen.
Outdoor rearing. In study III half of each litter was reared outdoors in a 30,000 m^2 field.
Organic rearing. The pigs in study IV were organically produced, following the KRAV regulations (KRAV, 1998) and were kept outdoors in a 6,000m^2 large grass field. The field had trees in one corner and a small brook flowed through it. The animals had access to two huts lined with straw. An overview of the different rearing systems and feeds used in the studies is shown in Table 1.

Table 1. *Distribution of females and castrated males and slaughter weight (mean weight, kg) of the pigs in the studies*

Study	Slaughter weight kg	Number of animals	Sex		Rearing	Feed	Sensory methods		Cooking loss
			Females	Castrated males			Descriptive test	Consumer test	
I	108	23	13	10	Indoors in pen (120 m^2)	a) Conventional feed+red clover silage b) Conventional feed	X		X
II	108	29	13	16	Indoors in pen (120 m^2)	As in study 1	X		X
III	102	48	24	24	a) Outdoor in a field, (30,000 m2) b) Indoors in pen (120 m^2)	a) Conventional feed+pasture of peas, oats and barley b) Conventional feed	X		X
IV	107	40	23	17	a) Indoors in pen (120 m^2) b) Outdoors according to KRAV's regulations	a) Feed according to KRAV's regulations b) Conventional feed	X	X	X

Feed

In studies I and II half of 9 litters were fed conventional feed during the entire rearing period and the other half were fed a conventional feed admixed with red clover silage (Table 1) until they reached a weight of 108 kg. In study III pigs reared both indoors and outdoors were fed conventional slaughter pig feed mixture administered *ad libitum* until they reached a weight of 60 kg and thereafter a restricted diet of 2.75 kg per pig and day. The outdoor pigs had continuous access to fresh pasture in a field sown in so-called “strip grazing fashion” with growing peas, barley and oats. At regular intervals the outdoor group was moved to a new section of the field and thereby given access to fresh pasture. The organic feed in study IV was composed according to KRAV regulations (KRAV, 2000; Table 1) and all pigs were fed restrictedly in accordance with the standard feeding regimen for growing pigs in Sweden (Andersson, 1985).

Slaughter, cut of meat and ageing

The slaughter procedure was the same in all four studies: the animals were transported 5-10 km to a commercial slaughterhouse, laired for approximately 2h, stunned with CO_2 and exsanguinated. The mean slaughter weights of the animals in the studies are presented in Table 1. After slaughter the carcasses were chilled in a blastchill and thereafter transferred to a cooler room. After 24h, cutting of the carcasses took place.

The selection of samples was based on genotype, sex and rearing, this in order to get as balanced an experimental design as possible. In studies I, II and IV the loin muscle (*M. longissimus dorsi),* was used as material and in study III the ham muscle (*M. biceps femoris)*.

The loin samples for the sensory analyses were cut out from the *M. longissimus dorsi* 20 cm anterior to the last rib. The meat samples used in the sensory analyses were vacuum-packed, aged and thereafter stored at –20°C. The ageing time was calculated from day of slaughter. In study I both sides of the loin muscle were used for ageing of the meat, four days (right side of the loin) and eight days (left side of the loin). In the other studies the meat was aged four days.

RN genotype Determination

The carcasses were classified as carriers or non-carriers of the RN¯ allele depending on the amount of residual glycogen (including glucose and glucose-6-phosphate) in the post-mortem muscle. The threshold was chosen after the bimodal distribution (Figure 4) using the value between the bimodal peaks in each animal material, which varied from 35 to 40 µmol/g-wet weight. Animals with a higher amount of glycogen were classified as RN¯ carriers and the others as non-carriers.

As a first test at the slaughterhouse a "rapid prediction method" was used to select an even distribution of RN¯ carriers and non-carriers for the relevant study. In the " rapid prediction method" meat juice instead of muscle tissue was used for a quick answer about the genotype of the pigs (Lundström and Enfält, 1997). This method was not used when the pigs were selected for studies I and II.

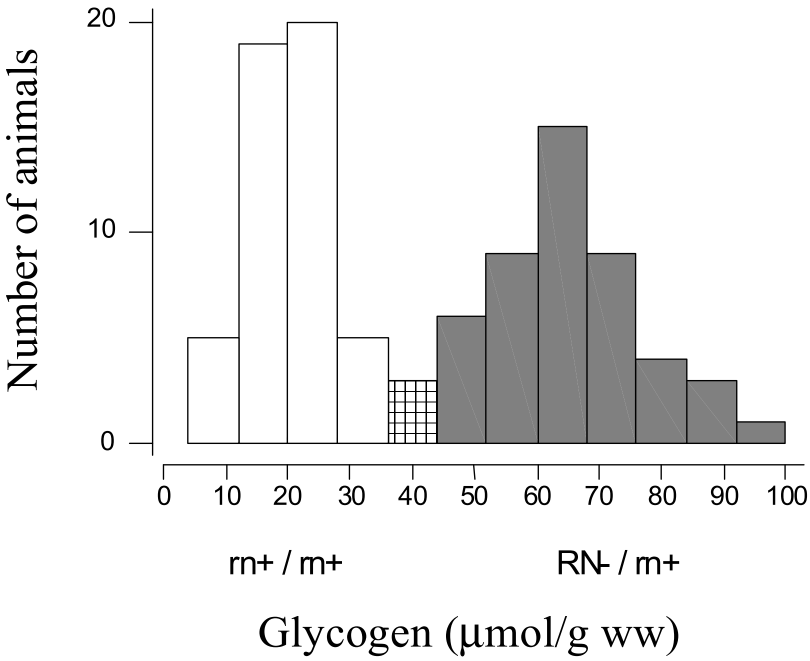

Figure 4. *Example of a bimodal distribution of glycogen (including glucose and glucose-6-phosphate) in M. longissimus dorsi of Hampshire crosses (V. Nilzén pers. comm.).*

