Final Report

Inclusion of guanidinoacetic acid in finishing pig diets to improve growth performance and meat quality

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Report prepared by Karen Moore
On behalf of Pork Innovation WA Inc
karen@klmconsulting.com.au

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Technical summary

Guanidinoacetic acid (GAA) is a precursor for the formation of creatine, an important component in energy metabolism. At varying concentrations and time periods the inclusion of GAA in pig diets has been found to increase daily gain and decrease back fat. The current recommended inclusion rate of GAA is 1 kg/T in the grower/finisher period, however there is recent evidence in the literature that the utilisation rate of GAA is higher in finisher pigs and perhaps including a lower concentration in the finisher period only may be sufficient. This project aimed to 1) identify the optimum feeding strategy and inclusion concentration for GAA in finishing diets to improve the growth performance, carcass quality and meat quality of pigs; and 2) conduct a cost-benefit analysis of including GAA in finishing diets.

One thousand one hundred and seventy six female pigs were used in a completely randomised experiment with the treatments 1) Control – Basal diet fed from 17 weeks to slaughter; 2) Basal diet + 0.03% GAA fed from 17 weeks of age to slaughter; 3) Basal diet + 0.03% GAA fed from 20 weeks of age to slaughter; 4) Basal diet + 0.06% GAA fed from 17 weeks of age to slaughter); 5) Basal diet + 0.06% GAA fed from 20 weeks of age to slaughter; 6) Basal diet + 0.09% GAA fed from 17 weeks of age to slaughter; and 7) Basal diet + 0.09% GAA fed from 20 weeks of age to slaughter. Growth performance, carcass characteristics, meat quality parameters, colour stability and economic considerations were determined.

The inclusion of GAA in the diet did not significantly improve growth performance, however there appeared to be a commercial difference in growth rate with pigs not receiving GAA being between 2 to 4 kg lighter at the end of the experimental period than the pigs receiving GAA. This was subsequently reflected in the carcass weight where pigs not receiving GAA were significantly lighter than those receiving GAA at any concentration or period of time ($P<0.05$). The effect of GAA on meat quality was inconclusive. For producers to maximise the net margin/pig received then the suggested inclusion of GAA in finisher diets is 0.03% from 17 weeks of age until slaughter.

Background

The amino acid creatine is an important component in energy metabolism (Wyss and Kaddurah-Daouk, 2000). Two-thirds of the daily requirement for creatine can be met by de novo synthesis, however the remainder needs to be supplied by the diet (Jayaraman *et al.* 2018). Incorporating creatine directly into pig diets has been shown to improve growth performance and pork quality (Li *et al.* 2018).

Guanidinoacetic acid (GAA) is a precursor for the formation of creatine (Lu *et al.* 2020). Recent research has focused on the inclusion of GAA in pig diets instead of creatine because it is more stable and less expensive (Liu *et al.* 2015). GAA (at varying concentrations and time periods) has consistently been found to increase daily gain and decrease back fat (Jayamaran *et al.* 2018; Li *et al.* 2018; He *et al.* 2018, Lu *et al.* 2020). Others have found an increase in feed intake (Li *et al.* 2018) and an improvement in the conversion of feed to gain (Jayamaran *et al.* 2018). In contrast, Wang *et al.* (2020) found no improvement when varying concentrations of GAA were included in the growing/finishing period. The variation between studies can be attributed to when the GAA was fed, the concentrations and the duration of feeding (Lu *et al.* 2020).

The current recommended inclusion rate of GAA is 1 kg/T (0.1%) in the grower/finisher period. However, there is recent evidence that shows that the utilisation rate of GAA is higher in finisher pigs and that a lower concentration in the finisher period only may be sufficient to improve growth

performance and decrease back fat (Liu *et al.* 2015; Lu *et al.* 2020). The effect of the lower inclusion rate of GAA in the finisher period and late finisher period on growth performance and carcass quality does not appear to have been evaluated using typical Australian diets and production conditions. If shown to be successful at a lower inclusion rate and included in the diet for a shorter time period then this would be a cost saving for producers.

It is also important to ensure that any feed additives incorporated into the diet do not negatively affect meat quality. At various inclusion rates GAA has been found to have positive effects on meat quality including increasing the pH at 45 minutes post-slaughter, decreasing drip loss and improving the shear force (Liu *et al.* 2015; Li *et al.* 2018; Wang *et al.* 2012). However, Lu *et al.* 2020 found that the inclusion of GAA at 0.06% for the last 60 days before slaughter increased shear force due to an increasing percentage of type II muscle fibres. Jayamaran *et al.* (2012) found no effect on meat quality when GAA was included at 0.12% from 25 to 60 days preslaughter.

All of the effects on meat quality have been evaluated either immediately or at 24 hours post-slaughter. However, there may also be the potential for GAA to improve the colour stability of pork as it has been found to decrease lipid perioxidation (Wang *et al.* 2012). This has implications for the colour and colour stability of fresh pork sides and cuts in case ready packaging and may positively affect consumer purchasing decisions in both the domestic and export markets.

