EFFECTS OF MIXING ON THE GROWTH PERFORMANCE OF FINISHING PIGS AND FACTORS AFFECTING THE RESPONSE TO MIXING

BY

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DISSERTATION

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ABSTRACT: Five studies were conducted to evaluate the effects of mixing finishing pigs on growth performance and morbidity and mortality. Study 1 evaluated the effect of gender and of time of mixing (at either wk 9, 11, 13, 15, or 17 post-weaning) from 33.4 to 130.0 kg BW. The results of this study suggested that pigs can be mixed as late as week 17 post-weaning without affecting overall growth performance, carcass characteristics, or morbidity and mortality levels. Study 2 evaluated the effect of gender and of frequency of mixing during the marketing phase of the finishing period on the growth rate, carcass characteristics, and morbidity and mortality levels. This study showed no effect of gender or frequency of mixing (i.e., Not-mixed vs. Mixed Once vs. Mixed Twice) on morbidity and mortality levels. However, overall ADG was lower for pigs mixed twice than for those not mixed or mixed once. Studies 3 and 4 evaluated the effect of gender and BW (i.e., Light vs. Medium vs. Heavy BW) at mixing at the start of the finishing phase on growth performance and morbidity and mortality. In both studies, mixing had no effect on the growth performance of Light pigs. Mixing reduced the growth performance of Medium pigs on Study 3 but not in Study 4. Moreover, Mixing reduced the growth performance of Heavy pigs in both studies. The results of Studies 3 and 4 suggested that Mixing can have a short-term effect on the growth performance pigs, and that this effect may be influenced by other factors such as BW of pigs, but that no major long-term effect of mixing should be expected for growth performance and morbidity and mortality levels. Study 5 evaluated the effect of mixing pigs twice during the finishing phase on growth performance, and behavior (feeding and activity patterns, and aggression). The results of this study suggest that mixing pigs in the finishing period can increase the level of aggression for a short period of time, with no impact on overall growth performance or feeding patterns.

Keywords: Pigs, Mixing, Growth Performance

I would like to dedicate the work of this dissertation to my family, particularly to my Mother Lucila, my father Victor, and my siblings Victor, Paulina, Diego and Fernando; without their love, advice and support this journey would not have been possible.

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CHAPTER 1: LITERATURE REVIEW

INTRODUCTION

Current production practices often require the mixing of unfamiliar pigs at different stages in the pig production process. For example, pigs are mixed at weaning and/or at the beginning of growing-finishing period, when groups of pigs are moved into larger pens to meet their floor space requirements as pigs grow. In addition, mixing can occur when pigs of similar weight are moved into a different pen to reduce the within-group variation in weight.

The effect of mixing on pigs has been evaluated in a number of studies. Generally speaking, these studies evaluated the effect of mixing on social structure, aggression, growth performance, and metabolism of pigs. Unfortunately, few of these studies have compared responses between a mixed and a control (non-mixed) treatment, but instead reported how other factors (e.g., social, individual and environmental factors) impacted the effect of mixing. Therefore, the aim of the present review of literature review is to summarize the response of pigs to mixing on the traits previously mentioned, and to describe how this response is affected by other factors.

Effects of mixing on pigs

Effects of mixing on aggression

A summary of studies that have evaluated the effects of mixing on aggression is presented in Table 1.1. Generally speaking, the most common consequence of mixing is the increase in the level of aggression between pigs (Table 1.1). Although procedures differ between studies, most of them reported increases in aggression based on the number and duration of fights, total time spent fighting, and numbers of skin lesions per pig. For instance, Li and Johnston (2009) grouped 8-week old pigs with either familiar pigs (control) or unfamiliar pigs (mixed), and found that pigs that were mixed had 8 times more fights/pig and 87 times longer fights than the control group.

A number of authors (Meese and Ewbank, 1973; Couret et al., 2009; and Puppe et al., 2008) have attributed the increase in aggression (i.e., fights, threat, head knock, thrust, biting attempt, and biting) to the formation of a new dominance hierarchy-based social structure between the unfamiliar pigs when they are brought together. It is commonly agreed that the hierarchy order is established within the first 24 to 48 hours post mixing, after which the fighting is replaced by threats and submissive acts, and the social conditions within a newly mixed pen are stable (Meese and Ewbank, 1973; Jensen, 1982; McCort and Graves, 1982; Luescher et al., 1990). However, there is evidence that aggression levels of mixed pigs can remain higher than those of the non-mixed pigs for longer periods. For example, Stookey and Gonyou (1994) detected differences in time spent fighting between control and mixed pigs 8 days after mixing. This could indicate that different conditions (dominance hierarchy, threats and other aggressive behavior) exist between mixed and non-mixed groups, even after the first overt aggression (Jensen, 1982; Stookey and Gonyou, 1994).

Generally speaking, the increase in the levels of aggression at mixing of pigs is important because of potential impacts on, firstly, the growth performance of the animals (Stookey and Gonyou, 1994); and, secondly, their welfare (Oldigs et al., 1992; Arey and Edwards, 1998; Ruis et al., 2002).

A more detailed review of the effects of mixing on growth performance is given in later sections of this review.