Sensory Analysis

Sample preparation

Thawing. The vacuum-packed meat was thawed in the vacuum bag in a chill (+2 C) for about 14 hours and then the meat and exuded meat juice (thawing loss) were weighed and the thawing loss calculated for each loin or ham. The sections of loin used for the sensory analysis (Studies I, II and IV) are shown in Figure 5. The cuts of meat were trimmed and tendons and fat removed.

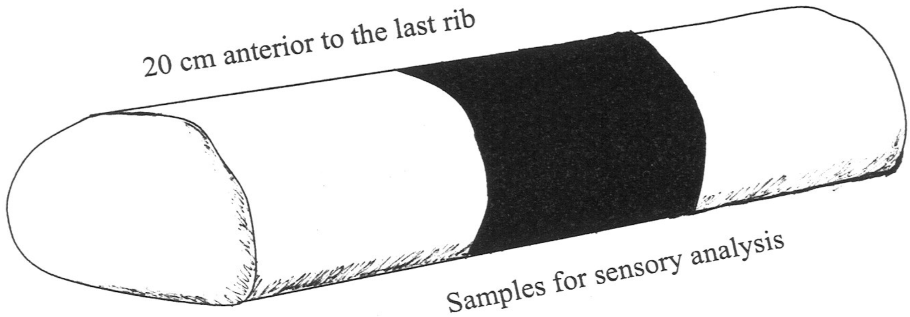

Figure 5. *Section of the M. longissimus dorsi used for the sensory evaluation.*

Oven temperature. The loins and hams were prepared in one piece in an uncovered stainless steel dish in a conventional oven at 150°C. A thermocouple (Pentronic AB, Gunnebobruk, Sweden) was inserted in the centre of each piece of meat to register the core temperature.
Core temperature. The core temperature was not allowed to exceed 68° and therefore the meat was removed from the oven at approximately 65 to 66.5°C to avoid post-heating rise.
Cooking loss. Before and after cooking the weight of the loins and hams and the liquid loss were measured in order to calculate the cooking loss. Together thawing and cooking loss made up total loss.
Serving temperature. After cooking, the meat was left to rest for 15 minutes in a cooling cupboard (Electrolux, 0 °C) to facilitate slicing, whereafter the ends of the meat samples were discarded (30 mm) and then divided into slices of 3mm with a cutting-machine (Electrolux 50, 220-24, kW 0.2).

In studies I and II two half-slices with a thin fat layer were placed in three-digit coded petri dishes. The samples were placed in a cupboard at 60°C for 30 minutes, and were randomly served to the panel at a temperature of approximately 60°C. In studies III and IV two half-slices of meat without a fat layer were served randomly to the panel at room temperature. The assessors only tasted the centre of the slice and thus not the fat layer (Figure 6). They commented on off-flavour and off-odour on separate forms.

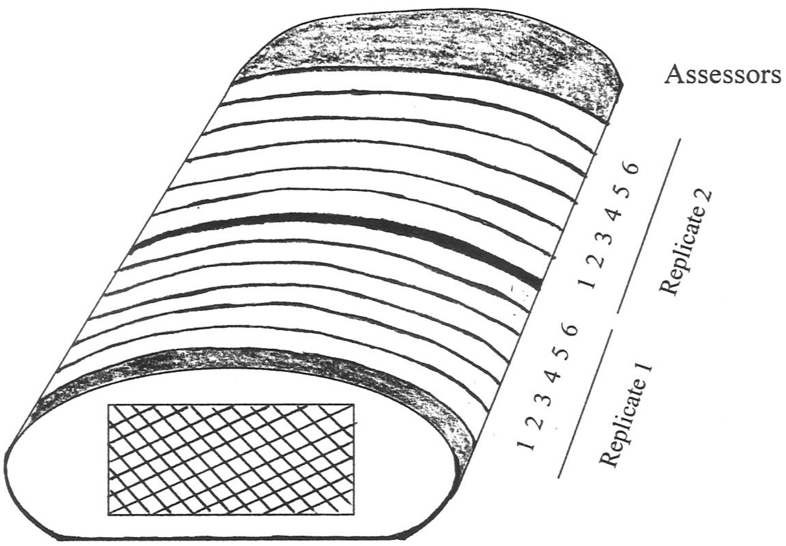

Figure 6. *The cut of pork for the sensory evaluation for each assessor.*

External panel recruitment

A sensory panel was recruited through advertising in the local newspapers and on local radio. A total of 180 candidates showed their interest in calls and in letters. They were all invited by letter to participate in screening tests; *sensitivity test* to evaluate their sensitivity to the basic tastes, *discrimination test* to evaluate their ability to discriminate between levels of stimuli, *detection test* to evaluate their ability to detect differences, *descriptive test* to evaluate their verbal skill and to evaluate their ability to reproduce their judgements, *odour descriptive test* by direct method to evaluate their ability to identify odours and *colour vision test* to detect abnormal colour vision (Ishihara's test for colour blindness, 1994, Kanchara & Co., Ltd., Tokyo, Japan). The guidelines for selecting and training of a panel in ISO, 8586-1 (1993) were used.