The aims of the project were:

1. To identify the optimum feeding strategy and inclusion concentration for guanidinoacetic acid in finishing diets to improve the growth performance, carcass quality and meat quality of pigs.
2. Conduct a cost-benefit analysis of including GAA in finishing diets.

The hypotheses were:

1. Including guanidinoacetic acid in the diet of finisher pigs will increase the growth rate and feed conversion ratio and decrease back fat compared to those not receiving guanidinoacetic acid.
2. There will be no difference in growth performance and backfat between pigs receiving the lower concentration of guanidinoacetic acid for a longer time period preslaughter or those receiving the same concentration for a shorter period preslaughter.
3. Guanidinoacetic acid will improve the colour and colour stability of fresh pork in case ready packaging compared to pork from pigs that did not receive guanidinoacetic acid.

Methods

This experiment was conducted in a commercial grow out facility in Western Australia. The experimental protocol used in this study was approved by the Murdoch University Animal Ethics Committee (RR3303 20). The animals were handled according to the Australian code of practice for the care and use of animals for scientific purposes (NHMRC, 2013).

Experimental design

One thousand one hundred and seventy six female pigs (CEFN genetics) were used in this experiment. The experiment was a completely randomised design with the following treatments:

1. Control – Basal diet fed from 17 weeks to slaughter (control)
2. Basal diet + 0.03% Guanidinoacetic acid (GAA) fed from 17 weeks of age to slaughter (0.3 17)
3. Basal diet + 0.03% GAA fed from 20 weeks of age to slaughter (0.3 20)
4. Basal diet + 0.06% GAA fed from 17 weeks of age to slaughter (0.6 17)
5. Basal diet + 0.06% GAA fed from 20 weeks of age to slaughter (0.6 20)
6. Basal diet + 0.09% GAA fed from 17 weeks of age to slaughter (0.9 17)
7. Basal diet + 0.09% GAA fed from 20 weeks of age to slaughter (0.9 20)

Animals and housing

Pigs were randomly allocated to pen when they entered the grower facility at approximately 10 weeks of age. At 17 weeks of age the pens were randomly allocated to treatment and the experiment diets commenced. The pigs were group housed (n=40) in a naturally ventilated fully slatted shed with 4 pens per treatment. Pigs had *ad libitum* access to feed (one wet/dry feeder per 40 pigs) and water (two nipple drinkers/40 pigs).

Diets

The commercial farm's standard finisher diet was fed to all pigs. All diets were created by blending the basal diet and the basal diet + 0.09% diet in the required ratios to meet the required GAA concentration using a Feedlogic system (automated feed delivery system, FeedPro, Feedlogic Corp., Willmar, MN, USA). The source of GAA was CreAmino® (Feedworks).

Growth performance and mortality

The pigs were weighed at the commencement of the experiment (17 weeks of age), at 20 weeks of age and when they reached market weight, to determine average daily gain (ADG). Weekly feed disappearance was calculated by feed dispensed by the automatic feed system less feed remaining at the end of the experiment. The feed conversion ratio (FCR) was calculated on a per pen basis by dividing the total weight of feed eaten by the LW gain in the same period. Mortality, pig removals and the number of pigs per pen not reaching target slaughter weight was also determined.

Slaughter procedure

When they reached market weight the pigs were tattooed and transported to a commercial abattoir (approx. 90 min transport time). Hot carcass weight (AUSMEAT Trim 13; head off, fore trotters off, hind trotters on; AUS-MEAT Ltd., South Brisbane, Qld, Australia) and P2 backfat depth, 65 mm from the dorsal midline at the point of the last rib (PorkScan™ system, PorkScan Pty Ltd., Canberra) was measured approximately 35 min after exsanguination, prior to chiller entry. The carcasses were reweighed at approximately 24 hours post-slaughter to determined chiller loss.

Objective pork quality

Twelve pigs per treatment (4 pigs/pen) were randomly selected for meat quality assessment at 22 weeks of age. At 24 hours post-slaughter approximately 1 kg of the *Longissimus thoracis* muscle was removed from the left hand side of the carcass.

Muscle pH was measured using a portable pH/temperature meter (Cyberscan pH 300, Eutech Instruments, Singapore) fitted with a polypropylene spear-type gel electrode (Ionode IJ44, Ionode Pty Ltd, Brisbane, QLD) and a temperature probe.

Colour (lightness (L*), redness (a*) and yellowness (b*)) was measured with a Minolta Chromameter CR-400 (Minolta, Osaka, Japan), using D65 illumination, a 2° standard observer, and an 8-mm aperture in the measuring head, standardised to a white tile after a bloom time of 30 minutes. Differences between total pork colour (ΔE), visible to the naked eye, were quantified from the average L*, a*, b* measures by using the following formula:

$$\Delta E_{Lab} = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2}$$

Drip loss was measured using a modification of the method described by Rasmussen and Andersson (1996). The muscle was cut to a 40±2 g cube, devoid of visible external fat and connective tissue, then wrapped in netting and suspended in a sealed plastic container. The samples were stored for 24 h at 4°C before being removed and gently patted dry to remove excess moisture and then reweighed. Drip loss was calculated by dividing the difference in the initial and post storage weights by the initial weight.