Welfare is vague concept which is difficult to clearly define and measure. Some authors based their definition of welfare on the capacity of animals to behave in a natural way (Kiley-

Worthington, 1989; Rollin, 1993), or on mental states or feelings of the animals (Dawkins, 1990; Duncan, 1993; Fraser et al., 1997). However, both approaches can result in subjective assessments that are difficult to objectively measure and interpret. In contrast, it could be argued that more objective and quantitative measurements of welfare are given with the use of indices such as morbidity and mortality levels and skin lesions scores. With exception of Meese and Ewbank (1972), none of the studies reviewed have reported any increase in morbidity and mortality levels of pigs after mixing. In terms of skin lesions, Li and Johnston (2009) reported that pigs mixed at 8 weeks of age (23 kg BW) had 3.4 times more skin lesions than the control (non-mixed). Therefore, from a welfare standpoint, it could be concluded that the aggression commonly observed when unfamiliar pigs are mixed rarely results in an increase in mortality levels.

Effects of mixing on growth performance and carcass characteristics

The effect of mixing on the growth performance of pigs is summarized in Table 1.1. A total of 14 experiments evaluating the growth performance between control (non-mixed) and mixed pigs were found. In summary, 10 experiments showed no significant difference ($P > 0.05$) for overall ADG between control and mixed pigs, and 4 experiments showed that pigs that were mixed grew between 6.3 and 19.7% slower ($P < 0.05$) than control pigs for the overall study period. However, these studies were carried out over relatively short study periods (i.e., 2 to 4 weeks), therefore, any long term effect (i.e. > 4 weeks) was not measured on these studies. Interestingly, while the highest level of aggression is usually found within the first 2 days after mixing, a number of studies showed that treatment differences for ADG occurred in the second, but not the first week post-mixing (Hyun et al., 1998a and 1998b; Stookey and Gonyou, 1994). One possible reason for this delayed negative response in ADG, according to McCort and Graves

(1982), is that it is the stress of threats and submissions that follow the first overt aggression, and not that first increase in aggression per se that are responsible for the reduction in growth performance. However, when present, the negative effect of mixing on growth performance is usually considered to be transitory and without long-term effects on the overall growth performance of pigs (Sherritt et al., 1974; Greer, 1987; Heetkamp et al., 1995; Hyun et al., 1998a; Coutellier et al., 2007; Li and Johnston, 2009). For example, Li and Johnston (2009) mixed 28 kg pigs and showed a lower ADG for mixed pigs compared to the control during the first 6 weeks post-mixing; nevertheless, no differences between treatments were detected for the overall 14-week study period. Similarly, O'Connell et al. (2005) concluded that mixing pigs at the start of the finishing period (10 weeks of age) had no long-term adverse effects on performance.

Table 1.1 shows the results from studies evaluating the effect of mixing on ADFI and G:F. There were 10 studies reporting ADFI and 11 studies reporting G:F results. Generally speaking, the response to mixing for ADFI and G:F was more consistent across studies, with no treatment differences found in 8 experiments for overall ADFI, and in all 11 experiments for overall G:F.

The lack of effect on G:F suggests that the growth reduction results from a reduction on feed intake without reducing feed efficiency. Moreover, Heetkamp et al. (1995 and 2002) showed strong evidence that mixing pigs does not have a direct impact on the feed utilization of pigs. In these studies mixing 20 kg BW pigs increased heat production related to activity immediately after mixing (1 hour), but had no long term (2 to 4 weeks) effect on energy metabolism (i.e., metabolizability of feed, total heat production, activity-related heat production, or maintenance requirements).

In addition, the reduction in ADFI after mixing detected by Hyun et al. (1998a) and Li and Johnston (2009) but not in other studies could suggest that changes on ADFI were not detected possibly due to small treatment differences, or to short-term effects that were not detectable over the time period that feed intake was measured. For example, Hyun (1998b) concluded that mixing can affect the feeding behavior of pigs in the week following mixing but had no long-term effect on either feeding behavior or feed intake levels, suggesting that pigs are capable of adjusting their feeding behavior (i.e., fewer but longer visits to feeder, and increasing feed intake per visit) to keep their feed intake levels similar to those of non-mixed pigs. Nevertheless, Hyun (1998b) also reported that this adjustment in feeding behavior took place between 4 to 6 days post-mixing. This suggests that the ADFI of pigs might be compromised during the time needed for pigs to adjust their feeding behavior to meet their intake requirements, however, this period is short and could be missed depending on the period over which feed intake was measured. However, this response in ADFI does not explain the reduction in ADG associated with mixing that can be found for several days (Rundgren and Löfquist, 1989) or even weeks (Stookey and Gonyou, 1994) after pigs are mixed.

Only one study in the literature that was reviewed measured the effects of mixing on the carcass characteristics of pigs. Greer (1987) mixed 50 kg BW pigs and reported no treatment effect on the growth performance and carcass characteristics (i.e., backfat and carcass yield) of mixed pigs. These results are not surprising assuming that the effects of mixing on growth performance are short-lived, and, therefore, are likely to have no impact on carcass characteristics.

It can be concluded that mixing pigs can have a short-term negative impact on their growth performance, however, no long term effects have been shown when pigs are given enough time to recover from the mixing event. As a result, mixing is likely to have little or no effect on the carcass characteristics of pigs. However, due to the different conditions used across studies (i.e., proportion of pigs mixed, age and BW at mixing, group size, length of study and periods between data points, variables measured, etc.) further research is needed to clearly understand the mechanism responsible for the growth performance response of pigs to mixing.

Factors affecting the response to mixing

In addition to the evaluation of the aggression and growth performance of non-mixed vs. mixed pigs, a number of studies have also evaluated the effect of other factors (e.g., weight asymmetry, feed restriction, space allowance, and group size) on the response to mixing, and these studies are summarized on Table 1.2. However, these studies lacked of a control treatment (i.e., non-mixed) and, therefore, the evaluation of treatments were carried out between mixed pigs.

