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The Effect of Cooking Conditions on the Eating Quality of Pork

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ABSTRACT

Two experiments were conducted to examine the effects of cooking parameters, including final internal temperature (65, 72·5 or 80°C), *on the eating quality of pork. Assessments were made by a* 10*-member trained taste panel. In Experiment* 1 *on loin steaks* (m. longissimus) *from* 28 *carcasses weighing* 66 ± 1·9 (SD) kg, *increasing the final internal temperature from* 65 *to* 80°C *had the following effects on mean scores* (1–8): *tenderness* –1·0; *juiciness* –1·5, *pork flavour* +0·6 *and abnormal flavour* –0·5. *The medium temperature of* 72·5°C *was suggested as ideal. In Experiment* 2 *on leg roasts* (m. gluteobiceps) *from* 96 *carcasses weighing* 65 + 2·7 *(SD) kg, increasing the final internal temperature from* 65 *to* 80°C *had the following effects on mean scores* (1–8): *tenderness* –0·2 *(not significant), juiciness* –0·6, *pork flavour* +0·3 *and abnormal flavour* –0·5. *The effects of final internal temperature were therefore smaller in roasts and temperatures towards the upper end of the range would be recommended for ideal eating quality, balancing small losses in tenderness and juiciness against gains in flavour scores. Although the experiments were not designed to examine source and sex effects there was evidence that tenderness can be improved through the use of Duroc genes and pelvic suspension of carcasses and no evidence of differences in eating quality between entire males and females.*

INTRODUCTION

The tenderness, juiciness and flavour of pork, which together constitute 'eating quality', are an important part of the consumers' overall judgement of quality.

They can be influenced by several factors in production (e.g. breed and feeding system) and processing (e.g. chilling rate and conditioning time) and, by combining these in optimal ways ('Blueprints'), measurable improvements in eating quality can be made (Warkup, 1993). Such approaches are particularly important considering the strong current demand for very lean pork which tends to have lower eating quality than the fatter product (Wood *et al.*, 1986).

Eating quality characteristics are also affected by cooking conditions such as the final internal temperature to which the meat is cooked. Experiments with pork have shown that juiciness is most affected, declining as the final temperature is increased in the range 60–80°C (Fjelkner–Modig, 1985; Simmons *et al.*, 1985; Heymann *et al.*, 1990). Tenderness is also reduced but the effects on flavour are less clear, some studies showing an increase in pork flavour and a reduction in abnormal flavour with increasing temperature (Heymann *et al.*, 1990) and others showing only small effects on flavour (Fjelkner-Modig, 1985; Simmons *et al.*, 1985). Some of these discrepancies could be due to the use of different cuts, cooking methods and levels of fatness, the latter often being greatly different from the current UK norm.

Evidence that cooking temperatures in the UK are higher than in most other EU countries (Dransfield *et al.*, 1984) suggests that there is scope to improve eating quality by offering better cooking advice to consumers. A study was therefore conducted with lean British pork using the two most popular cooking methods (grilling and roasting) to assess the effects on all three components of eating quality and to suggest optimum cooking parameters.

MATERIALS AND METHODS

Experiment 1

The experiment used 28 pigs weighing 66·2 ± 1·90 (SD) kg with P_2 fat thickness of 10·8 ± 1·3 (SD) mm. There were four groups of seven: gilts and entire males of white breeding (Large White × Landrace) from a commercial source; and gilts and entire males from the MLCs Stotfold Pig Development Unit. The latter were progeny from several breeding companies and had some meat-type and Duroc genes. The pigs were transported to the University of Bristol's abattoir at Langford where carcasses and cuts received different treatments: carcasses from the commercial source were suspended from the achilles tendon, chilled slowly (< 0·5m/s at 1°C) and loin joints were conditioned for 6 days; carcasses from Stotfold were suspended from the pelvis, chilled slowly (< 0·5m/s at 1°C) and loin joints were conditioned for 12 days.