An 80 ± 2 g sample, devoid of visible external fat and connective tissue, was cut to measure thaw loss, cooking loss and shear force (Bouton, Harris, & Shorthose, 1971). The samples were then frozen in individual bags at 20°C for subsequent analysis. The bagged frozen samples were thawed overnight, weighed and then suspended from a metal rack and placed in a water bath which was pre-heated to 70°C. The samples were then cooked at 70°C until an internal temperature of 70°C was reached (approximately 30 minutes). After removal from the water bath, the samples were cooled in running water for 10 minutes and then refrigerated at 4°C until completely cooled. The samples were patted dry to remove excess moisture and re-weighed. Cooking loss percentage for each sample was determined by dividing the difference in the thawed loss and cooked weights by the weight of the thawed raw pork sample. The cooked sample was then refrigerated at 4°C overnight before being cut into five cross-section samples (1 cm^2) parallel to the muscle fibres. Warner Bratzler shear force was measured using a Warner Bratzler shear blade fitted to a Lloyd Texture Analyser (TA1 Series, AMETEK Lloyd Instruments Ltd, United Kingdom). The crosshead speed was 300 mm/minute. An average Warner Bratzler shear force was determined from the 5 samples.

Shelf life and colour stability

Twelve pigs per treatment were used to assess shelf life and colour stability. Four x two cm thick steaks were cut from each loin sample and packaged in foam trays and covered with plastic wrap. The samples were allocated a measurement day at 5, 10, 15 and 20 days after packaging. Trays were stored at 4°C. On the allocated measurement day, trays were opened and surface colour (L*, a*, b*) measured immediately by a Minolta Chromameter after which the steak was allowed to bloom in air

for 30 minutes and the colour measured again. Differences between total pork colour were determined as described above.

Statistics

One-way analysis of variance was performed with the GENSTAT 21 program (VSN International Ltd, Hemel Hempstead, UK) to analyse the main effect of treatment on growth performance, carcass quality and objective pork quality. Repeated measures analysis of variance was used to assess the effect of treatment on colour stability. Pig was used as the experimental unit for the carcass analysis, objective pork quality and colour stability. Slaughter date was used as a block in the analysis of carcass weight and back fat. Initial weight was used as a covariate for the growth performance analysis. Carcass weight was used as a covariate for analysis of backfat. The concentrations of GAA at the 2 time points were combined at each time point and post-hoc analysis of the data was also undertaken. The treatments were then control, GAA 17 weeks and GAA 20 weeks. A trend was defined as a level of probability of more than 0.05 but less than 0.1. Fisher's unprotected least significant differences test was used to compare the least significant difference among treatments when the treatment effect was significantly different.

A cost-benefit analysis was also undertaken.

Results

Growth performance and carcass quality

Final weight was not significantly (P>0.05) different between treatments (Table 1). However, there was a commercial difference with pigs not receiving guanidinoacetic acid (GAA) between 2 to 4 kg lighter at the end of the experimental period than the pigs receiving GAA. This was reflected in the carcass weight where pigs not receiving GAA were significantly lighter than those receiving GAA at any concentration or period of time with the exception of those receiving 0.3 20. Backfat was not affected by treatment (P>0.05).

Daily gain and FCR were not significantly different (P>0.05) between treatments for any time period. However, there was a commercial difference in average daily gain where it appears that daily gain was lower in pigs fed GAA by at least 0.05 kg/day compared to those that received any concentration of GAA for any period of time. Again this was reflected in the significant difference in carcass weight at slaughter.

Feed intake was significantly higher (P=0.006) for pigs not receiving GAA and those receiving GAA regardless of the concentration (0.3 17, 0.6 17 and 0.9 17) compared to those not receiving GAA (0.3 20, 0.6 20 and 0.9 20). This finding was unexpected as the pigs the pigs receiving the control and those on the 0.3 20, 0.6 20 and 0.9 20 treatments were all receiving the same diet in this period. Feed intake did not differ between treatments for the entire experimental period (P>0.05).

Table 1: Liveweight, average daily gain, feed intake and feed conversion ratio for female pigs fed different concentrations of GAA.