Effects of weight asymmetry on the response to mixing

As previously mentioned, one of the reasons for mixing pigs is to try to reduce within-group variation in weight by forming new groups of pigs of similar weight (O'Connell et al., 2005). However, a theory proposed by Enquist and Leimar (1983) suggested that confrontations between animals of similar size usually result in longer fights, compared to confrontations between animals of different size. This increase in aggression, according to Enquist and Leimar (1983), is due to the inability of animals to determine the strength of their opponent when differences in body size between the animals are small. As a result, it is possible that mixing pigs of similar weight exacerbates both the aggression related to mixing and also the effects on the growth performance of pigs.

A small number of studies have evaluated the effect of mixing pigs in groups with different weight asymmetry (i.e., variation in body weight within a pen of pigs) on aggression (Rushen, 1987; Francis et al., 1996; Andersen et al., 2000; O'Connell et al., 2005) and growth performance of pigs (Tindsley and Lean, 1984; O'Connell et al., 2005).

The results by Rushen (1987) and Andersen et al. (2000) were in agreement with Enquist and Leimar (1983), where mixing pigs with small differences in BW (< 0.5 kg, Rushen, 1987; 1.2 kg, Andersen et al., 2000) resulted in longer fights and more bites than for groups of pigs with large differences in BW (> 3.0 kg, Rushen, 1987; 3.1 kg Andersen et al., 2000). However, Tindsley and Lean (1984) and O'Connell et al. (2005) found no significant differences in the overall growth performance of pigs mixed in groups with small compared to large weight asymmetry. However, the growth performance measurements reported by O'Connell et al. (2005) were taken 6 and 17 weeks post-mixing, therefore, it is possible that any short lived response was no longer detectable at the time of measuring growth performance.

Therefore, it could be suggested that mixing pigs of similar live weight can result in increased levels of aggression compared to mixing pigs with large weight differences, without long term effects on growth performance. However, because of factors such as the lack of control treatments (i.e., non-regrouped), time of data collection after mixing, and the early timing of mixing [i.e., weaning (O'Connell et al, 2005), and 18 kg BW (Tindsley and Lean, 1984), further research is needed to determine how weight asymmetry within a group of pigs impacts the growth performance response of pigs to mixing (e.g., duration and size of negative effects), particularly during later stages of the finishing process.

Effects of group size on the response to mixing

The effect of group size on the response to mixing, including the aggression levels of pigs, is presented in Table 1.2.

A number of studies have shown that the number of fights per pig during mixing events decreases with increasing group size (Nielsen et al., 1995; Turner et al., 2001; Andersen et al., 2004). However, Andersen et al. (2004) also reported an increase in the duration of fights with increasing group size (i.e., 11.4 vs. 36.5 sec. for groups of 12 vs. 24 pigs per pen, respectively). According to Andersen et al. (2004), this reduction in the frequency and increase in the length of fights are due to two main reasons. Firstly, increasing group size reduces the proportion of pigs in the pen that can afford to risk a fight, therefore, reducing the number of fights. Secondly, because of the reduction in the proportion of pigs that can afford a fight, pigs gain more (in terms of available resources) by becoming a winner. As a result, pigs that can afford to risk a fight are likely to fight more intensely, increasing the duration of fights.

A similar reduction in the frequency of aggressive behavior with increasing group size was found by Turner et al. (2001), Andersen et al. (2004), Turner and Edwards (2004), and Samarakone and Gonyou (2009). These studies showed a change towards less aggressive behaviors for pigs reared in large groups. For example, Turner et al. (2001) mixed two pigs (one pig from each group size treatments, i.e., 20 vs. 80 pigs per pen), and found that pigs that came from the large group had lower frequency of aggressive behaviors and started fewer fights than pigs from small group size treatments.

Conversely, Andersen et al. (2004) showed that in small group sizes, pigs with low ability to fight for resources were more likely to be involved in fights because of the reduced number of competitors and the lower intensity of fights. Based on their results, Andersen et al.

(2004) concluded that pigs are able to alter their behavior, i.e., by increasing non-aggressive behavior, as the number of pigs in the group increases, according to how the competitive situation changes with group size.

Current research does not allow for the determination of a specific group size at which levels of aggression are minimized when mixing pigs. However, an approximation to this group size could be obtained based on the results of Andersen et al. (2004) and Schmolke et al (2004). Firstly, Andersen et al. (2004) compared aggression levels of pigs on different group sizes (i.e. 6 vs. 12 vs. 24 pigs per pen), and differences in aggression levels were found only for the largest group size (24 pigs per pen) compared with the smaller groups (6 and 12 pigs pen pen). Secondly, Schmolke et al. (2004) evaluated the effect of group size of 10, 20, 40, and 80 pigs per pen, and found no differences in the aggression levels (based on the number of skin lesions) between group sizes of 20, 60, and 80 pigs. These results could suggest that changes in the behavior of pigs (i.e., lower aggression levels) can be expected with the group size of around 20 pigs. Also, the similar response of pigs in a group size of 20 compared to 80 pigs per pen shown by Schmolke et al. (2004) could suggest that once group size changes behavior to a lower level of aggression (i.e., from 10 to 20 pigs per pen), no major changes with increasing group sizes would be expected (up to 80 pigs per pen as measured by Schmolke et al., 2004). Moreover, it could be suggested that the aggression levels of pigs on group size above 80 pigs per pen would also be relatively low, however, this has not been evaluated.