In the sensitivity test water solutions with four concentrations of each of the basic tastes sweet, salt, sour and bitter, and pure water were included. The same solutions were also used in the discrimination test evaluated by ranking. A triangular test on rosehip soup (a popular food in Sweden) was used for the detection test. Panel members' ability to reproduce an assessment and their ability to describe a food item was tested on orange juice. Each candidate assessed the sample using his or her own choice of attributes. Olfactory materials for the odour descriptive test included both commonly used items and less commonly used ones. All participants answered a questionnaire concerning their dietary and smoking habits, health and availability. The tests were analysed and 30 candidates were judged as being qualified to be on the list of external panel members.

Table 2. *Overview of the sensory attributes used in studies I - IV*

Attributes	Study I	III	IV	V
Odour				
Odour intensity		X		
Off-odour		X		X
Appearance				
Porosity				X
Consistency				
Juiciness	X	X	X	X
Tenderness	X	X	X	X
Crumbliness				X
Taste				
Acidulous taste	X	X	X	X
Meat taste	X		X	X
Off-flavour				X

Sensory assessments

Before each new study the qualified assessors were contacted by phone and were informed about the schedule of the sessions for sensory training and testing. They then had to decide if they were able to participate during the entire test-period. They were made to understand that it was important to participate on all occasions of training and testing. The number of assessors varied from 6 to 9 in the different studies. The time used for training varied from 8 to 12 hours. All assessors were familiar with pork meat and descriptive analysis procedures.

The sensory training started with the creation of a sensory vocabulary list, relevant to the samples. This was done in collaboration between the panel leader and the assessors. The training and the selection of the attributes were always done with direct reference to the material that was to be evaluated. Reference samples were presented to the panel. The samples had for instance different pH values, shear force values, genotypes and final core temperatures. During discussions between the panel leader all assessors agreed on the attributes to be used and expressed the conviction that they had the ability to detect, recognise and identify them. The chewing time, how to handle the sample in the mouth and the order in which the attributes should be evaluated were decided upon. At the beginning of the training sessions the assessors were trained on one attribute at a time to make them assess each attribute and make them detect small differences between samples. Thereafter the panel was trained on one attribute at a time on a continuous scale, from low to high intensity. Finally the assessors were trained to evaluate several attributes and samples at the same time on the scale using a sensory registration computer system (PSA, 1994). The attributes for each of the four sensory studies are given in Table 2 and their definitions in Table 3.

Table 3. *Definition of the sensory attributes for all four sensory studies*

Profile Attribute	Description
Odour	
Odour intensity	The intensity of total odour perceived by sniffing.
Off-odour	Associated with deterioration or transformation of the product. When a negative odour occurs.
Appearance	
Porosity	Use sight to evaluate the size and the number of pores. Use the reference pictures.
Consistency	
Juiciness	The degree of juice released while chewing the meat.
Tenderness	The force needed to masticate the meat ready for swallowing.
Crumbliness	Describes the size and shape of particles in the mouth.
Taste	
Acidulous taste	Describes a product whose taste is slightly acid, as the intensity of a positive acidulous taste.
Meat taste	A total pork taste with a balance of bitter, sweet and acidulous taste.
Off-flavour	Atypical flavour associated with deterioration or transformation of the product. Describes a negative off-flavour as in rancid meat.

Consumer preference test

Two preference tests, paired comparisons (ISO 5495, 1983), were performed, one to evaluate the preference of loins from pigs of different RN genotype and the other to evaluate the preference of either organically produced (KRAV) or conventionally produced loin. 200 consumers at a supermarket in Uppsala, Sweden, performed each preference test over a period of two days. The first test utilised loin samples selected with respect to RN genotype. The second test contained loin samples selected with respect to rearing system. The samples were prepared and sliced in the same way as described in study II. The loin slices were served in random order at room temperature in petri dishes coded with three-digit numbers. The consumers tasted the two loin slices and answered the question: “Which of these pork samples do you prefer?” The form also contained the following question: “How often do you eat pork?” and some demographic questions about age, gender and profession.

Statistical analysis

The statistical analysis on the sensory and cooking loss data was performed by the procedure MIXED in study I and by GLM (General Linear Models) in studies II-IV, in the statistical program package SAS (1995). Assessors and animals were treated as random factors and RN genotype, sex, rearing and feed as fixed factors. In study II-IV animal was nested within sex, RN genotype and rearing-system/feed.

When the interactions between the fixed factors were not significant they were ignored. In study I the interactions between sex and feed and sex and genotype, were ignored because of small numbers in some subgroups. There were no interactions between the fixed factors genotype, feed and sex for any of the sensory attributes in studies II, III and IV and therefore general conclusions could be drawn. The model used on cooking loss data included the fixed effects of RN genotype, sex and feed. Data from the two consumer tests were analysed by SAS using procedure Frequency tables and chi-square test.