Parameter	0	0.3 17	0.6 17	0.9 17	0.3 20	0.6 20	0.9 20	SED	*P*-value	*P*-value GAA time
IW (kg)	71.1	71.3	71.2	72.0	71.0	71.6	71.9	1.90	0.997	0.947
FW (kg)	104.3^{a}	108.1^{b}	106.9^{ab}	106.1^{ab}	107.2^{ab}	107.5^{ab}	106.6^{ab}	1.52	0.318	0.059
ADG (kg/day)										
D0-21	0.86	0.95	0.87	0.84	0.77	0.82	0.83	0.081	0.559	0.235
D0-sale	0.79	0.89	0.87	0.84	0.87	0.88	0.84	0.041	0.300	0.196
FI (kg/day)										
D0-21	2.34^{c}	2.36^{c}	2.31^{bc}	2.37^{c}	2.18^{a}	2.20^{ab}	2.16^{a}	0.063	0.006	<0.001
D0-sale	2.56	2.56	2.48	2.66	2.48	2.64	2.54	0.093	0.360	0.943
FCR										
D0-21	2.82	2.52	2.67	2.84	2.87	2.83	2.60	0.30	0.842	0.759
D0-sale	3.31^{b}	2.88^{a}	2.87^{a}	3.15^{ab}	2.86^{a}	3.02^{ab}	3.04^{ab}	0.186	0.184	0.355
CW (kg)	75.4^{a}	77.2^{b}	76.8^{b}	76.6^{b}	76.2^{ab}	76.7^{b}	76.7^{b}	0.500	0.015	0.004
P2 (mm)	9.81	10.2	10.1	9.86	9.86	10.3	10.0	0.228	0.298	0.954

^{a,b,c}Means within a row with different superscripts differ significantly (P<0.05); ^{1}SED - standard error of difference of the means

Pig removals, death and the numbers of pigs per pen not reaching target slaughter weight (P>0.05) were not affected by treatment (Table 2).

Table 2: A comparison of pig removals, deaths and the numbers of pigs per pen not reaching target slaughter weight between the treatments.

Parameter	0	0.3 17	0.6 17	0.9 17	0.3 20	0.6 20	0.9 20	SED	*P*-value
Number removed/treated for illness[1]	0	0	0	0	0	0	2	-	-
Sudden deaths[2]	1	0	0	0	0	0	0	-	-
Number of pigs per pen not reaching target slaughter weight	2.25	0.5	2.00	2.25	2.25	1.50	1.00	1.48	0.837

[1]Removed/treated for illness (for example, pale) and not for physical reasons (for example lameness and tail bite); [2]Reason for deaths unknown

Objective pork quality

Objective pork quality is given in Table 3. Ultimate pH, chiller loss, relative lightness, cook loss and shear force were not affected by treatment (P>0.05). Pork from pigs that did not receive GAA for any time period was redder compared to pigs that received GAA for 0.3 17, 0.6 17, and 0.3 20. When the results for GAA and time fed were pooled and compared to the control pork from pigs fed GAA for 35 days prior to slaughter or from pigs fed GAA for 14 days prior to slaughter was less red (P=0.028). There were also differences in relative redness (a*) between other diets (P=0.011). There was a trend for pigs receiving 0.9 17 and 0.3 20 to have a reduced drip loss compared to those receiving 0.3 17 and 0.9 20 (P=0.082). There was also a trend for relative yellowness to be affected by dietary treatment with pork from pigs on the 0.6 17 and 0.3 20 diet being less yellow than those not receiving GAA or 0.3 17. Thaw loss tended to be higher for 0.9 20 compared to the control, 0.6 17, 0.9 17 and 0.3 20 (P=0.069). When the results for GAA and time fed were pooled and compared to the control there was no difference for ultimate pH, drip loss, chiller loss, surface lightness, yellowness, thaw loss, cook loss and shear force.

Table 3: Objective meat quality at 24 hours post-slaughter for seven different dietary treatments.

Parameter	**0**	**0.3 17**	**0.6 17**	**0.9 17**	**0.3 20**	**0.6 20**	**0.9 20**	**SED**	***P*-value**	***P*-value GAA time**
pH_{24}	5.50	5.51	5.61	5.52	5.57	5.52	5.55	0.045	0.230	0.416
Drip loss (%)	6.78^{ab}	7.18^{b}	6.00^{ab}	4.87^{a}	4.73^{a}	5.17^{ab}	7.15^{b}	1.13	0.082	0.528
Chiller loss (%)	2.98	2.98	3.08	3.00	3.11	3.09	3.06	0.124	0.779	0.378
L*	47.7	48.3	44.9	45.2	45.4	44.9	45.8	1.48	0.137	0.323
a*	2.31^{d}	1.31^{ab}	1.09^{a}	2.00^{bcd}	1.43^{abc}	2.05^{cd}	2.02^{cd}	0.377	0.011	0.028
b*	6.66^{b}	6.61^{b}	5.59^{a}	6.01^{ab}	5.82^{a}	6.40^{ab}	6.18^{ab}	0.410	0.084	0.231
Thaw loss (%)	9.10^{a}	10.2^{ab}	8.02^{a}	8.81^{a}	9.32^{a}	10.5^{ab}	12.5^{b}	1.48	0.069	0.109
Cook loss (%)	25.3	25.6	23.9	25.4	25.1	25.2	24.7	1.14	0.796	0.943
Shear force (N)	29.5	28.4	29.4	28.2	30.1	26.9	29.4	2.45	0.860	0.904

[a,b,c]Means within a row with different superscripts differ significantly (P<0.1); [1]SED - standard error of difference of the means

Shelf life and colour stability

Pork generally became lighter from Day 0 to Day 20 (Figure 1). There was no effect of diet or interaction for any measure of colour as the pork aged.