In conclusion, it could be suggested that mixing of pigs should be carried out in large group sizes to promote a change in the behavior of pigs towards a less aggressive behavior, and, therefore, reduce the level of aggression at the moment of mixing. However, the optimum group size required to mix pigs has not been clearly defined, and more research is needed to determine such a group size.

Effect of environmental stressors on the response to mixing

In addition to mixing, the individual effect of other environmental stressors, such as extreme ambient temperatures (Lopez et al., 1991; Nienaber et al., 1991; Xin and DeShazer, 1992; Hyun et al., 1998a; Wellock et al., 2003), and floor space allowance (Kornegay and Notter, 1984; Kornegay et al., 1993; Nielsen et al., 1995; Hyun et al., 1998a and b; Hamilton et al., 2003; Wellock et al., 2003) have been reported to reduce the growth performance of pigs. However, different stressors can occur simultaneously at the time of mixing and could exacerbate the negative effects of mixing (Hyun et al., 1998a).

A number of studies have attempted to quantify the effect of different concurrent environmental stressors on the growth performance and behavior of pigs. A study by Hyun et al. (1998a) showed that the effect of individual environmental stressors (floor space, high ambient temperature, and mixing) on the growth performance of pigs was, generally speaking, additive. Therefore, Hyun et al. (1998a) suggested that the growth performance of pigs under multiple concurrent environmental stressors could be significantly improved by removing a single stressor.

However, non-additive effects between environmental stressors can occur (Hyun et al., 1998a; Wellock et al., 2003). For example, Wellock et al. (2003) mixed groups of 10 pigs (BW = 60 kg) in "cold" vs. "hot" temperatures (i.e., 5 vs. 28°C, respectively), and compared them to control groups (not-mixed) at each temperature treatment. Similarly to other studies, Wellock et al. (2003) showed a reduction on growth performance (i.e. ADG) during the 7 d following mixing. However, the reduction on ADG immediately after mixing was greater for pigs mixed in cold conditions (i.e., −40% of control) than pigs mixed in hot conditions (−29% of control).

In conclusion, different environmental stressors can occur in swine facilities and they could exacerbate the negative effects of mixing on the growth performance of pigs. However, it still remains unclear how these stressors interact with each other and with the effects of mixing. Therefore, more research is needed to clearly understand the response to mixing in the presence of other stressors.

Effect of feed restriction on the response to mixing

To our knowledge, only two studies (Sherritt et al., 1974; and Graves et al., 1978) have evaluated the effect of mixing under conditions of feed restriction, and the results of these are summarized in Table 1.2. In both studies, pigs were mixed at weaning under ad libitum or restricted feed conditions and found a treatment interaction for growth rate: growth rate of pigs that were either mixed or under feed restriction was similar of that of pigs without a stressor (i.e. control), however, the growth rate was lower for pigs with both stressors occurring simultaneously (i.e. mixing + restricted feed). In both studies, the lack of effect of feed restriction on growth rate is surprising and could be attributed to the short duration of the restricted feeding treatment (i.e., 10 days). Therefore, these results suggest that pigs were able to cope with either mixing or restricted feed separately, however, the presence of both factors combined (i.e., mixing and limited feeding) had a negative impact on their growth rate, and pigs were not able to overcome this negative effect.

In conclusion, the available literature evaluating the effect of restricted feed on the response to mixing was published more than 30 years ago, and the results may not be applicable to current genotypes and production systems. However, both studies strongly suggested that feed restriction could exacerbate the negative effects of mixing on the growth performance of pigs. Therefore more research is needed to clearly understand this interaction with modern genotypes and production systems.

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TABLES

Table 1.1. Summary of studies evaluating the effect of mixing on growth performance, aggressive behavior, cortisol levels and heat production of pigs*