In study IV a Principal Component Analysis (PCA) was conducted with the Unscrambler (1986-1999) in order to interpret the relationship between samples and sensory variables. The analysis was performed on sensory attributes with significant differences in the analysis of variance. As the scale was used in the same way for all included attributes, no scaling was performed. The analysis was validated with cross-validation. Næs (1996) have described the PCA technique.

An ANOVA (Analysis of Variance) was used in studies I, II and III to determine the assessors’ ability to differentiate between samples and their ability to replicate their assessments.

A newly designed piece of software, “PanelCheck” (1998), was used to evaluate the assessors’ performance in study IV. The use of the software has been described by Næs (1998).

RESULTS and DISCUSSION

Effects of Internal Factors on Sensory Quality

Genotype

Loins from RN^- carriers scored higher for acidulous taste and meat taste intensity and tended also to be juicier than loins from non-carriers (Table 4), while genotype had no effect on tenderness (Study I). Regarding juiciness and acidulous taste these results were confirmed in study II (Table 4). In studies II and IV the loins from RN^- carriers scored higher for tenderness. Furthermore the loins from RN^- carriers were more crumbly (Study IV). Genotype did not have any effect on off-odour and off-flavour intensity (Studies II, III) or on porosity (Study IV).

Ham from the RN^- carriers in study III had higher odour intensity, was more tender and had a higher meat taste intensity than ham from non-carriers (Table 4). There was also a tendency towards a more acidulous taste in ham from RN^- carriers than in ham from non-carriers (Table 4).

In sum, the results of these four studies clearly show that the RN^- allele causes the main difference in sensory quality of pork (*M. longissimus dorsi* and *M. biceps femoris*), making it more juicy (II, IV) and tender (II, III, IV), with a higher intensity of acidulous taste (I, II, IV) and meat taste (I, III, IV). The PCA plot showed the same result as the analysis of variance (Study IV), namely that pigs with the RN^- allele gave more juicy and tender meat with high acidulous taste and meat taste. These results are in accordance with those of previous sensory investigations, where meat from RN^- carriers had high acidulous taste (Lundström et al., 1996; Lundström et al., 1998), high meat taste intensity, strong smell intensity (Lundström et al., 1996) and high juiciness (Lundström et al., 1998). These attributes are central for the perception of meat. The sensory attributes describing whole meat are relatively few and relate mostly to texture attributes. Risvik (1996) stated that whole meat texture could be summarised in two attributes, tenderness and juiciness.

Differences in results between sensory studies can originate from differences in e.g. design of the studies (choice of breed, differences in rearing and different feed for the pigs) and handling of the meat (ageing, frozen storage, cooking).

One of the most important changes *post-mortem* is the pH fall, which seems to cause variation in meat quality (Warris and Brown, 1987; Bendall and Swatland, 1988). The sensory quality is also affected by pH. Fernandez and Tornberg (1992) found that ultimate pH and tenderness had curvilinear relationships, and Dransfield et al. (1985) found relationships between pH and toughness, flavour and juiciness. They found maximum toughness and flavour and minimum juiciness after roasting meat with about pH 5.9. Juiciness had a significant correlation with ultimate pH (DeVol et al., 1988; Cameron, 1990). The difference between RN¯ carrier meat and non-carrier meat in acidulous taste is probably mostly an effect of the high pH value in RN¯ meat. However, during the sensory training sessions more than one type of acid taste was perceived, thus it could be that different acids are involved in the perception of acidulous taste.

The high juiciness in RN¯ meat are hard to explain since a previous study (Lundström et al., 1996; Lundström et al., 1998) has shown that loins from RN¯ carriers had greater drip loss and cooking loss than non-carrier loins. One speculation about that is that the water might be transported out of the cells and being stored differently in the muscle of the two different genotypes.

The RN¯ carriers' lower protein content (Monin et al., 1992; Estrade et al., 1993; Enfält et al., 1997a; Johansson et al., 2000), can affect the sensory quality. Lundström et al. (1998) showed by chemical analysis that high protein content in *M. longissimus dorsi* had a negative effect on tenderness, juiciness, meat taste intensity and overall acceptability. Tornberg et al. (1994) found that chewing time and chewing residual were affected by the percentage of leanness, where a high percentage of leanness gave higher scores for chewing time and chewing residual, which indicated a higher toughness.

Table 4. *p-values for sensory attributes of loin (I, II, IV) and ham (III) from pigs of different genotypes (rn+/rn+ and rn+/RN¯).*

	Study			
	I	**II**	**III**	**IV**
Odour				
Odour intensity		0.984	**0.012**	
Off-odour		0.857		0.132
Texture				
Porosity			0.288	0.144
Juiciness	0.095	**0.003**	0.336	**0.001**
Tenderness		**0.017**	**0.004**	**0.001**
Crumbliness				**0.005**
Taste				
Acidulous taste	**0.001**	**0.009**	0.074	**0.027**
Meat taste	**0.006**		**0.029**	**0.001**
Off-flavour		0.929		0.096

Significant interaction (p=0.005) between feed and genotype for tenderness

Some studies on raw pork did not indicate any difference in lipid content between RN^- carrier meat and non-carrier meat (Monin et al., 1992; Lundström et al., 1998). In a study on cooked loin on the same animal material as in study I and II, no difference in IMF content was found between RN^- carrier loins and non-carrier loins. (Johansson et al., 2000) and therefore the sensory differences in cooked pork in studies I and II could probably not be explained by differences in IMF content.

