Nutritional Manipulation of Iron level in Finisher Pigs and Fresh Pork

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Report prepared for the
Co-operative Research Centre for an Internationally Competitive Pork Industry

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Executive Summary

Rationale:

Iron deficiency is one of the most common nutritional deficiencies affecting 80% of the world's population including infants, children, adults & elderly. There are two forms of dietary iron: haem and non-haem. Plant foods are the main source of non-haem iron. Animal tissues such as muscle, liver and kidney are a good source of haem iron and it is more readily absorbed than non-haem iron. The absorption level and the bioavailability of iron in the body can be influenced by the availability of inhibiting and/or enhancing substances in the diet. Previous studies have shown that blood circulatory iron levels can be increased in weaner piglets by dietary means but the effect of dietary iron supplementation on muscle tissue iron forms in pigs has not been investigated in detail.

The key objectives of this study were to examine whether the iron level in fresh pork can be enhanced by supplementation with organic iron or through naturally available feeds such as chicory inulin, and to examine any differences between male and female pigs in muscle tissue iron content and retail colour stability.

Outcomes of the project:

- Factorial analysis showed that there was no interaction observed between inulin x iron x sex for any of the growth performance, carcass traits, serum iron levels or muscle iron contents examined
- Feeding of chicory inulin at 5% in the finisher ration significantly increased haem iron content of pork compared with pigs fed without inulin in their ration
- The increase in muscle haem iron did not significantly increase the total iron content of pork. Feeding an organic iron supplement did not change the haem or total iron content of pork
- Male pigs fed the chicory inulin diet had higher haem and total iron content than their female counterparts
- The inclusion of inulin from chicory in pig diets significantly improved daily weight gain and carcass weight compared to diets that did not contain inulin
- The inclusion of an organic iron source in the diet did not influence growth rate or carcass weight compared with non iron diet
- P2 fat depth was not significantly influenced by feeding treatment, though heavier carcass weights of pigs fed an inulin diet suggests that these carcasses may have had a higher muscle content
- Factorial analysis between inulin x iron x sex x day of retail display showed that pork in male pigs from pigs fed inulin was redder and darker (lower L* value) compared with female pigs
- Feeding organic iron in the diet at 500 ppm reduced the redness and increased the lightness of pork in male pigs compared with their female counterparts
- Pork from male pigs displayed an increased lightness indicated by higher L-value than pork from female pigs
- Pork from organic iron fed pigs was paler under retail display, as indicated by a higher L*value, than pigs not fed an iron supplemented diet, however iron supplementation had no effect on redness of pork
- Pork from inulin fed pigs was redder under retail display than those fed without inulin. The significant improvement in the redness of pork with the inulin diet over the 5 days of retail display could be due to a significant increase in the haem iron content when compared with a non inulin diet

Relevance of the project's outcomes to the Australian Pig Industry:

- Haem iron content and redness of pork can be increased by addition of inulin from chicory at 5% into the finisher diet.
- The increase in redness of pork in male pigs that were supplemented with inulin could be due to an increase in haem and total iron content compared with female pigs.
- Based on the a*values obtained, consumer acceptability of pork may be improved by increasing the redness of fresh pork under retail display using dietary sources like chicory inulin.
- There is potential to improve average daily gain and carcase lean content in pigs by dietary inulin supplementation

However, further studies are needed to understand the effect of feeding inulin sources at higher levels on growth rate & muscle deposition in pigs, haem & total iron content in pork and the colour stability (redness of pork) in different genotypes.

Table of Contents

1. Introduction

Background and rationale for conducting the research

Iron is an essential trace element for human and animal life and plays an integral part in many proteins and enzymes that maintain good health. Iron is essential for the regulation of cell growth and differentiation, oxygen transport in muscle systems and maintenance of immunity status, affecting all stages of life. Animals and humans receive iron from dietary sources and iron status in the body is regulated by intestinal iron absorption. There are two forms of dietary iron, haem and non-haem. Haem iron is found in animal muscle foods and non-haem iron is found in plant foods such as grains, pulses and leafy materials. Haem iron is more readily absorbed by the body than non-haem iron. Vitamin C and peptides in muscle foods can increase the bioavailability and absorption of non-haem iron through binding iron in soluble complexes, preventing them from reaction with inhibitors. Phytic acid and polyphenols are found in plant based diets and are major inhibitors of non-haem iron absorption in animals including humans (Storcksdieck et al., 2007).

Supplementation of organic sources of iron in the diet has been a path to increase the iron levels in the circulatory systems in order to maintain an active life. The absorption level of iron from the diet can vary with the age, species, nutritional & physiological status, food sources and the composition of the diet (chemical forms, levels of other dietary components including vitamins, protein types, fiber, secondary plant compounds) (National Institute of Health, 2007).