	Growth performance (kg)				Aggressive behavior				Cortisol, ng/ml		Heat production, kJ/kg^0.75/day		
Reference / Treatments	Start BW	ADG	ADFI	G:F	No. Lesions/pig	No. Fight/pig	Fights duration	Time fighting	Saliva	Plasma	Total	Activity-related	Non activity related
Couret et al., 2009													
Nulliparous gilts (age or weight not described)													
Control (not mixed)	-	0.67	-	-	-	-	-	-	-	-	-	-	-
Mixed with sows	-	0.65	-	-	-	-	-	-	-	-	-	-	-
Coutellier et al., 2007													
Pigs mixed at 4 weeks of age													
Control (not mixed)	-	-	-	-	-	-	-	-	5.80^{a}	24.52^{a}	-	-	-
Mixed pigs	-	-	-	-	-	-	-	-	9.04^{b}	36.73^{b}	-	-	-
Graves et al., 1978													
Pigs mixed at weaning (age and weaning weight not reported)													
Full fed not mixed (littermate)	-	0.77^{a}	-	-	-	-	-	-	-	-	-	-	-
Full fed mixed	-	0.76^{a}	-	-	-	-	-	-	-	-	-	-	-
Limit fed littermate	-	0.76^{a}	-	-	-	-	-	-	-	-	-	-	-
Limit fed mixed	-	0.66b	-	-	-	-	-	-	-	-	-	-	-
Greer, 1987													
Control (not moved and not mixed)	20	0.64	1.85	0.35	-	-	-	-	-	-	-	-	-
Pigs moved to a different pen every 4 weeks	20	0.64	1.93	0.33	-	-	-	-	-	-	-	-	-
Pigs moved to a different pen every 4 weeks and mixed after 8 weeks	20	0.64	1.90	0.34	-	-	-	-	-	-	-	-	-
Francis et al., 1996- Trial 1													
Mixed at 27 days of age													
Day 0-5													
Control (not mixed)	-	0.10	0.18^{a}	0.54	-	-	-	-	-	-	-	-	-
Mixed in groups of uniform weight	-	0.10	0.16^{b}	0.55	-	-	-	-	-	-	-	-	-
Mixed in groups of heterogeneous weight	-	0.07	0.12^{c}	0.57	-	-	-	-	-	-	-	-	-
Day 0-19													
Control (not mixed)	-	0.33^{a}	0.43^{a}	0.75^{a}	-	-	-	-	-	-	-	-	-
Mixed in groups of uniform weight	-	0.29b	0.42^{b}	0.70^{ab}	-	-	-	-	-	-	-	-	-
Mixed in groups of heterogeneous weight	-	0.24c	0.35^{c}	0.76^{b}	-	-	-	-	-	-	-	-	-
Francis et al., 1996- Trial 2													
Mixed at 27 days of age													
Day 0-5													
Control (not mixed)	-	0.10b	0.15	0.61^{b}	-	-	-	-	-	-	-	-	-
Mixed in groups of uniform weight	-	0.10b	0.16	0.68^{b}	-	-	-	-	-	-	-	-	-
Mixed in groups of heterogeneous weight	-	0.15^{a}	0.15	0.99^{a}	-	-	-	-	-	-	-	-	-
Day 0-19													
Control (not mixed)	-	0.27b	0.39	0.72	-	-	-	-	-	-	-	-	-
Mixed in groups of uniform weight	-	0.28^{a}b	0.39	0.72	-	-	-	-	-	-	-	-	-
Mixed in groups of heterogeneous weight	-	0.30^{a}	0.40	0.76	-	-	-	-	-	-	-	-	-
Heetkamp et al., 1995													
Pigs mixed at 8 weeks of age													
Control (not mixed)	19.1	0.33	0.66	0.50	-	-	-	-	-	-	611	154	456
Mixed	19.6	0.35	0.67	0.52	-	-	-	-	-	-	605	138	467
Heetkamp et al., 2002													
Pigs mixed at 9 weeks of age													
Control (not mixed)	19.6	0.19	0.46	0.41	-	-	-	-	-	-	573	123	450^{a}
Mixed	19.1	0.20	0.45	0.44	-	-	-	-	-	-	572	108	464^{b}
Hyun et al., 1998a													
4-week study period													
Week 1													
Control (not mixed)	35.8	0.69	1.88	0.37	-	-	-	-	-	-	-	-	-
Mixed twice (Start & 3rd week of study)	35.8	0.68	1.89	0.37	-	-	-	-	-	-	-	-	-
Week 2													
Control (not mixed)	-	0.78^{a}	1.96	0.40^{a}	-	-	-	-	-	-	-	-	-
Mixed twice (Start & 3rd week of study)	-	0.68b	2.02	0.34^{b}	-	-	-	-	-	-	-	-	-
Week 3													
Control (not mixed)	-	0.71^{a}	2.12	0.34	-	-	-	-	-	-	-	-	-
Mixed twice (Start & 3rd week of study)	-	0.70b	2.04	0.34	-	-	-	-	-	-	-	-	-
Week 4													
Control (not mixed)	-	0.74^{a}	2.13	0.35	-	-	-	-	-	-	-	-	-
Mixed twice (Start & 3rd week of study)	-	0.65b	2.10	0.31	-	-	-	-	-	-	-	-	-
Overall (week 1 – 4)													
Control (not mixed)	-	0.73^{a}	2.02	0.36	-	-	-	-	-	-	-	-	-
Mixed twice (Start & 3rd week of study)	-	0.68b	2.02	0.34	-	-	-	-	-	-	-	-	-

[a,b,c] Within a study, means with different superscripts are different ($P < 0.05$).

*Where no superscripts are presented, there were no differences ($P > 0.05$) between treatments