Sex

In all four studies females and castrated males are used, this because they are the most common for slaughter pigs in Sweden. Intact males are castrated to avoid the unpleasant boar taint which may occur in meat from intact males.

Sex did not significantly affect the sensory characteristics of loins in studies I and II (Table 5), while loins from castrated males in study IV had a higher off-odour and were less juicy than loins from females (Table 5). There was no significant effect of sex in study IV for porosity, tenderness, crumbliness, acidulous taste, and off-flavour but there was a tendency towards a higher meat taste (Table 5). In study III ham from castrated males scored higher for juiciness and tenderness than ham from females, while there was no effect of sex on odour intensity, porosity or acidulous taste (Table 5).

In sum, the four studies showed contradictory effects of sex on sensory quality. The results of study I are in accordance with Fjelkner-Modig and Persson (1986), who found no sensory effects of sex and also with Wood et al. (1986), who found no differences in eating quality between entire males and gilts. Neither did Ellis et al. (1996) find any difference in eating quality between castrated males and gilts.

There are different opinions whether there are any differences in protein and fat content between castrated males and females. Protein and fat were analysed on the same animal material as in studies I and II (Johansson et al., 2000) and it was found that cooked loins from castrated males compared with those from females did not differ in protein or fat content. Hams from the same animal material as in study III were chemically analysed by Nilzén et al. (2000) and they found no differences in IMF content between sexes.

Table 5. *p-values for sensory attributes of loin (II, IV) and ham (III) from pigs of different sex (females and castrated males).*

	Study			
Attribute	**I**	**II**	**III**	**IV**
Odour				
Odour intensity		0.879	0.806	
Off-odour		0.341		**0.015**
Texture				
Porosity			0.856	0.308
Juiciness	0.347	0.786	**0.013**	**0.045**
Tenderness	0.113	0.833	**0.008**	0.990
Crumbliness				0.244
Taste				
Acidulous taste	0.502	0.664	0.286	0.417
Meat taste	0.549		0.089	0.192
Off-flavour		0.394		0.348

Effects of External Factors on Sensory Quality

Rearing

Hams from outdoor-reared pigs scored lower for juiciness and acidulous taste than hams from indoor-reared pigs (Study III), while there was no effect on odour intensity, porosity, tenderness or meat taste intensity (Table 6).

Pork loins from the two rearing systems, organic (KRAV) and conventional, showed that organically produced loins were less juicy and scored higher for crumbliness than conventionally produced loins, while there were no effects of rearing system concerning the attributes off-odour, porosity, tenderness, acidulous taste, meat taste, and off-taste (Study IV).

In sum, the rearing system had negative effects on the sensory properties of both hams (*M. biceps femoris*) and loins (*M. longissimus dorsi*) as regards juiciness (Study III; Fig. 1a and Study IV; Fig. 1a). Andersson et al. (1990) found no effect on loin sensory quality (tenderness, juiciness and meat taste) due to rearing. Bridi et al. (1998) did not find any major differences for odour intensity, porosity, tenderness or meat taste intensity in loins from pigs reared indoors versus outdoors. Neither did Van der Wal et al. (1993), find differences in juiciness and tenderness between loins from free-range pigs and loins from those exposed to an intensive fattening system. Our result as regards juiciness is in accord with that of Enfält et al. (1997b), who stated that outdoor rearing impaired juiciness. Petersen et al. (1997a) found that hams from male pigs reared "free" in a large pen were juicier than those from trained and untrained pigs in smaller pens. However, Enfält et al. (1997b) found also that tenderness was impaired, which was not found in our studies (III and IV*).* Enfält et al. (1997b) studied, however, neither the same crossbreed nor the same cuts as in study III. They studied loins from the crossbreed Yorkshire or Yorkshire x Landrace sows with Duroc or Yorkshire as terminal sire.

The effect of exercise on tenderness has been investigated with contradictory results. On the one hand Lewis et al. (1989) found that muscles from exercised pigs tended to be less tender than muscles from non-exercised pigs, which they explained as an effect of a high level of physical activity. On the other hand Essén-Gustavsson et al. (1988) and Van der Wal et al. (1993) found no effect of physical activity on tenderness, which is in accordance with our studies on ham (III) and loins (IV).

The results of studies III and IV showed a lower juiciness in both hams and loins from outdoor-reared pigs as compared with indoor-reared pigs (III, IV), which possibly can be explained by a higher degree of physical activity in the case of the outdoor pigs (due to larger exercise-area) than in the case of the conventionally reared-pigs.

Jensen (1996), however, stated that the effects on loins and hams from pigs reared outdoors versus indoors were greater than the effects on loins and hams from pigs reared conventionally versus organically.