Literature shows that the muscle tissue of pigs contains at least half the level of iron observed in beef and lamb (Holland et al., 1991). Iron content varies with muscle type and the pork shoulder contains more than twice the level in pork *longissimus dorsi*; the values were 13 and 5 mg/kg wet tissue (Leonhardt et al., 1997). A wide range of iron content was observed in a study carried out among 21 muscle tissues in pig carcases (Kim et al., 2006). Among the types of pork muscles examined, *vastus intermedius* and *infraspinatus* muscles had the highest iron content while muscle *longssimus dorsi* had the lowest iron content. Previous studies have indicated that dietary iron supplementation increased the Fe bioavailability in the circulatory systems of young pigs (Yasuda et al., 2006) but had no effect on performance, carcass or muscle characteristics in adult pigs (Apple et al., 2007). To date, there are no reports available on the iron content of muscles in grower pigs fed with organic iron supplements with and/or without inulin supplementation.

This study examined whether the iron content in pig muscles could be increased by dietary manipulation using an organic source of iron supplement (Bioplex-Fe Alltech; an iron amino acid complex) and/or chicory inulin (Fibrulin Instant from Salkat; dietary chicory fibre).

The objectives of the study were:

1. To determine whether dietary Fe supplementation of finisher pigs increases total iron content of pork muscle
2. To determine whether the addition of inulin (a complex carbohydrate) to the diet changes the incorporation of Fe into pork muscle
3. To determine whether the muscle Fe content in male pigs can be increased to the level similar to that female counterpart

2. Methodology

This experiment was a preliminary study conducted in grower pigs to identify whether Fe content in pork muscle can be manipulated by dietary means, without compromising the production and meat quality parameters of pigs and pork, respectively.

Experimental design

A total of forty pigs were used in this study. At the commencement of feeding experimental diets, eight pigs (4 males & 4 females) were slaughtered in two sets (2 males & 2 females at each time). Iron levels in the *longissimus dorsi* were obtained to determine baseline values. For the feeding study, 32 finisher pigs were divided into four groups (8 animals/treatment) and allocated in individual pens in randomized blocks, to the following:

1. Basal diet, commercial wheat based finisher diet
2. Inulin diet, Basal + 5 % Inulin (chicory fiber Fibruline®, Warcoing, S.A. Belgium)
3. Iron diet, Basal + Iron, 500 mg/kg (Bioplex™, Alltech Inc., Kentucky, USA) 15 %)
4. Iron+Inulin diet, Basal + 5 % Inulin (Fibruline®) + Iron, 500 mg/kg (Bioplex™ ,15 %)

Table 1: Ingredients and chemical composition of rations used for finisher pigs[a]

Ingredients	***[a]Diet1 g/kg^{-1}***	***[b]Diet 2 g/kg^{-1}***	***[b]Diet 3 g/kg^{-1}***	***[b]Diet4 g/kg^{-1}***
Wheat 15% CP	*485.00*	*485.00*	*485.00*	*485.00*
Barley 16% CP	*350.00*	*350.00*	*350.00*	*350.00*
Meat & Bone Meal 50 %	*40.00*	*40.00*	*40.00*	*40.00*
Canola Meal	*60.00*	*60.00*	*60.00*	*60.00*
Blood Meal	*12.50*	*12.50*	*12.50*	*12.50*
Tallow	*20.00*	*20.00*	*20.00*	*20.00*
Di-calcium Phosphate	*16.30*	*16.30*	*16.30*	*16.30*
Limestone	*8.30*	*8.30*	*8.30*	*8.30*
Salt	*2.00*	*2.00*	*2.00*	*2.00*
Methionine	*1.50*	*1.50*	*1.50*	*1.50*
Lysine	*1.50*	*1.50*	*1.50*	*1.50*
Threonine	*1.43*	*1.43*	*1.43*	*1.43*
Vitamin Mineral Premix (P210M)	*1.50*	*1.50*	*1.50*	*1.50*
Supplements				
Fibruline (5 % inulin)	*0.00*	*55.6*	*0.00*	*55.6*
Bioplex Iron (15 % Fe) 500 PPM	*0.00*	*0.00*	*3.42*	*3.42*
Starch	*55.6*	*0.00*	*55.6*	*0.00*
Analysed values (iron levels)				
Bioplex Iron (15 % Fe) 500 mg/kg Iron, Mg/kg	*304.55*	*303.91*	*694.08*	*684.36*

[a]Diet 1, Commercial finisher diet; [b]Diet 2, Basal + 5 % Inulin (Fibrulin); Diet 3, Basal + Iron, 500 mg/kg (Bioflex, 15 %); Diet 4, Basal + 5 % Inulin (Fibrulin + Iron, 500 mg/kg (Bioflex, 15 %).

Feeding, slaughter procedure and sample collection

Pigs were fed their respective diets at 95% *ad libitum* for 5 weeks. The 95% of *ad libitum* intake was estimated from the intakes of pigs recorded during the 1 week adaptation period where wheat based basal diet was offered to all pigs used in this study. Diets were offered twice a day at 9:00 and 16.00 h. The control diet had no supplemented Fe as bioplex Iron. Diets were balanced for dietary energy (13.5 MJ DE/kg) and protein (19%) levels across the treatments using the dietary ingredients shown in Table 1. Feed intake and weight gain over the five weeks of feeding were recorded. Fasting blood serum samples were collected after 5 weeks of feeding for the measurement of iron, hemoglobin content and red blood cells. At the end of the study, pigs were transported (8 km) to a commercial abattoir for slaughter.