Measurements of pH and colour using a glass electrode and fibre optic probe respectively were taken at 45 min and 24 h after slaughter in *m. longissimus* at the last rib position and were similar in all groups. The concentration of ether-extractable lipid (marbling fat) in *m.longissimus* was 1·0 ± 0·40 (SD)% and 1·3 ± 0·38 (SD)% in commercial and Stotfold samples, respectively.

Following removal from the carcass 24 h after slaughter, loin joints (4th thoracic to last lumbar vertebrae) from both sides were vacuum packed and stored at 1°C for a 6 or 12 day conditioning period. After conditioning, the loins were deboned and 30 steaks were cut, alternatively thick (2·5 cm) or thin (1·9 cm). These

individual steaks were then vacuum packed, blast frozen at –40°C and stored at –20°C before taste panelling.

After overnight thawing at room temperature, steaks were grilled, turning every 3 min, until an internal temperature of 65, 72·5 or 80°C was reached as measured by a thermocouple probe. This was the range thought to be used in UK households. The weight before and after grilling was determined and steaks were kept warm at 60°C before samples approximately 5·0 × 2·5 cm were taken for sensory testing from the approximate centre of each steak.

Sensory assessments were performed by 10 female assessors (age range 35–55 years) who had been selected in accordance with the British Standard Institution BS7667 (1993) method for the selection, training and monitoring of assessors. Assessors received further training relating specifically to meat following the principals outlined by Cross *et al.* (1978). They used 8-point category scales to rate the attributes of texture, juiciness, pork flavour intensity and abnormal flavour intensity.

At each session, assessors rated six samples comprising three thick (2·5 cm) and 3 thin (1·9 cm) steaks cooked to 65, 72·5 and 80°C. Thirty steaks from the same carcass were therefore evaluated at each session [two thicknesses × three final internal temperatures × 10 assessors/2 (each steak served two assessors)]. All assessments took place in a panel room illuminated by red light so that assessors were not aware of colour variation associated with different degrees of doneness.

Experiment 2

Ninety-six pigs from the same sources as in Experiment 1 were used. Mean carcass weight and P_2 fat thickness were 64·9 (2·68 SD) kg and 10·7 (1·38 SD) mm. There were four groups of 24, gilts and entire males from the commercial source and gilts and entire males from Stotfold. The latter contained some meat–type and Duroc genes. Slaughter, and carcass processing procedures were similar to Experiment 1 i.e. the Stotfold carcasses were suspended from the pelvis whereas the commercial carcasses were suspended from the achilles tendon during chilling.

Measurements of pH and colour using a glass electrode and fibre optic probe respectively were taken at 45 min and 24 h after slaughter in *m. longissimus* at the last rib position and were similar in all four groups. The concentration of ether–extractable lipid (marbling fat) in *m. gluteobiceps* was 2·0 ± 0·49 (SD)% and 2·10 ± 0·59 (SD)% in commercial and Stotfold samples, respectively.

Twenty-four hours after slaughter leg joints were removed from both sides of the carcass, vacuum packed and stored at 1°C for 6 days in all cases. After conditioning, the *m. gluteobiceps* muscle was removed from each leg and three joints of the same size were cut, two from one leg (anterior and posterior) and one from the other. These were then vacuum packed, blast frozen at –40°C and stored at –20°C before panelling.

After overnight thawing at room temperature, joints were placed in computer-controlled ovens set at 170, 180 or 190°C, rind side uppermost. Roasting on foil–covered enamel trays then continued until internal temperatures of 65, 72·5 or 80°C were reached (the same as in Experiment 1), as measured using a thermocouple probe. The weight before and after roasting was determined and joints were kept warm at 60°C before slices, 5 mm thick cut at right angles to the muscle fibre direction, were taken for panelling.

The three joints from each pig were cooked to the same internal temperature but at three oven temperatures. They were evaluated by 10 assessors in the same session at which a further three joints from the same group (a different internal temperature, same three oven temperatures) were evaluated. Eight pigs from each group were used at each internal temperature. The same assessors participated in both Experiments 1 and 2 and the same procedures were used including the use of red light so that differences in doneness could not be detected.