Feed

Conventional feed admixed with red clover silage had no significant effect on tenderness, acidulous taste, or meat taste intensity (Study I). For the variable juiciness, however, there was a significant interaction (p=0.05) between feed and ageing time and therefore comparisons between sub-groups were performed. Loins from conventionally fed pigs aged for four days were juicier than loins from silage-fed pigs aged for four days, while there was no difference in juiciness when the meat was aged eight days (Study I; Fig. 3). When loins from the same animal material as in study I were stored frozen for one year at -20°C another sensory test was performed (Study II). The results of the test showed that loins from silage-fed pigs scored higher for acidulous taste and off-flavour than loins from pigs fed conventional feed. The other sensory characteristics of the loins in study II were not affected by the feed (Table 6). In studies III and IV the feed and rearing system were confounded and therefore the results will be discussed under "rearing system".

In sum, no major sensory effects of feed have been found in the four studies, which is in accordance with several previous studies on loins from pigs fed alternative feed with highly unsaturated components (e.g. St John et al*.,* 1987;

West and Myer, 1987; Morgan et al., 1992; Myer et al., 1992; Sheard et al., 2000). Larick et al. (1992) stated that in a triangle test with 15 experienced flavour panellists the fatty acid composition in pork had little effect on the flavour on patties from chops of pork. St. John et al. (1987) found, in a descriptive test, no difference in juiciness, flavour and tenderness due to unsaturated fat levels, which is in agreement with Sheard et al. (2000) who found no sensory difference between control and test diets with raised n-3 fatty acid levels.

The high off-flavour in loin from silage-fed pigs (Study II) was most probably caused by the high content of oxidised polyunsaturated fatty acids (PUFA) (Johansson et al., 2000). This is in agreement with Miller et al. (1990) who found that loin from pigs fed a canola oil supplemented feed had a high off-flavour.

Danielsen et al. (1999) found that loins from pigs feed a higher level of conventional feed were more tender, with less acidulous taste than loins from pigs fed a lower level of conventional feed supplemented with roughage. An unpublished study by Jonsäll et al. (2000) showed that loin from castrated males fed conventional feed scored higher for acidulous taste than loin from castrated males fed conventional feed admixed with hay.

Table 6. *p-values for comparisons between rearing systems and/or feed*

	Study			
Attribute	**I**	**II**	**III**	**IV**
Odour				
Odour intensity		0.780	0.226	
Off-odour		0.382		0.116
Texture				
Porosity			0.423	0.220
Juiciness		0.525	**0.045**	**0.001**
Tenderness		0.247	0.651	0.484
Crumbliness				0.003
Taste				
Acidulous taste	0.561	**0.035**	**0.007**	0.552
Meat taste	0.437		0.684	0.305
Off-flavour		**0.047**		0.613

Significant interaction between feed and ageing for juiciness and between feed and genotype for tenderness

within each of the studies I, II, III and IV

To admix green leaf nutrient to pig feed can cause feeding problems in that the pigs refuse to eat the unfamiliar feed. Håkansson et al. (1984) investigated the nutritive value of grass-, clover- and pea-crop meals for growing pigs, and they stated that an admix with 30% clover should not be recommended for pig feed due to the high level of estrogenic compounds. Fat from pigs fed red clover silage admixed to feed used in studies I and II was analysed for estrogenic isoflavones and coumestrol according to the methods of Lindner (1966) and Lundh et al., (1988). The analysis showed no significant levels of theses compounds and their metabolites, only trace amounts of formononetin was registered (unpublished, T. Lundh, pers. comm.).

Handling

Ageing. In study I there was an interaction between feed and ageing. Loins from silage-fed pigs aged for four days were significantly less juicy than loins from silage-fed pigs aged for eight days. Furthermore loins aged eight days were more tender ($p<0.001$), less acidulous ($p<0.05$) and more tasty ($p<0.05$) than loins aged four days. A prolongation of ageing time from four to eight days could thus be one way to reduce the acidulous taste of fresh pork of RN^- carriers and at the same time produce more tender and tasty cuts of pork. A tenderising effect of prolonged ageing time of pork has also been found after six days by Bejerholm (1991) and after eight days by Tornberg et al. (1994). Ellis et al. (1998) found an increase in juiciness and tenderness with increased ageing time (2 to 16 days). Both free amino acids and peptides contribute to the typical meat taste, which will contribute to the higher meat taste in loins aged eight days.

Seewald et al. (1993) investigated both the breakdown of adenosine triphosphate and the sensory quality in the case of three different storage times at two storage temperatures, and they found no correlation between sensory characteristics and the slight difference in the level of hypoxantine for the different samples.

Frozen storage. All loins (Studies I-III) were frozen until the sensory analyses were carried out, also the hams in study IV. Study II showed that most of the pork without a fat layer was acceptable for eating after one year of frozen storage but pork loins from silage-fed pigs scored higher for off-flavour and acidulous taste than the ones from pigs fed conventional feed.

In study II, the panel members found a large number of descriptors of off-odour, such as sharp, sticky, old smell, pig, rancid and oily. The descriptors of off-flavour were fewer and encompassed attributes such as rancid and oily. Only two, sometimes three, assessors had comments on off-flavour. However, the comments indicated that the assessors responded more to the off-odour than to the off-flavour. An explanation could be that the thin fat layer produced the off-odour and the panel only evaluated the centre of the meat slices during the sensory tests and thus avoided the thin fat layer with the off-odour. The aim of study II was not to study different lengths of shelf life but to investigate if red clover silage with a high level of unsaturation (Johansson et al., 2000) affected the sensory characteristics after such a long time of frozen storage. The off-flavour in the pork (study II) with a prolonged storage time (12 months) most likely originates from the oxidation of the polyunsaturated fatty acids in the loins from silage-fed pigs.