After overnight fasting (12 h) with unlimited access to water, pigs were exsanguinated following CO_2 stunning, hair removed and eviscerated. At 45 minutes postmortem, hot carcass weight (AUS-MEAT Trim 1) and P2 fat were recorded and muscle longissimus samples were collected from the loin for the analysis of iron content. Since the levels of iron in the loin (12.3 mg/kg) and the leg (11.7 mg/kg) muscle from pigs fed basal diets as a group in the previous study (Jayasooriya et al., 2008) were found to be very similar, only the loin muscle iron content was determined in this study.

At 24 h postmortem, a section of loin muscle (from 5^{th} – 8^{th} rib) was collected from carcasses, maintained at $4^{o}C$ and transported to the Meat Research and Training Centre, Werribee for the assessment of meat colour.

pH: The pH of the muscle was measured with an ionode electrode (Model No. IJ44 Tennyson, Qld, Australia) fitted to a digital pH meter (Jenco pH Vision Model 6007, Jenco Instruments, San Diego, CA).

Meat Colour and Retail Shelf life assessment: At 24 hour post mortem, 3 loin slices were placed on foam trays, over-wrapped with polyethylene film and displayed under refrigerated condition for colour and shelf life assessment. Meat colour and retail shelf life were assessed on the loin at 0d (1 day post-mortem), 2d, 4d and 6d after slicing and packing into retail packs. The redness and lightness of meat i.e., a*-value and L-value were used as an indicator of colour and shelf life improvement in the pork.

Analysis of Iron content in pork: Samples of loin muscle collected at 45 min postmortem were analysed for iron content and forms at the Food & Health Science laboratories, Department of Primary Industries, Werribee, Victoria. For total Iron, pork muscle was digested using microwave digestion (milestone ML1200) with nitric acid/ hydrogen peroxide and the total iron concentration determined by ICP-OES (Varian Vista). Non-Haem Iron was analysed by the procedure described by Rhee & Ziprin, 1987 and determined by UV/ visible spectroscopy (Varian Cary).The Haem iron content was determined by difference of total and nonhaem iron content in the muscle (Total - Nonhaem).

Statistical analyses: Statistical analyses of data were performed using the GenStat Statistical Package, Eleventh Edition. Data were subjected to ANOVA procedure using a split plot factorial design. In detail, a 2 x 2 x 2 factorial analytical procedure was used where inulin level, iron level and sex were tested as main effects and their interactions. Replicates were used as block structure. Interactions between inulin level x iron level x sex were tested for significance levels of animal performance, carcass traits, fresh pork quality, and iron content of blood and muscle tissue. Initial live weight and carcass weights were used as covariates in the analysis of hot carcass weight and P2 fat, respectively. Shelf life of the fresh pork i.e., colour stability was evaluated by testing the interaction between inulin level x iron level x sex x days of display for redness of muscle (a* value) and lightness of muscle (L value).

In order to answer the statements raised in the objectives, results were presented as treatments means and means for gender. Standard errors of differences of means were used to identify the significant differences between means at P <0.05.

3. Outcomes

The feeding study was conducted during September to October 2008. Animals were fed at 95% *ad libitum* and supplements of inulin and iron were mixed into the wheat based diet at the levels stated in the methodology section. The pigs were slaughtered at a commercial abattoir approximately 8 km away from the DPI Werribee research centre.

Feed intake, performance and carcass traits

There were no interactions between inulin x iron x sex observed for any feed intake, performance or carcass traits measured. Therefore, results are reported to show the differences between diets and differences between sexes in order to explain the outcomes for the objectives of this project. When comparing the inulin and iron feeding, the final weight of animals fed the iron plus inulin (Both) was higher (P <0.06) than all other groups. As a main effect, animals fed diets containing inulin had higher final live weights (82.88 vs 85.95 kg, sed 1.16; P <0.02) than those fed non inulin diets . This may be explained by a greater average daily gain (795 vs 869 g/day, sed 26.3; P<0.01) of pigs fed inulin diets compared with those on the non inulin diets. Animals fed inulin plus iron (both) had the higher average daily gain, inulin alone a moderate gain and basal or iron diet the lowest daily gain, though these differences were not significant (P=0.22)(Table 2). Male pigs tended to have higher average daily gain (P=0.13) and heavier final live weight (P=0.11) than female pigs, respectively. There was no difference in feed conversion ratio (feed efficiency) between pigs in the different treatment groups.

Table 2: The effect of dietary inulin or iron or both treatment on feed conversion efficiency, growth performance of pigs and carcass traits in finisher pigs fed a wheat-based diet[a] . Carcass weight and P2 fat are adjusted to live weight and carcass weight, respectively.