Table 1.1. Continued.*

	Growth performance (kg)				Aggressive behavior				Cortisol, ng/ml			Heat production, kJ/kg^0.75/day	
Reference / Treatments	Start BW	ADG	ADFI	G:F	No. Lesions/pig	No. Fight/pig	Fights duration	Time fighting	Saliva	Plasma	Total	Activity-related	Non activity related
Hyun et al., 1998b													
4-week study period													
Week 1													
Control (not mixed)	34.7	0.72	1.77	0.41									
Mixed twice (Start & 3rd week of study)	34.7	0.66	1.69	0.39									
Week 2													
Control (not mixed)	-	0.80^{a}	1.93	0.42									
Mixed twice (Start & 3rd week of study)	-	0.68^{b}	1.81	0.38									
Week 3													
Control (not mixed)	-	0.75^{a}	2.06	0.36									
Mixed twice (Start & 3rd week of study)	-	0.67^{b}	1.99	0.34									
Week 4													
Control (not mixed)	-	0.76	2.21	0.33									
Mixed twice (Start & 3rd week of study)	-	0.71	2.08	0.34									
Overall (week 1 – 4)													
Control (not mixed)	-	0.75^{a}	1.99^{a}	0.37									
Mixed twice (Start & 3rd week of study)	-	0.68^{b}	1.89b	0.36									
Li and Johnston, 2009													
Mixed at 23 kg BW													
Week 0-6					2-d after Mixing	Day of Mixing							
Group of familiar pigs	22.9	0.83^{a}	1.78^{a}	0.48	1.8^{b}	0.2^{b}	1.9^{b} sec	-	-	-	-	-	-
Group of unfamiliar pigs	23.0	0.80^{b}	1.74^{b}	0.48	6.6^{a}	1.6^{a}	30.9^{a} sec	-	-	-	-	-	-
Overall week 0-14													
Group of familiar pigs	-	0.82	2.2	0.40	-	-	-	-	-	-	-	-	-
Group of unfamiliar pigs	-	0.81	2.17	0.40	-	-	-	-	-	-	-	-	-
Moore et al., 1994													
Control (not mixed)	29.1	0.75	-	-	-	-	-	-	-	-	-	-	-
Mixed	29.1	0.73	-	-	-	-	-	-	-	-	-	-	-
O'Connell et al., 2005													
Mixed at 4 weeks of age					2 days post mixing (aggressions/minute)								
Control (not mixed)	30.2	NS	NS	NS	-	0.45^{a}	-	-	-	-	-	-	-
Mixed	30.2	NS	NS	NS	-	0.95^{b}	-	-	-	-	-	-	-
Sherritt et al., 1974													
Experiment 1, wean to finish period, weaning age and weight was not described)													
Control (litters not mixed)	N/A	0.73	2.25	0.32	-	-	-	-	-	-	-	-	-
Litters mixed at weaning	N/A	0.73	2.28	0.32	-	-	-	-	-	-	-	-	-
Litter mixed 3 weeks post weaning	N/A	0.76	2.34	0.33	-	-	-	-	-	-	-	-	-
Experiment 2, 6-week study period, end at 54 kg													
Control (Ad libitum and litter not mixed)	23	0.78^{a}	-	-	-	-	-	-	-	-	-	-	-
Ad libitum and mixed litters	23	0.77^{a}	-	-	-	-	-	-	-	-	-	-	-
Limited feeding for 10 days and litter not mixed	23	0.77^{a}	-	-	-	-	-	-	-	-	-	-	-
Limited feeding for 10 days and mixed litters	23	0.65^{b}	-	-	-	-	-	-	-	-	-	-	-
Stookey and Gonyou, 1994													
Week 1													
Control (not mixed)	83.1	0.85	-	0.28	-	-	-	-	-	-	-	-	-
Mixed	83.5	0.83	-	0.30	-	-	-	-	-	-	-	-	-
Mixed 24 h, then returned to original pen mates	84.8	0.81	-	0.28	-	-	-	-	-	-	-	-	-
Week 2													
Control (not mixed)	-	0.88^{a}	-	0.25	-	-	-	-	-	-	-	-	-
Mixed	-	0.71^{c}	-	0.22	-	-	-	-	-	-	-	-	-
Mixed 24 h, then returned to original pen mates	-	0.80^{b}	-	0.22	-	-	-	-	-	-	-	-	-
Overall (week 1-2)													
Control (not mixed)	-	0.87^{a}	-	0.28	-	-	-	-	-	-	-	-	-
Mixed	-	0.77^{b}	-	0.27	-	-	-	-	-	-	-	-	-
Mixed 24 h, then returned to original pen mates	-	0.80^{b}	-	0.27	-	-	-	-	-	-	-	-	-
Time fighting m/day (6 h observation period)													
Day 1													
Control (not mixed)	-	-	-	-	-	-	-	0.26^{b}	-	-	-	-	-
Mixed	-	-	-	-	-	-	-	1.72^{a}	-	-	-	-	-
Mixed 24 h, then returned to original pen mates	-	-	-	-	-	-	-	-	-	-	-	-	-
Day 2													
Control (not mixed)	-	-	-	-	-	-	-	0.13^{b}	-	-	-	-	-
Mixed	-	-	-	-	-	-	-	0.39^{a}	-	-	-	-	-
Mixed 24 h, then returned to original pen mates	-	-	-	-	-	-	-	0.12^{b}	-	-	-	-	-
Day 8													
Control (not mixed)	-	-	-	-	-	-	-	0.04^{b}	-	-	-	-	-
Mixed	-	-	-	-	-	-	-	0.23^{a}	-	-	-	-	-
Mixed 24 h, then returned to original pen mates	-	-	-	-	-	-	-	0.02^{b}	-	-	-	-	-

[a,b,c] Within a study, means with different superscripts are different ($P < 0.05$).
*Where no superscripts are presented, there were no differences ($P > 0.05$) between treatments

Table 1.2. Factors affecting the growth performance and aggression response to mixing of pigs.*