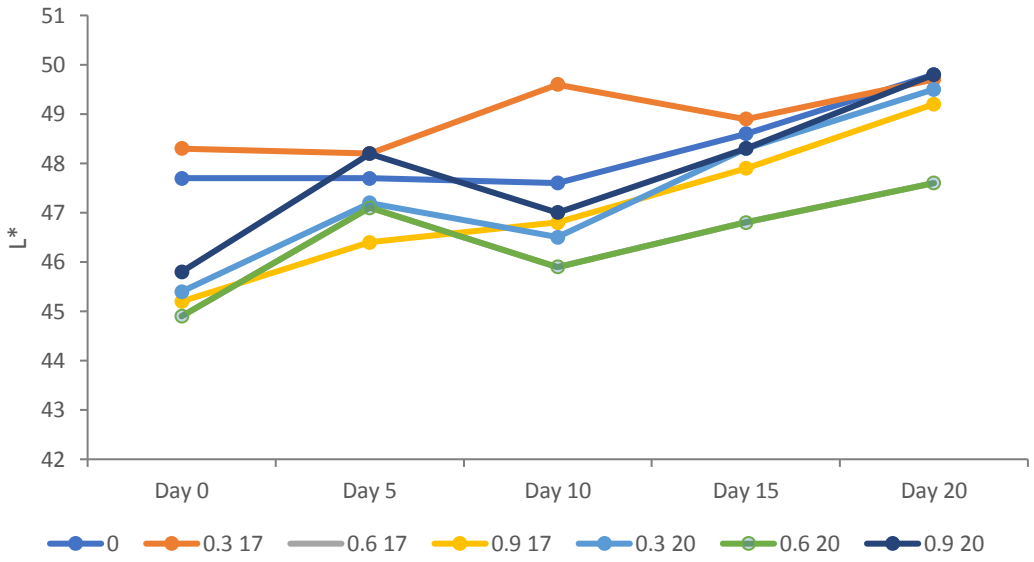

Figure 1: Change in relative lightness (L*) for pigs fed seven different diets. The P-value for time was P<0.001). All other P-values were not significant.

Pork became less red as it aged with the highest redness on Day 0 and the lowest on Day 20 (P<0.001; Figure 2). Pork from pigs receiving 0.3 20 was redder than pork from the control, 0.6 20 and 0.9 20 (P=0.038). There was no difference in redness between the other treatments.

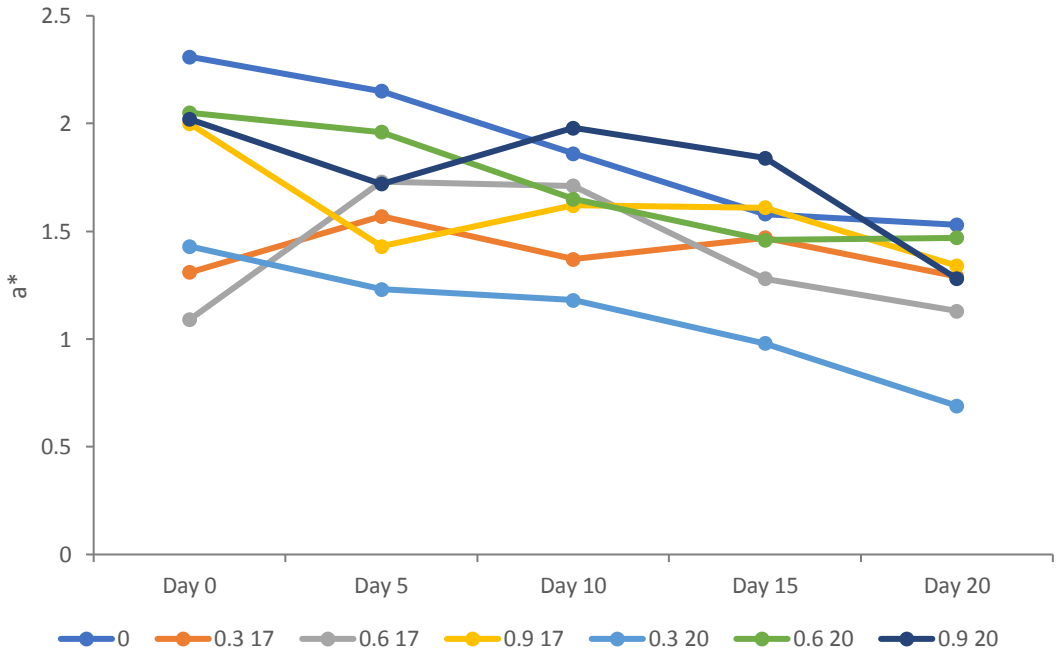

Figure 2: Change in relative redness (a*) for pigs fed seven different diets. The P-value for time and diets was P<0.001 and P=0.038, respectively. All other p-values were not significant (P>0.05).