	Treatments[c]				Sex		SED		P-value	
	Basal	Inulin	Iron	Both	Female	Male	Inulin x Iron	Sex	Inulin x Iron	Sex
Initial live weight, kg	51.77	50.89	50.38	51.40	50.26	51.96	0.90	1.23	0.20	0.22
Final live weight, kg	83.56	84.31	82.19	87.50	82.25	86.53	1.65	2.30	0.06	0.11
Feed efficiency	3.01	2.79	2.72	2.87	2.85	2.84	0.16	0.14	0.12	0.96
ADG, g	795	836	795	902	800	864	37.2	37.3	0.22	0.13
Carcass weight, kg	63.57	63.80	62.23	66.50	63.29	64.76	1.09	0.58	0.02	0.05
Carcass P2 fat	9.75	9.79	11.26	10.45	9.18	11.44	1.24	0.93	0.88	0.06

[a]Means are average of eight observations for each dietary group and 16 observations male and female groups.
[b]Diets were offered at 95% *ad libitum* to all animals over the 5 weeks.
[c]Dietary treatments were 1) a wheat-based control diet; 2) 500 ppm iron supplemented diet (as Bioplex-Fe Alltech); 3) a diet with 5% inulin (Fibruline® chicory fibre); 4) a diet with 5% inulin & 500 ppm Fe.

Animals fed the inulin plus iron diet had significantly higher carcass weights (P=0.02) than the other groups. As a main diet effect, carcases from pigs fed inulin diets were heavier (65.15 vs 62.90 kg, sed 0.76; P<0.02) when compared to diets not containing inulin. The increase in average daily gain and final live weight with the inulin diet in fact resulted in a larger carcass weight compared with non inulin feeding group. However, there was no difference in carcass fatness as indicated by P2 fat depth between the treatment groups. This suggests that animals fed diets containing may have had a higher carcase muscle content than the other treatment groups. Male pigs had significantly heavier carcass weight (P= 0.05) and tended to be higher in carcass fatness (P=0.06) than female pigs.

Meat quality traits

There were no interactions between inulin x iron x sex observed for any of the meat quality characteristics measured. Ultimate pH of meat was similar in all groups and was within the range for quality pork (pH range 5.4 - 5.8). Drip loss of meat was not affected by treatments or sex groups (Table 3). There was an inulin x sex interaction observed in a* value of fresh pork in such that the inulin diet increased the redness of fresh pork in male pigs (7.10 to 8.10; P <0.08) compared with their female (8.20 to 8.00) counterparts. Similarly there was an interaction between inulin x sex and iron x sex for lightness of fresh pork where the inulin diet significantly reduced (P <0.05) the lightness in male pigs (56.78 to 54.41, sed 1.14) than female pigs (52.55 to 53.55) while the iron diet significantly increased (P <0.04) the lightness of pork in male pigs (54.11 to 57.08, sed 1.14) than female pigs (53.35 to 52.75) compared with other groups respectively. Fresh pork from male pigs was paler (P =0.02) than pork from female pigs but no gender differences were observed for a* or b* values.

Table 3: The effect of dietary inulin or iron or both treatment on ultimate pH, drip loss and meat colour of fresh pork from finisher pigs fed a wheat-based diet[a]

	Treatments[c]				Sex		SED		P-value	
	Basal	Inulin	Iron	Both	Female	Male	Inulin x Iron	Sex	Inulin x Iron	Sex
Ultimate pH (pHU)	5.46	5.44	5.57	5.44	5.49	5.46	0.06	0.04	0.16	0.30
Drip loss, %	8.77	8.61	8.64	8.79	8.69	8.71	0.20	0.16	0.29	0.73
Meat colour, *L**	54.17	53.29	55.16	54.67	53.05	55.59	1.15	0.79	0.82	0.02
Meat colour, *a**	7.81	8.10	7.49	7.98	7.96	7.73	0.47	0.49	0.77	0.35
Meat colour, *b**	14.52	14.43	14.57	14.72	14.61	14.50	0.37	0.36	0.65	0.78

[a]Means are average of eight observations for each dietary group and 16 observations male and female groups.
[b]Diets were offered at 95% *ad libitum* to all animals over the 5 weeks.
[c]Dietary treatments were 1) a wheat-based control diet; 2) 500 ppm iron supplemented diet (as Bioplex-Fe Alltech); 3) a diet with 5% inulin (Fibruline® chicory fibre); 4) a diet with 5% inulin & 500 ppm Fe.

Serum and Muscle iron content

No interaction between inulin x iron x sex were observed (P >0.05; Table 4) on serum iron content. Blood serum iron level was higher (P=0.03) in pigs that had been supplemented with organic iron, intermediate in inulin or inulin plus iron supplementation and lowest in control diet fed pigs. There were no differences in haemoglobin levels or red blood cell counts between dietary treatments. Female pigs had a higher blood haemoglobin content than the male pigs; 124 and 121 g/L for females and males, respectively.