Treatments	Growth performance, kg						Aggression/behavior				
	Start BW	End BW	Start CV	ADG	ADFI	G:F	Bites given	Lesions/ pig	Fights/ pig	Fight duration	Time fighting
Weight asymmetry within group											
Andersen et al., 2000											
Large weight asymmetry (3.1 kg between each pig)	16.6	-	-	-	-	-	38.8[a]	46.6	15	135.1[a]	-
Small weight asymmetry (1.2 kg between each pig)	14.1	-	-	-	-	-	57.2[b]	41.7	17.2	215.9[b]	-
O'Connell et al., 2005											
Growing period (4 wk age to 10 wk age)											
Mixed at weaning (4 wk age) in groups of small weight asymmetry	9.7	-	0.07[a]	0.51	0.76	0.67	-	-	-	-	-
Mixed at weaning (4 wk age) in groups of large weight asymmetry	9.7	-	0.16[b]	0.51	0.76	0.67	-	-	-	-	-
Finishing period (10 wk age to 21 wk age)											
Mixed at weaning (4 wk age) in groups of small weight asymmetry	30.1	-	0.13	0.83	2.15	0.38	-	-	-	-	-
Mixed at weaning (4 wk age) in groups of large weight asymmetry	30.1	-	0.15	0.83	2.15	0.39	-	-	-	-	-
Rushen, 1987											
Pigs mixed at 5 wk of age											
Mixed in group of small weight asymmetry	10.0	-	10.4	-	-	-	-	-	-	591.8[a]	-
Mixed in group of large weight asymmetry	10.9	-	21.8	-	-	-	-	-	-	163.4[b]	-
Tindsley and Lean, 1984											
10 week-study period											
Gilts, regrouped with animals of even weight, SD = 0.5 kg	18.0	33.6[a]	2.8[a]	0.47	1.48	0.32	-	-	-	-	-
Gilts, regrouped with animals of mixed weight, SD = 4.5 kg	18.0	30.9[b]	25.0[b]	0.46	1.47	0.31	-	-	-	-	-
Group size											
Andersen et al., 2004											
Group size = 6 pigs	14.5[a]	-	-	-	-	-	-	-	33.1[a]	14.1[a]	442.1
Group size = 12 pigs	12.8[b]	-	-	-	-	-	-	-	33.8[a]	11.4[a]	411.5
Group size = 24 pigs	12.7[b]	-	-	-	-	-	-	-	5.1[b]	36.5[b]	232.1
Feed restriction											
Sherritt et al., 1974											
Control (Ad libitum and litter not mixed)	23	-	-	0.78[a]	-	-	-	-	-	-	-
Ad libitum and mixed litters	23	-	-	0.77[a]	-	-	-	-	-	-	-
Limited feeding for 10 days and litter not mixed	23	-	-	0.77[a]	-	-	-	-	-	-	-
Limited feeding for 10 days and mixed litters	23	-	-	0.65b	-	-	-	-	-	-	-
Graves et al., 1978											
Pigs mixed at weaning (age and weaning weight not reported)											
Full fed not mixed (littermate)	-	-	-	0.77[a]	-	-	-	-	-	-	-
Full fed mixed	-	-	-	0.76[a]	-	-	-	-	-	-	-
Limit fed littermate	-	-	-	0.76[a]	-	-	-	-	-	-	-
Limit fed mixed	-	-	-	0.66[b]	-	-	-	-	-	-	-
Proportion mixed											
Barnett et al., 1994											
6-months of age at start of study											
No food provided at time of Mixing (Control)	-	-	-	-	-	-	-	28.4	118	-	-
Food present at time of Mixing in the morning	-	-	-	-	-	-	-	21.4	112	-	-
Food present at time of Mixing in the afternoon	-	-	-	-	-	-	-	31.1	128	-	-
Food present ad libitum for 24 h	-	-	-	-	-	-	-	18.5	89	-	-
Food present ad libitum for 48 h	-	-	-	-	-	-	-	25.3	122	-	-
Mixed 30 minutes after sunset, no food provided at mixing	-	-	-	-	-	-	-	27.8	77	-	-
Giersing and Andersson., 1998											
12 wk of age at start of study								1.5-2 h period			
Male to male interactions	-	-	-	-	-	-	-	-	2.34[a]	-	-
Male to female interactions	-	-	-	-	-	-	-	-	3.43[b]	-	-
Female to male interactions	-	-	-	-	-	-	-	-	2.18[a]	-	-
Female to female interactions	-	-	-	-	-	-	-	-	2.38[a]	-	-
O'Connell et al., 2004											
Multiparous sows (age or weight not described)								1d post mixing (aggressions/minute)			
4 pigs added to a pen of 40 (10%)	-	-	-	-	-	-	-	-	0.018	-	-
8 pigs added to a pen of 40 (20%)	-	-	-	-	-	-	-	-	0.013	-	-
12 pigs added to a pen of 40 (30%)	-	-	-	-	-	-	-	-	0.011	-	-
16 pigs added to a pen of 40 (40%)	-	-	-	-	-	-	-	-	0.029	-	-
Others (i.e., Amperozide and tryptophan)											
Barnett, J.L. et al., 1996											
7months of age at start of study											
Unfamiliar pigs Mixed (control)	-	-	-	-	-	-	-	19.4	47.2	-	-
Control + partial stalls in pen	-	-	-	-	-	-	-	13.4	49.9	-	-
Control + 0.5 mg/kg of amperozide 5 minutes pre-mixing	-	-	-	-	-	-	-	14.9	35.6	-	-
Mixed 30 minutes after sunset	-	-	-	-	-	-	-	13.4	21.3	-	-
Koopmans et al., 2006											
Study started at 30 days of age. Trp diet fed from d 0 to 10 of study. Data available only from day 10 to 20											
Mixed pig fed 5 g/kg tryptophan on diet	-	-	-	0.24	0.35	0.68	-	-	-	-	-
Mixed pig with no supplemental Trp	-	-	-	0.17	0.36	0.49	-	-	-	-	-

[a,b] Within a study, means with different superscripts are different ($P < 0.05$).
*Where no superscripts are presented, there were no differences ($P > 0.05$) between treatments

CHAPTER 2: EFFECTS OF GENDER AND TIME OF MIXING OF PIGS DURING THE GROW-FINISH PERIOD ON THE GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS IN A COMMERCIAL WEAN-TO-FINISH FACILITY.