Relative yellowness of pork increased from Day 0 to Day 20 (P<0.001, Figure 3). Pork from pigs fed 0.3 20, 0.6 17 and 0.9 17 tended to be less yellow compared to the other treatments over time.

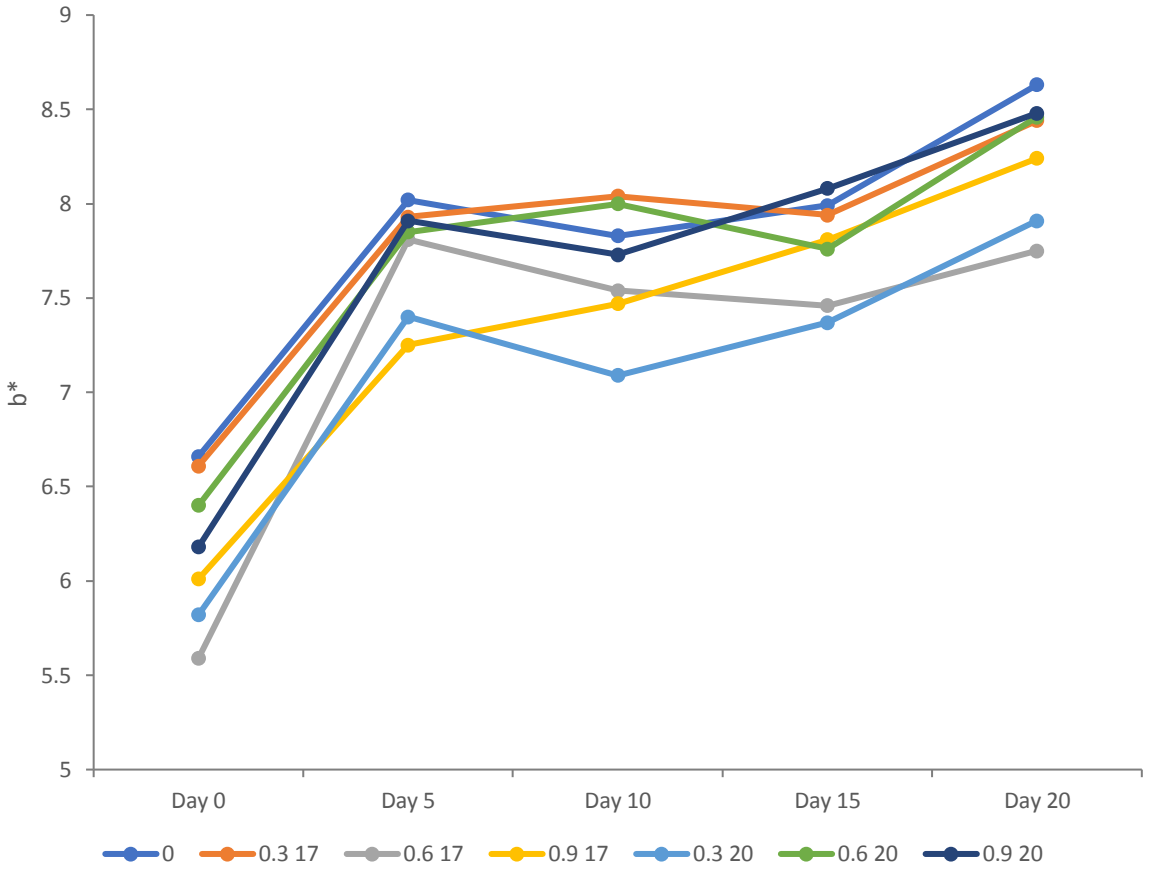

Figure 3: Change in relative yellowness (b*) for pigs fed seven different diets. The P-value for time and diet was P<0.001 and P=0.029, respectively. All other p-values were not significant (P>0.05).

There were differences in total pork colour as determined by the naked eye (total pork colour >2, Figure 4). With the exception of 0.3 17 the other concentrations of GAA and time period could be differentiated from the control on Day 0. As the pork aged the consumer was no longer able to differentiate between treatments on Day 5, 10 and 15. However, by Day 20 pigs receiving 0.6 17 or 0.6 20 could be differentiated by colour from the control.