Table 4: The effect of dietary inulin or iron or both treatment on serum iron and haemoglobin contents, and the level of iron components of fresh pork from finisher pigs fed a wheat-based diet[a]

	Treatments[c]				Sex		SED		P-value	
	Basal	Inulin	Iron	Both	Female	Male	Inulin x Iron	Sex	Inulin x Iron	Sex

Serum iron, µmol/L	26.93	29.90	32.26	29.42	29.62	29.64	1.66	1.55	0.03	0.99
Haemoglobin	124	123	124	119	124	121	1.72	0.82	0.14	0.08
Muscle total iron	4.60	4.79	4.95	5.25	4.79	5.01	0.33	0.39	0.82	0.60
Muscle nonhaem iron	1.97	1.95	2.49	2.08	1.96	2.27	0.23	0.08	0.27	0.008
Muscle haem iron	2.62	2.84	2.47	3.16	2.51	3.04	0.29	0.36	0.26	0.19

[a]Means are average of eight observations for each dietary group and 16 observations male and female groups, except for blood haemoglobin where only 4 observations per treatment.
[b]Diets were offered at 95% *ad libitum* to all animals over the 5 weeks.
[c]Dietary treatments were 1) a wheat-based control diet; 2) 500 ppm iron supplemented diet (as Bioplex-Fe Alltech); 3) a diet with 5% inulin (Fibruline® chicory fibre); 4) a diet with 5% inulin & 500 ppm Fe.

As for serum iron, there was no inulin x iron x sex interactions observed for muscle iron contents as haem, non-haem or total (Table 4). However, there was an inulin x sex interaction for haem ($P < 0.05$) and total iron ($P < 0.05$) contents where inulin significantly increased haem and total iron contents in male pigs compared with female pigs, respectively. The corresponding values of haem for male and female were 2.60 vs 3.47 mg/kg and 2.49 vs 2.53 mg/kg (sed 0.42, $P = 0.05$), respectively. The corresponding values of total iron content for male and females were 4.65 vs 5.37 mg/kg and 4.91 vs 4.66 mg/kg (sed 0.46, $P = 0.05$), respectively. This indicates that the increase in total iron content in pork from male pigs fed inulin in their diets was due to an increase in haem iron content compared with their female counterparts. The inulin diet improved the haem iron content of pork compared with pigs fed without inulin (2.55 vs 3.00, sed 0.20; P <0.04). The increase in haem iron content with the inulin diet was inadequate to make a significant increase in total iron content. Female pigs had higher non-haem iron content than male pigs (P <0.008).

The values observed for total iron content of pork from muscle *longissimus dorsi* (loin) in the present study were similar to those published in several other studies from Australasia, US and Europe. Other studies had reported iron levels from 4.18, 4.6, 5.0 and 6.6 mg/ kg of pork (Reichardt et al., 2002; walz & Pallauf, 1998; Leonhardt et al., 1997; Van Laack et al., 1994; Belitz & Grosch, 1992, respectively). Iron levels of the *longissimus dorsi* in the present study ranged from 4.60 to 5.25 mg/kg of pork. However, other studies conducted in Europe have reported higher levels (18 to 21 mg/kg of pork) of iron content in the muscle *longissimus dorsi* (Senser and Scherz, 1991; Oster, 1994; Souci et al., 1994).

A recent Asian study (Kim et al., 2008) using 21 pork muscle tissues showed that the muscle *longissimus dorsi* had the lowest iron content (4.48 mg/kg pork) while the highest iron content was observed in leg muscles, muscle *vastus intermedius* and muscle infraspanatus that had 11.88 mg and 11.70 mg/ kg pork, respectively.

Pigs slaughtered at the commencement of the present study showed higher levels of iron content in pork (mean - 8.5 mg/kg pork & range 7.1 to 9.7 mg/kg g of pork) than the pigs slaughtered at the end of experimental study. The reduction in iron content of pork in experimental pigs, compared with the initial slaughter group, could be due to the level of phytic acid present in the wheat and barley ingredients in the basal diet. This may have resulted in the binding of the available iron into insoluble complexes and therefore reducing the solubility, digestibility and absorption of dietary iron in the gastro-intestinal tract of experimental pigs. Alternatively, this may have been due to restriction in body movements and exercise with animals in the restricted pens compared with animals in group pens. The greater blood circulation in pigs reared in group pens and ecosystems may have provided more iron to the tissues compared to those maintained in single pens. Further study is needed to investigate the effect of management systems (individual pens vs group pens or ecosystems) on muscle iron content.

Shelf life or colour stability of pork

Colour stability of pork was evaluated by assessing the lightness and redness of pork between inulin x iron x sex over the time of display as shown in Figures 1, 2, 3 & 4, respectively.

Lightness

There were no significant interactions (P >0.05) observed between inulin x iron x sex x days of display for lightness of muscle over the 5 days of display. Also, interactions between inulin x iron x days of display, inulin x sex x days of display or iron x sex x days of display were not significant.