In previous studies the effect of a high level of vitamin E in pig feed has been investigated. The vitamin E in silage could stop the oxidation or slow down the oxidation rate through its antioxidative effects. Jensen et al. (1997) found for example a higher amount of vitamin E and a lower lipid oxidation in meat from pigs fed rape-seed oil supplemented with vitamin E as compared with meat from the control group. That effect was also shown in other investigations (Cannon et al., 1995; Cannon et al., 1996; Jensen et al.,1998). Cannon et al. (1995) also found that off-flavour intensity was lower for meat from pigs fed a vitamin E supplemented feed than meat from the control group.

Consumer Preference

RN^{-} genotype

There was a significant difference (p=0.039) in preference between loins from RN^{-} carriers and loins from non-carriers. The consumers preferred loins from RN^{-} carriers (113 persons, 57.4%) to loins from non-carriers (84 persons, 42.6%).

A preference test on cured cooked hams showed an opposite result: 22% of the consumers preferred ham from the RN^{-} carriers, while 65% of the consumers preferred the non-carrier cured ham. 13% of the consumer could not find any difference between the samples (Lundström et al., 1998). This preference test was done on a small number of consumers (n=37). The results, however, were confirmed by an unpublished study by A. Hullberg (pers. comm.), who found that the consumers preferred cured loins from non-carriers to ones from carriers. When consumer tests are performed the results are dependent on what group of people are participating in the test. The number of people the test is based on might not be great enough to have the results generalised to the Swedish population. Consumer tests are important but the descriptive test has a greater information value on the same material. Together the consumer test and descriptive test give valuable information on the one hand about consumers' likes and dislikes and on the other hand about what attributes characterise these likes and dislikes. These aspects have been described by Muñoz (1998) investigating sausages.

Rearing

There was no significant difference (p=0.429) in preference between organically produced loins and conventionally produced ones. 90 consumers (47.6%) preferred conventionally produced loins and 99 (52.4%) preferred organically produced ones. The same result was shown in the descriptive test, where only minor differences between the two rearing systems occurred. This result is in agreement with a pilot study reported by Fagerberg (1994), who did not find any difference in consumer preference between organically and conventionally produced shoulder of pork, bought in a shop. Even if the consumer did not prefer either the organically produced loin or the conventionally produced loin it can be different if relevant information has been given simultaneously. Johansson et al. (2000) found that information on growing system regarding tomatoes had an effect on consumers' preference. The knowledge about rearing conditions for pigs could change the consumers' preference.

Cooking Loss

Loins from RN^{-} carriers had a greater total loss (p=0.030) of water during thawing and cooking than ones from non-carriers (Study I). Loins aged eight days had a smaller thawing loss (p=0.007) than loins aged four days (Study I). In study III ham from RN^{-} carriers had a significantly greater cooking loss (p=0.008) than ham from non-carriers (25.6% and 22.9%, respectively). In studies II and IV no significant difference between genotypes was found regarding losses during thawing and cooking. Studies I and III show a higher loss from RN^{-} carrier meat than from non-carrier meat, while this cannot be seen in studies II and IV. Greater cooking losses from RN^{-} carrier meat than from non-carrier meat (Study IV) were found in previous studies (Lundström et al., 1996; Enfält et al., 1997a; Lundström et al., 1998).

The high glycogen level in glycolytic muscle from Hampshire pure-bred or crossbred pigs caused the low ultimate pH (Sayre et al., 1963; Kastenschmidt et al., 1968; Monin and Sellier, 1985; Essen-Gustavsson and Fjelkner-Modig, 1985). 1 g of muscle glycogen can bind 2 to 4g of water (Greenleaf et al., 1969) and protein can bind, 3.3g water/g protein (Sellier and Monin, 1994).
The reason why the RN^{-} carriers' meat loses more water during cooking than the non-carriers' meat does is that the former has low protein content and high glycogen content, which results in an abnormally high water to protein ratio (Monin et al., 1986; Barton Gade et al., 1988). Ellis et al. (1998) found a decrease in cooking loss with an increasing ageing time from 2 to 16 days.

Sex had no effect on total loss in study I and no effect on cooking loss in study II. However, ham from females had a significantly higher cooking loss (Study III) and thawing loss (Study IV) than ham from castrated males.

Jeremiah et al. (1998) found no differences in cooking properties between barrows and gilts when it came to cured and smoked pork.

The only effect of rearing system and feed on losses occurred in study I, where the silage-fed pigs tended to give rise to greater cooking ($p=0.07$) and total ($p=0.06$) losses than the conventionally fed pigs. Andersson et al. (1990) found a higher meat juice loss in meat from pigs reared outdoors than in meat from pigs reared indoors. Cannon et al. (1995) found lower storage/cooking losses for meat from pigs fed a vitamin E supplement than meat from the control group.