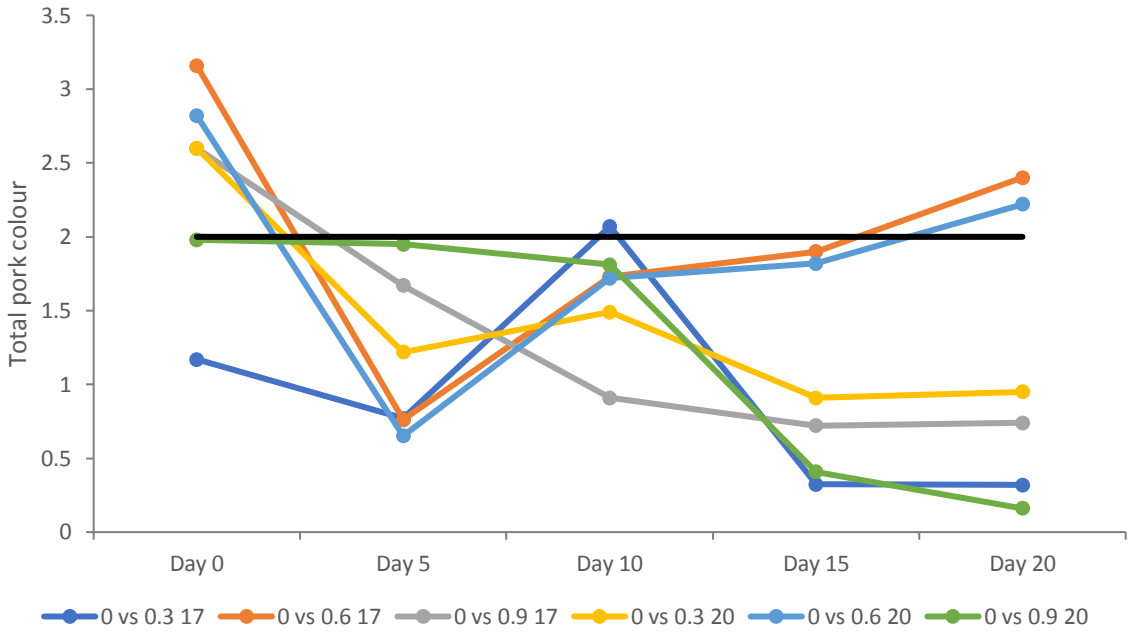

Figure 4: Total pork colour difference between seven different treatments. The values above the black line represent when the total pork colour difference is able to be detected by consumers.

Cost-benefit analysis

The cost-benefit analysis is given in Table 4. Due to the increase in carcass weight it was between $2.94 to $6.63 more beneficial to feed GAA compared to the control. Feeding GAA at 0.3 g/kg from 17 weeks to slaughter provided the greatest benefit relative to the control.

Table 4: Cost benefit analysis of including guanidinoacetic in the diet at varying concentrations and time periods.

	Treatment						
	0	0.3 17	0.6 17	0.9 17	0.3 20	0.6 20	0.9 20
Costs							
Cost of GAA	0	0.349	0.675	1.088	0.167	0.353	0.520
Total costs ($)	0	0.349	0.675	1.088	0.167	0.353	0.520
Benefits							
Increase in carcase value[1]	0	6.98	5.43	4.66	3.10	5.04	5.04
Total benefits ($)	0	6.98	5.43	4.66	3.10	5.04	5.04
Net margin/pig ($)	0	6.63	4.75	3.57	2.94	4.69	4.52

[1]Assumption: Carcasses in optimal P2 and weight range; Price schedule and GAA costs used were those current in July 21 and June 2021, respectively.

Discussion

The hypothesis that including guanidinoacetic acid in the diet of finisher pigs will increase the growth rate and feed conversion ratio and decrease back fat compared to those not receiving guanidinoacetic acid was not supported. There was no significant difference in growth rate, feed conversion ratio and back fat between any of the concentrations and time periods. While there was no significant difference in daily gain between treatments there appeared to be a commercial difference with pigs on the control diet growing between 0.05 to 0.1 kg/day slower than those which received guanidinoacetic acid (GAA) for any time period. This then resulted in a significant difference in carcass weight which was increased by between 0.8 to 1.8 kg for pigs that received GAA for any time period compared to the control.

The results from this experiment are supported by Wang *et al.* (2012) who found that when GAA was fed at 0.8, 1.2 or 2.0 g/kg from 45 kg LW until slaughter there was no effect on the feed to gain ratio, average daily gain and average daily feed intake. Lealiifano *et al.* (2021) also found no effect of GAA on backfat. Jayamaran *et al.* (2018) found that pigs fed 0.12% GAA for 60 days before slaughter had an increased growth rate, improved gain to fed and reduced back fat compared to the control. However, there was no difference if pigs were fed 0.12% for either 25 or 40 days before slaughter. In contrast, when GAA was fed at 0.1% for 15 days, pigs fed GAA had an increased average daily feed intake and daily gain (Li *et al.* 2018).

He *et al.* (2018) used a broken line model to determine the optimum concentration of GAA in the diet. They found that when GAA was included at 0, 300, 600, 900 and 1200 mg/kg for 98 days that the optimum inclusion to maximise gain to feed was 300 mg/kg. They then investigated the inclusion of 0, 150, 300, 600 and 1,200 mg/kg of GAA for 35 days and concluded that the optimal concentration of GAA to maximise daily gain and final body weight was 300 mg/kg. Therefore, they concluded that to maximise the growth performance of growing-finishing pigs then 300 mg/kg of GAA was suitable.