However, a significant interaction (P = 0.006) between inulin x iron x sex was observed where pork from male pigs fed inulin alone was darker than those from non inulin fed pigs (55.03 vs 58.11, sed 0.90) compared with other groups (all others have similar between male vs female). There was an inulin x sex interaction observed in muscle lightness (P <0.001) where inulin reduced the lightness of pork in male pigs (58.67 to 56.81, sed 0.75, respectively) compared with female pigs fed inulin (55.10 to 56.11), but feeding an iron supplement increased the lightness of pork in male pigs (56.57 to 58.91, sed 0.75; P <0.002) compared with female pigs fed iron (55.56 to 55.64; Figure 2). Overall, pork from iron fed animals was paler than those fed without an iron supplement diet (57.28 vs 56.07, sed 0.35; P <0.001) and pork from male animals displayed lighter colour than those of female pigs (57.74 vs 55.60, sed 0.50; P <0.02).

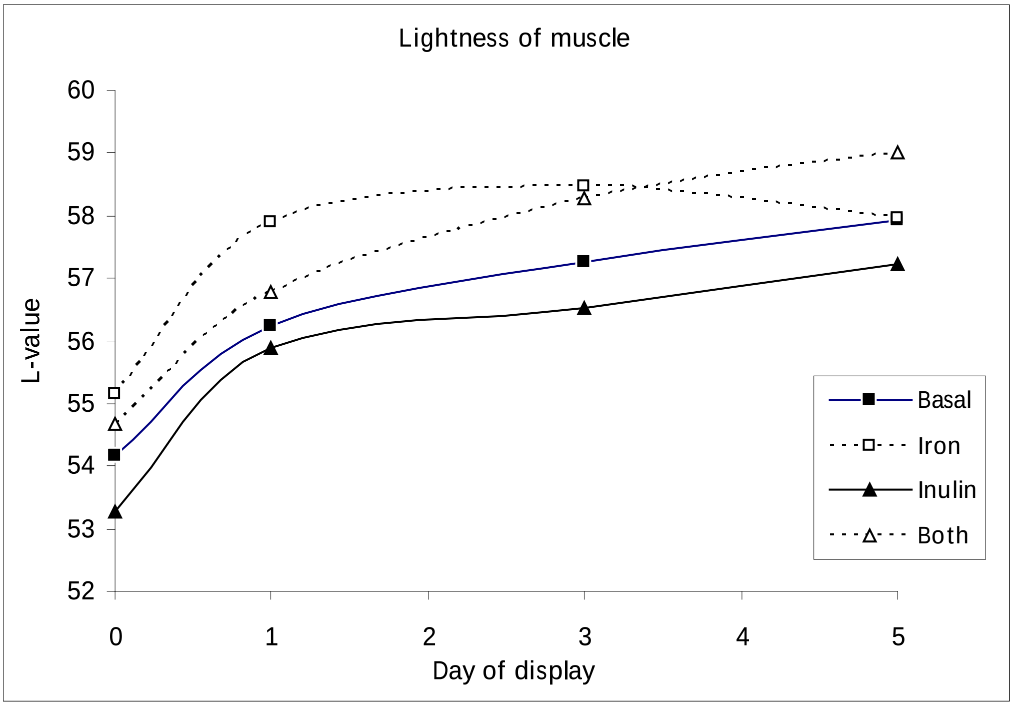

Figure 1: Lightness of pork muscle evaluated for colour stability over a 5 day display period stored at 4 °C refrigerated condition.

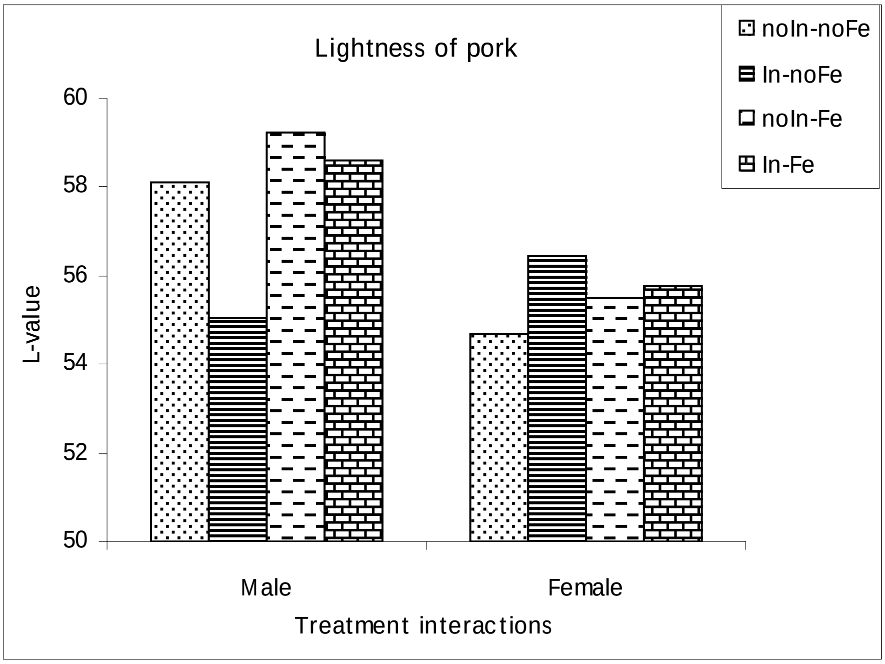

Figure 2: Lightness of pork over the 5 days of display when tested for Inulin x Iron x Sex interactions. Treatment codes**: noIn = non inulin diet; In = inulin diet; noFe = non iron diet; Fe = iron diet**, respectively.