Statistical analysis

Analysis of variance was used to determine the effects on eating quality of steak thickness and final internal temperature (Experiment 1) and the effects of oven temperature and final internal temperature (Experiment 2). In Experiment 1, both factors were examined within pig and within panel. In Experiment 2, oven temperatures were examined within pig and within panel as were two final internal temperatures. Differences between the three final internal temperatures were based on analysis of the pooled panel means.

RESULTS

Experiment 1

Although thinner steaks reached the final internal temperatures more quickly (15·7 vs 18·9 min overall), there were no significant effects of steak thickness on any aspect of eating quality. The effects of final internal temperature are shown in Table 1. As this increased from 65 to 80, tenderness and juiciness declined by, on average, 1·0 and 1·5 units, respectively, pork flavour increased by 0·6 units and abnormal flavour declined by 0·5 units. These effects were consistent in the four groups. Cooking loss increased from 288·0 to 417·2 g/kg between the two extreme temperatures and cooking time increased by 8 min, from 13·5 to 21·7 min.

Although the experiment was not designed to evaluate sex and source effects, it is clear that there were no large differences between gilts and entires. The commercial source entires were slightly more tender and juicy than the gilts but this was not the case for the Stotfold sample. There was no sex difference in flavours. The Stotfold pigs were the more tender and there were no source effects on juiciness and flavour.

Experiment 2

Oven temperature itself had no effects on eating quality except that joints from commercial source entires were less juicy ($P < 0{\cdot}01$) when cooked to the higher temperatures (5·4, 5·2, 5·0 at 170, 180 and 190°C, respectively). The effects of final internal temperature are shown in Table 2. As this increased from 65 to 80°C, tenderness was not significantly affected except in group 4 (reduced by 0·6 units), juiciness declined by on average 0·6 units, pork flavour increased by 0·3 units and abnormal flavour declined by 0·5 units. Cooking loss increased by 82·3 g/kg as internal temperatures increased from 65 to 80°C and cooking time increased by

12·8 min. These average results were less consistent between groups than in Experiment 1.

In this experiment entires tended to produce the more juicy meat but other aspects of eating quality were similar between the sexes. The Stotfold pigs were markedly more tender than the commercial pigs but other aspects of eating quality were similar between the sources.

TABLE 1
Effect of Final Internal Temperature on Eating Quality of Loin Steaks (Experiment 1)

	Final internal temperature (°C)			*s.e.d. and significance*	
	65	72·5	80		
Group 1. Commercial gilts					
Tenderness	5·1	4·5	4·2	0·15	***
Juiciness	5·0	4·3	3·5	0·13	***
Pork flavour	3·4	3·5	4·1	0·14	***
Abnormal flavour	3·3	3·1	2·7	0·17	**
Cooking loss (g/kg)	294·8	349·8	419·2	4·50	***
Cooking time (min)	14·1	17·1	22·1	0·28	***
Group 2. Commercial entires					
Tenderness	5·5	4·9	4·3	0·16	***
Juiciness	5·2	4·7	3·7	0·14	***
Pork flavour	3·4	3·7	4·2	0·15	***
Abnormal flavour	3·3	3·0	2·7	0·19	**
Cooking loss (g/kg)	282·7	343·5	414·3	3·79	***
Cooking time (min)	13·5	17·0	21·4	0·32	***
Group 3. Stotfold gilts					
Tenderness	5·6	5·2	4·6	0·16	***
Juiciness	5·0	4·6	3·6	0·11	***
Pork flavour	3·5	3·6	4·0	0·14	***
Abnormal flavour	3·2	3·0	2·8	0·19	NS
Cooking loss (g/kg)	285·6	337·1	419·3	3·91	***
Cooking time (min)	12·9	16·4	22·1	0·30	***
Group 4. Stotfold entires					
Tenderness	5·7	5·2	4·8	0·16	***
Juiciness	5·2	4·4	3·7	0·12	***
Pork flavour	3·6	3·6	3·9	0·13	*
Abnormal flavour	3·3	3·1	2·8	0·19	**
Cooking loss (g/kg)	285·6	337·1	416·1	4·37	***
Cooking time (min)	13·5	16·6	21·0	0·27	***

At each panel session, six loin steaks (from the same pig) were assessed, i.e. thin and thick, each grilled to three internal temperatures. There were seven pigs/sessions for each group, 28 pigs in total.
*$P < 0·05$; **$P < 0·01$; ***$P < 0·001$.