There has been a large variation in the concentration of GAA and the time period that GAA has been fed between studies which is likely to have contributed to the variation in outcomes. It has also been suggested that the nutrient levels of the diet may have an impact (particularly crude protein and methionine) (He *et al.* 2018; Lu *et al.* 2020). It was suggested by He *et al.* (2018) that there needs to be sufficient dietary methionine to meet the needs for creatine and protein synthesis as the inclusion of dietary GAA increases the demand. Perhaps the diet used in the present study did not contain sufficient crude protein and methionine to allow any improvements in growth performance to occur. It should be noted however, that pigs fed GAA regardless of the time period or concentration did have an increased carcass weight compared to the control so this may require further investigation.

The lower concentration and reduced time that GAA was fed for in this experiment was based on a suggestion by Lu *et al.* (2020) that the utilisation of protein may be increased by the supplementation with GAA in the finisher diet. Again, although there was no difference in growth performance there was an improvement in carcass weight which may indicate that a concentration of 0.3 g/kg of GAA from 17 weeks before slaughter is sufficient.

The hypothesis that there will be no difference in growth performance and backfat between pigs receiving the lower concentration of guanidinoacetic acid for a longer time period preslaughter or those receiving the same concentration for a shorter period preslaughter was supported. However, there was also no difference between pigs fed GAA for any time period and the control.

The hypothesis that guanidinoacetic acid will improve the colour and colour stability of fresh pork in case ready packaging compared to pork from pigs that did not receive guanidinoacetic acid was not

supported. Pork from pigs receiving GAA at any concentration or time period was less red than the control. The colour stability of fresh pork was also not improved with the inclusion of GAA in the diet as there was no interaction between treatment and time at any time point. It was thought that GAA may improve the colour stability of pork as it has been found to decrease lipid perioxidation (Wang *et al.* 2012). There have been no previous studies looking at how the colour of pork from pigs that received GAA changed over time.

At 1 g/kg GAA for 15 days pre-slaughter both Liu *et al.* (2015) and Li *et al.* (2015) found no differences in lightness, redness and yellowness between GAA and the control (Liu *et al.* 2015). In contrast, Lealiifano *et al.* (2021) found that when pigs were fed four concentrations of GAA (0, 0.33, 0.67, 1.0 kg/T) from 27 kg until slaughter at 21-22 weeks of age, pork from pigs fed GAA were darker. There was also a trend for the pork from GAA fed pigs to be less yellow.

Drip loss was not significantly different between treatments in the present study. However, there was a trend for pigs receiving 0.9 17 and 0.3 20 to have a reduced drip loss compared to those receiving 0.3 17 and 0.9 20. Thaw loss was also higher in 0.9 20 compared to the control, 0.6 17, 0.9 17 and 0.3 20. There does not appear to be any consistency between the concentrations of GAA fed and the time periods and it is not known why these results were obtained. The water-holding capacity of pork is related to the early post-mortem pH (Kim *et al.* 2014). The pH_{45} was not measured in this study so it is unknown if there was a delayed pH decline associated with GAA supplementation. The delayed pH decline would have resulted in reduced drip loss due to reduced protein denaturation (Li *et al.* 2018).

Jayamaran *et al.* (2018) also found no effect on drip loss when GAA was included at 0.12% from periods of 25 to 60 days preslaughter. In contrast, drip loss has generally been found to decrease when GAA has been included in the diet. For example, at a similar time period and concentration as the current study both Liu *et al.* and Li *et al.* (2018) found that the inclusion of 0.1 % GAA for 15 days pre-slaughter reduced drip loss. Others have also found that the inclusion of GAA at various rates and time periods have found that GAA decreases drip loss compared to the control (Wang *et al.* 2012; Lealiifano *et al.* 2021).

Shear force was not affected by the either the concentration or time fed. This is in agreement with Lealiifano *et al.* (2020). There have been conflicting results in the literature when GAA has been included in diets. For example, Lu *et al.* 2020 found that the inclusion of GAA at 0.06% for the last 60 days before slaughter increased shear force due to an increasing percentage of type II muscle fibres. In contrast when GAA was fed at 0.1% for 15 days pre-slaughter Li *et al.* (2018) found a decreased shear force in the *Longissimus dorsi* muscle with no difference in shear force in the semitendinosus muscle. Liu *et al.* (2015) also found a reduction in shear force when GAA was fed at 1 g/kg for 15 days pre-slaughter compared to the control.

Conclusion

This project aimed to provide a practical strategy which would enable producers to improve production efficiency and meat quality in finisher pigs. It appears that the inclusion of GAA in the diet did not significantly improve growth performance however, there appeared to be a commercial difference in growth rate with pigs not receiving GAA being between 2 to 4 kg lighter at the end of the experimental period than the pigs receiving GAA. This was subsequently reflected in the carcass weight where pigs not receiving GAA were significantly lighter than those receiving GAA at any concentration or period of time. The effect of GAA on meat quality was inconclusive. The highest net margin/pig was received when GAA was included in finisher diets at 0.3 g/kg from 17 weeks of age until slaughter.

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