Redness of pork

There were no significant interactions (P > 0.05) observed between Inulin x Iron x Sex x Days for redness of muscle displayed for 5 days. Interactions between Inulin x Iron x Days of display or Inulin x Sex x Days of display or Iron x Sex x Days of display were also not significant (P >0.05) for redness of muscle.

Similar to that observed with lightness of pork, there was a significant interaction (P <0.001) between Inulin x Iron x Sex observed where pork from male pigs fed inulin alone was redder than non inulin fed pork (8.35 vs 9.88, sed 0.49; all others had similar between male & female) . There was an inulin x sex interaction observed in muscle redness (P < 0.002) where inulin increased the redness of pork in male pigs (8.45 to 9.35, sed 0.44, respectively) compared with female pigs fed inulin (9.37 to 9.29) but, iron supplementation reduced the redness of pork in male pigs (9.12 to 8.69, sed 0.44; P <0.03) compared with female pigs fed an iron supplement diet (9.21to 9.45; Figure 4). Overall, pork muscle from inulin fed animals had higher a* values than those from pigs not fed inulin (9.32 vs 8.91, sed 0.15; P <0.008).

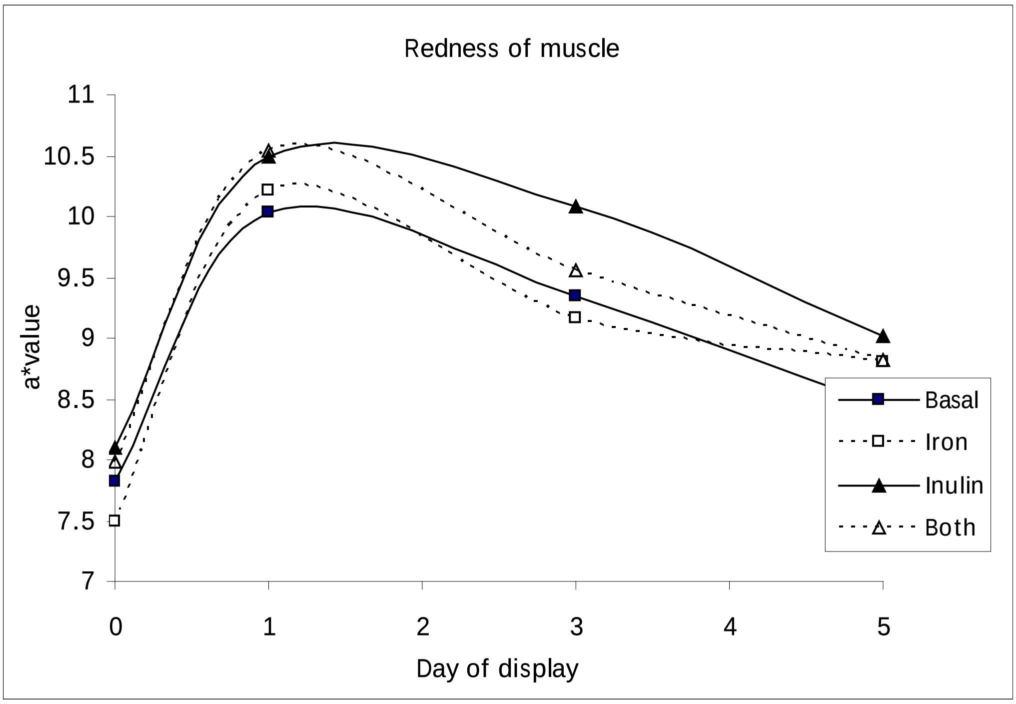

Figure 3: The redness of pork muscle evaluated for colour stability over a 5 day display period stored at 4 ^{o}C refrigerated condition.