Interrelationships

Correlations between eating quality scores and cooking parameters are shown in Table 3. In Experiment 1, tenderness and juiciness were positively correlated but this was not the case in Experiment 2 in which there was no effect of final internal

TABLE 2
Effects of Final Internal Temperature on Eating Quality of Leg Roasts (Experiment 2)

	Final internal temperature (°C)			*s.e.d. and significance*	
	65	72·5	80		
Group 1. Commercial gilts					
Tenderness	4·2	4·0	3·8	0·21	NS
Juiciness	5·2	4·8	4·7	0·15	**
Pork flavour	3·2	3·5	3·6	0·10	**
Abnormal flavour	4·1	3·8	3·5	0·15	**
Cooking loss (g/kg)	210·9	262·4	304·8	11·59	***
Cooking time (min)	93·9	87·0	79·7	2·86	***
Group 2. Commercial entires					
Tenderness	4·0	4·4	4·1	0·21	NS
Juiciness	5·5	5·1	5·0	0·11	***
Pork flavour	3·3	3·4	3·5	0·08	*
Abnormal flavour	4·0	3·7	3·2	0·12	***
Cooking loss (g/kg)	221·7	268·5	274·3	8·28	***
Cooking time (min)	93·8	85·5	80·5	2·03	***
Group 3. Stotfold gilts					
Tenderness	5·3	5·2	5·3	0·14	NS
Juiciness	5·0	4·6	4·4	0·10	***
Pork flavour	3·4	3·5	3·5	0·11	NS
Abnormal flavour	3·7	3·5	3·2	0·12	**
Cooking loss (g/kg)	235·8	291·0	315·1	6·99	***
Cooking time (min)	97·5	92·9	84·1	2·55	***
Group 4. Stotfold entires					
Tenderness	6·0	5·5	5·4	0·15	***
Juiciness	5·4	4·8	4·6	0·12	***
Pork flavour	3·2	3·6	3·7	0·12	***
Abnormal flavour	3·6	3·4	3·3	0·17	NS
Cooking loss (g/kg)	209·5	280·6	313·1	9·28	***
Cooking time (min)	86·4	81·7	75·9	2·63	***

At each panel session, six joints, cooked at three oven temperatures and to two internal temperatures were assessed. These joints came from two pigs in the same group. This process was repeated four times for each comparison of internal temperatures (i.e. 65°C vs 72·5°C; 65°C vs 80°C and 72·5°C vs 80°C). There were 24 pigs per group, making 96 pigs in total.
*$P < 0·05$; **$P < 0·01$; *** $P < 0·001$.

TABLE 3
Correlations (r) Between Parameters

Experiment 1. Loin steaks					
1 Tenderness					
2 Juiciness	0·35				
3 Pork flavour	−0·11	−0·02			
4 Abnormal flavour	−0·05	0·05	−0·30		
5 Cooking loss	−0·31	−0·54	0·18	−0·18	
6 Cooking time	−0·30	−0·44	0·19	−0·11	0·78
	1	2	3	4	5
Experiment 2. Leg roasts					
1 Tenderness					
2 Juiciness	0·00				
3 Pork flavour	0·03	−0·34			
4 Abnormal flavour	−0·24	0·33	−0·49		
5 Cooking loss	−0·03	−0·70	0·39	−0·33	
6 Cooking time	−0·09	−0·35	0·34	−0·31	0·56
	1	2	3	4	5

Values underlined are significantly different from zero ($P < 0·05$).

temperature on tenderness. In both experiments, pork flavour and abnormal flavour scores were negatively correlated and the negative correlations between cooking loss and juiciness score were high. Cooking time was also negatively correlated with the juiciness score in both Experiments. In Experiment 1, cooking loss and cooking time were also negatively correlated with the tenderness score. In Experiment 2 but not Experiment 1 there were significant correlations between cooking loss and cooking time on the one hand and pork flavour and abnormal flavour scores on the other.