Methodological Aspects

Choice of meat cut and sample preparation

The "rapid prediction method" to determine RN^- carriers was not in use when the pigs were selected for studies I and II and therefore small numbers in some subgroups occurred. In study III the ham muscle was chosen instead of loin muscle on the presumption that it would be more affected by an increased level of exercise in the outdoor-reared pigs and this would have an effect on the sensory characteristics.

An essential part of sensory analysis is the preparation of the meat sample: it has to be standardised or you are not measuring what you intended to measure and the validity is nil. The sample preparation is extremely product-dependent. For some products it is easy to get good reliability, e.g. homogeneous products with a large amount available, which can be served cold, while some products are more difficult, e.g. fish. The *M. longissimus dorsi* is not homogeneous, which makes it difficult when slicing. The fibres in the meat are twisted and the IMF content and connective tissue are distributed differently along the loin. In a pilot study the cutting angle with regard to the meat fibres was shown to affect the tenderness sensation of the meat.

In studies I and II the assessors were served hot samples (60°C) and in studies III and IV the samples were served at room temperature. On the same animal material as in studies I and II (unpublished pilot study) the effect of serving temperature (samples served hot and at room temperature) on loins aged four days was evaluated and no differences for the attributes juiciness, acidulous taste and tenderness could be found, while intensity of meat taste was higher in hot samples. To handle samples for the assessors hot is more complicated since the holding time must be the same through each and all sessions and there is also a risk of warmed-over flavour. Serving the samples at room temperature means that the meat can be prepared the day before the assessments take place and the slicing is easier to carry out. Furthermore the samples had to be served at room temperature in the preference test. This made them easier to handle. Thawing loss could not be calculated in study III because the original meat cut was not weighed.

Selection and training of a descriptive panel

The choice to recruit an external instead of an internal panel was based on the fact that it is advantageous to select the best candidates for assessors from a large group (ISO 8586-1, 1993) and the candidates should be available and willing to participate during long periods. The best thing would have been if the panel members had been the same in all four studies, but this was not the case. Since the aims of the different studies were not the same, the selection of the profile attributes had to vary.

The training of the panel is the most important way of calibrating the panel. Several investigations have studied the value of training time. Bennet et al. (1956) saw during a three-week training period on beef that the consistency of performance was improved by training time, while Wolters and Allchurch (1994), did not find any positive relationship between training time and panel performance, though they stated that the numbers of attributes and the agreement among assessors increase with training time. The training can be done in many different ways, the result dependent on the creativity of the panel leader, the ability of the assessor to respond and the complexity of the product. It is necessary to find the right means of training the panel and find references that will help the panel - a bad reference can destroy more than it helps, e.g. if samples for training purposes are not equivalent to the test samples. The panel will be misled if the reference samples are too different from the samples to be evaluated. There must also be enough material for training purposes: it is valuable to give the assessors a broad sensory spectrum within the sample batch. In these studies, pork from the same material was always used for training, e.g. cooked to different temperatures, with different pH and tenderness to illustrate meat taste intensity, acidulous taste and juiciness and tenderness.

No attributes regarding warmed over flavour (WOF) was suggested by the panel during the training sessions in studies I and II where hot samples were used. The numbers and types of attributes in the different studies vary with the different aims and designs (Table 3). The number of attributes to be used in sensory evaluation can vary depending on the product and on the praxis at the sensory laboratory. Horsfield and Tylor (1976) found that the descriptive attributes for meat could be reduced to three independent components, toughness, succulence and flavour, and they also found that these three components could predict the acceptability of the product.

The scales were all continuous line scales without any reference points and the training was performed equally in all studies, so the difference in the length of the scale should not influence the sensory results.

The number of assessors in a descriptive panel is often discussed. Cook and Homer (1996) suggest that more than about six assessors means only minor additional accuracy for most panels.

Some studies mix descriptive attributes with consumer related attributes like overall liking and palability, which can be risky because it is not the same being an ordinary consumer and being a selected and trained assessor on a descriptive panel. In the descriptive panel the assessor should act like an analytic instrument with no subjective thinking at all, while the consumer only answer subjectively what he/she likes or not. Shepherd et al. (1988) have studied this phenomena by looking at the relationship between consumer preference and trained panel responses, and have demonstrated that it is inappropriate to use trained panellist to provide measures of preference or acceptance.

CONCLUSIONS

Genotype had a major effect on sensory quality, where pork from RN^- carriers scored higher for juiciness, tenderness, acidulous taste and meat taste intensity.

Sex showed contradictory results with regard to effect on sensory quality.

Rearing system and feed had minor effects on sensory properties of pork loins, where hams (*M. biceps femoris*) from pigs reared outdoors scored lower for juiciness and acidulous taste than hams from pigs reared indoors. Loins from pigs organically produced (KRAV) compared with loins from pigs conventionally produced scored lower for juiciness and higher for crumbliness.

A prolongation in ageing time from four days to eight days caused the acidulous taste of pork become weaker and the tenderness and meat taste intensity to increase.

In the case of loins stored frozen one year, those from silage-fed pigs scored higher for acidulous taste and off-flavour than those from conventionally fed pigs.

Organically and conventionally produced loins were equally liked, while loins from RN^- carriers were preferred to loins from non-carriers.

Cooking, thawing and total loss data showed minor differences between genotypes, sexes, rearing systems and feeding regimes.

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