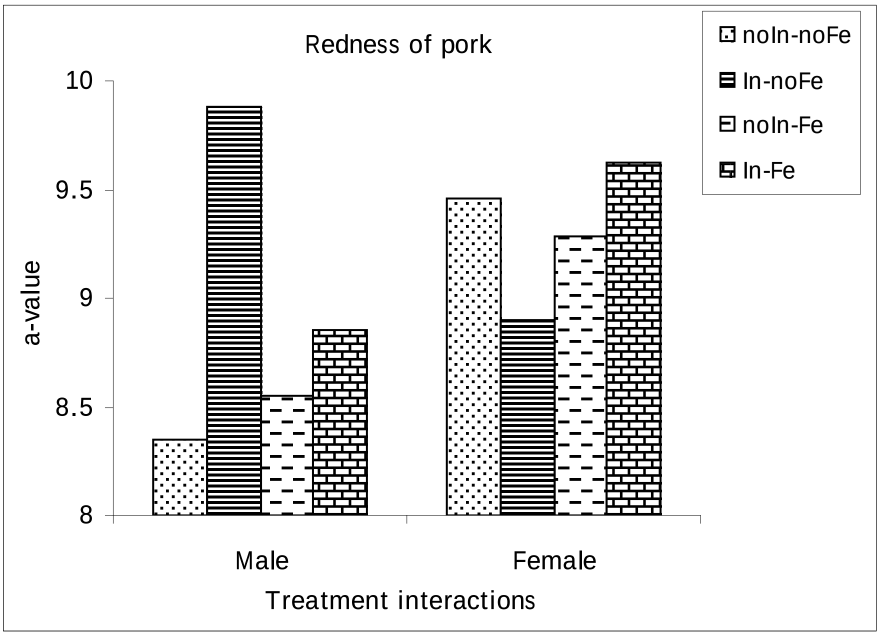

Figure 4: Redness of pork over the 5 days of display when tested for Inulin x Iron x Sex interactions. Treatment codes**: noIn = non inulin diet; In = inulin diet; noFe = non iron diet; Fe = iron diet**, respectively.

Together, these results demonstrate that inulin supplementation improved the colour stability of pork in male pigs by increasing the redness and reducing the lightness of pork compared with female pigs, which can be seen in both Figure 2 and Figure 4. The improvement in redness and lightness in fresh pork (day 0 display) and the 5 day retail display of pork in male pigs might have been due to the significant increase in haem- and total-iron contents in male pigs compared with their female counterparts.

4. Application of Research

Opportunities uncovered by the research

1. It is possible to increase haem iron content and redness of pork by feeding inulin at 5% level in the diet, but not the total iron content of pork
2. In male pigs, haem- and total-iron contents and redness of pork can be increased by dietary inulin supplementation
3. Dietary inulin inclusion at 5% level can be used for finisher pigs to increase the daily weight gain (growth rate) and muscle content

Commercialisation/Adoption Strategies

1. Potential benefits to cost of production

   There is improvement in production with the use of inulin in the diet through increase in growth rate and muscle content but this needs to be validated by using DXA analysis or other body composition analysis. The main economic benefits from the cost of production will go to pig producers

2. Ease of adoption by producers

   The nutritional enrichment process can be adopted into the current feeding systems by adding inulin sources into finisher feeds but further study is warranted.

3. Impact of the research

Inulin supplementation showed an improvement in the colour of fresh pork and the colour stability of pork and the benefits will be realised by retailers. The positive response of inulin supplementation on iron content and colour stability of pork needs further investigation to justify the influence of inulin diet on the nutritional value and quality of pork.

5. Conclusions

1. Pigs fed chicory inulin supplemented diets had significantly higher haem iron content in pork compared with pigs fed diets without inulin, but total iron content was not changed
2. Supplementation of diets with inulin from chicory at 5%, increased haem iron and total iron content of pork in male pigs compared with their female counterparts
3. Dietary organic iron supplementation at 500 ppm did not change total or haem iron content of pork. Dietary iron supplementation tended to increase serum iron content of pigs but inulin supplementation or sex did not influence serum iron content
4. The inclusion of inulin in diets increased the daily weight gain and carcass weight of pigs compared to the non inulin diet but organic dietary iron supplementation had no effect. Having similar P2 fat but greater carcass weight with inulin diet indicates that carcasses from the inulin treatment group had higher muscle content
5. Inulin supplementation at 5% increased the redness and reduced the lightness of pork in male pigs compared with female pigs
6. Organic iron supplementation at 500 ppm reduced the redness and increased the lightness of pork in male pigs compared with their female counterparts
7. Pork from organic iron supplemented pigs showed increased lightness under retail display than pork from pigs fed without iron supplemented diets
8. Pork from inulin fed pigs showed increased redness over retail display than those pigs fed diets without inulin
9. Pork from female pigs had greater nonhaem iron content than male pigs
10. Pork from male pigs displayed increased lightness than pork from female pigs on fresh and 5 day colour display

6. Limitations/Risks

This was a preliminary study investigating the effect of dietary iron sources on forms and levels of iron in pork and its influence on pork quality. Further studies are needed to demonstrate the effect of:

1. Higher levels of dietary inulin from chicory on muscle iron content and colour stability of pork
2. Different levels of dietary inulin on the performance, muscle iron content and meat quality traits from different genotypes

to support the benefits of natural feed sources (eg. Inulin from chicory) on carcass muscle content, muscle iron content and redness of pork

7. Recommendations

As a result of the outcomes in this study the following recommendations have been made:

1. Further study is warranted to examine the effect of supplementation of inulin at higher levels on growth performance, muscle deposition and iron content of pork, particularly haem and its association in the improvement of redness of pork
2. Detailed studies need to be carried out to understand the enrichment of iron in pork using different feed sources and different pig genotypes

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