DISCUSSION

The results for juiciness and tenderness are in general agreement with other published work showing that as final internal temperature is increased from about 60 to 80°C, both decline, juiciness more so than tenderness (Fjelkner-Modig, 1985; Simmons *et al.*, 1985; Heymann *et al.*, 1990). The results for roasts are similar in size to those obtained before but those for steaks (chops) are greater, even compared with those studies which have also used the relatively severe grilling procedure (Simmons *et al.*, 1985). Perhaps the greater leanness of the meat used here was a factor although the weight losses during grilling were similar to those observed by Simmons *et al.* (1985).

The results for flavour are similar to those obtained by Heymann *et al.* (1990) in eight different roasted cuts, showing an increase in pork flavour and a reduction in abnormal flavour as final internal temperature increased. Other studies have shown less clear effects on flavour (e.g. Simmons *et al.*, 1985) and have led to

calls for cooking temperatures to be generally reduced in order to benefit juiciness and tenderness, perceived as more important problems than flavour variation (Dikeman, 1987). Our results suggest that the effects on flavour are in the opposite direction and should also receive consideration.

It is generally agreed that reductions in tenderness and juiciness as cooking temperature increases are due to myofibrillar protein denaturation and structural changes in muscle which cause water to be expelled from the tissue (Davey and Gilbert, 1974). At higher temperatures, denaturation and shrinkage of endomysial and perimysial collagen sheaths contributes to the loss of water and increase in toughness (Bailey, 1988). On the other hand the increase in pork flavour intensity with temperature is caused by a greater activity of the Maillard reaction and associated reactions involving carbohydrates, proteins and lipids and their degradation products (Mottram, 1992). The increase in pork flavour may mask any abnormal flavours present although those associated with blood (e.g. metallic notes) are also less pronounced at higher temperatures (Heymann *et al.*, 1990). Volatile compounds such as androstenone and skatole would also be expected to have a smaller impact on the abnormal flavour score at higher temperatures. Indeed it has been speculated that higher cooking temperatures in the UK might be responsible for the similar reactions of consumers to meat from entire males and the other sexes (e.g. Meat and Livestock Commission, 1989). However in this study there was no evidence of any sex effects on abnormal flavour even at the lowest final internal temperature.

The size of the effect on steak tenderness of reducing cooking temperature from 80°C to 65°C (about 1·0 unit) is much greater than that due to production factors such as 50% or more Duroc genes or *ad libitum* feeding, each of which increase the score by about 0·5 units (Wood *et al.*, 1994). It is more comparable to that seen when processing factors such as carcass suspension, electrical stimulation and conditioning time are optimised and combined (Taylor *et al.*, 1992). However the importance of the cooking temperature effect does not nullify the effect of other factors as shown by the consistently higher scores for the Stotfold groups over the commercial sample at all temperatures, especially in roasts. These results support the concept of 'Blueprints' to improve the tenderness of pork (Warkup, 1993).

In previous studies at Langford which have investigated the effects of increasing carcass leanness on the eating quality of loin steaks, juiciness has been most affected (Wood *et al.*, 1981; Wood *et al.*, 1986). This study showed that juiciness was most affected by cooking temperature, the changes being directly related to the water losses incurred. In turn, lower juiciness was associated with lower tenderness, as has been observed in other studies.

Final internal temperature had a larger effect on tenderness and juiciness in steaks than roasts, associated with greater water losses. This is probably due to the larger surface area of the steak. On the other hand, the changes in pork flavour and abnormal flavour were roughly comparable in the two cuts. Recommendations for ideal cooking temperatures based on eating quality alone would therefore be different (it is accepted that other considerations such as colour are important to consumers). In the case of steaks, the intermediate final internal temperature (72·5°C) seems most appropriate, producing more tender and juicy meat than the higher temperature (80°C) and more flavoursome meat than the lower (65°C). In the case of roasts there seems no reason for UK consumers to

change their practice of cooking to a 'well done' state (Meat Promotion Executive, 1981) because tenderness and juiciness were less affected by final temperature and flavour scores were improved at the highest temperature.

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