ABSTRACT

The objective of this study was to evaluate the effect of gender and time of mixing of pigs during the grow-finish period on the growth performance and carcass characteristics. A RCBD was used with a 2 × 6 factorial arrangement of treatments: 1) Gender (barrows and gilts) and 2) Timing of mixing [Control (Not mixed), and week 9, week 11, week 13, week 15 and week 17 post-weaning]. The study involved two replicates (24 pens/replicate), with a total of 1,440 pigs housed in single gender pens of 30. The growth evaluation was carried out from week 9 post-weaning (33.4 ± 1.27 kg live weight) to a mean pen BW of 130.0 ± 2.15 kg live weight when pigs were sent for harvest to a commercial plant where carcass measurement were taken. There were no treatment interactions ($P > 0.05$) for any measurement. Morbidity and mortality levels were not affected ($P > 0.05$) by any of the treatments. There was no gender effect ($P > 0.05$) on overall ADG. Barrows had higher ($P < 0.05$) overall ADFI and lower ($P < 0.05$) overall G:F than gilts. Gilts had greater ($P < 0.05$) carcass yield, greater *Longissimus* muscle depth, and lower ($P < 0.05$) back fat thickness than barrows, resulting in gilts having a greater predicted carcass lean content ($P < 0.05$) than barrows. Mixing pigs had no effect ($P > 0.05$) on overall growth performance or on carcass measures, regardless of the time of mixing. There was a significant ($P < 0.05$) difference in G:F between mixing treatments for the period between week 11 and 13 of study, however, the differences were small and of little practical relevance. These results suggest that under the current conditions of the study, pigs can be mixed as late as week 17 post-weaning without affecting growth performance, carcass characteristics or morbidity and mortality levels. Key Words: pigs, growth, mixing, gender.

INTRODUCTION

Current commercial production practices often require the mixing of unfamiliar pigs at different stages in the pig production process. For instance, pigs are mixed at weaning and/or at the beginning of growing-finishing period, when groups of pigs are moved into larger pens to meet their floor space requirements as pigs grow, or when pigs of similar weight are moved into a different pen to reduce the within-group variation in weight.

The effect of mixing on the growth performance and morbidity and mortality levels of pigs has been evaluated in a number of studies. Generally speaking, it has been shown that mixing does not affect the levels of morbidity and mortality, and that it has either no effect (Heetkamp et al., 2002; O'Connell et al., 2004) or a negative effect (Tuscherer et al., 1998; Hayne and Gonyou, 2003; Coutellier et al., 2007) on the growth performance of pigs (i.e. ADG).

When present, the negative effects of mixing on ADG have been reported to be transitory [detected up to 2 to 6 weeks after mixing (Hyun et al., 1998b; and Li and Johnston, 2009) and pigs will recover that growth when given enough time. However, due to the different conditions used during these studies (e.g., length of study period, group size, proportion of pigs mixed, and age at mixing), it is difficult to apply their results to commercial conditions.

Moreover, practices such as penning barrows and gilts separated, moving pigs into larger pens to meet their space requirements, and mixing pigs of similar weight to reduce the within-group variation in slaughter weight, require pigs of the same gender to be mixed at later stages in the production process than those used in most studies. It could be speculated that the stress of mixing would increase at heavier weights; therefore, it is possible that mixing can have a bigger effect on pigs mixed at later stages of their growth period than on those mixed earlier at lighter weights. However, to our knowledge, no study has evaluated the effects of mixing pigs at a range of weights on the main production traits of barrows and gilts.

Therefore, the present study was carried out to evaluate the effects of gender and time of mixing of pigs during the grow-finish period on the growth performance and carcass characteristics in a commercial wean-to-finish facility.

MATERIALS AND METHODS

This preliminary study was carried out to evaluate the effects of gender and time of mixing of pigs during the grow-finish period on the growth performance and carcass characteristics in a commercial wean-to-finish facility. The study was carried out at the Georgia Technology Center of The Maschhoffs located near Carlyle, IL, which is a commercial wean-to-finish facility equipped with state of the art equipment to collect data on growth performance and feed intake under typical commercial conditions. The experimental protocol for this study was approved by the University of Illinois Institutional Animal Care and Use Committee (IACUC protocol number: 11202).

Experimental Design and Treatments

The study was conducted as a randomized complete block design with a 2 × 6 factorial arrangement of treatments: 1) Gender (barrows and gilts) and 2) Timing of mixing [Control (Not mixed), and week 9, week 11, week 13, week 15 and week 17 post-weaning]. Body weight as blocking factor. The study involved a total of 48 pens in 2 replicates (24 pens/replicate). The experimental unit was the 2 pens of the same gender on the same Timing of Mixing treatment level between which pigs were exchanged for the mixing process. The two replicates started on study on the same day.

Animals and Allotment to Growth Study

The study involved a total of 1,440 pigs (initial BW = 33.4 ± 1.27 kg live weight) that were the progeny of PIC 359 sires mated to PIC C29 dams (PIC USA, Hendersonville, TN). A total of 48 single-gender pens of 30 pigs were allotted to the study. Prior to allotment, pigs were reared in a different facility in mixed-gender pens of ~150 animals (original pens). At week 9 post-weaning, pigs were transferred to the Georgia Technology Center of The Maschhoffs. Upon arrival, pigs were weighed individually, given an individual identification (ear tag), and sorted by gender within original pen. New pens of 30 pigs were formed from the original pens (2 pens of barrows and 2 of gilts per original pen). The individual pig weights were used to calculate the average weight of the original pens. Within gender, the original pens were ranked by mean pen weight, and pigs were allotted from 3 of the original pens that were closest in weight to 6 new pens of each gender such that the mean pen weight and variation in weight were similar for the 6 new pens. Within gender, the new pens were randomly allotted to Timing of Mixing treatment level and immediately started on test. Pens on the Week 9 mixing treatment were mixed on the day of start on test.

Mixing process

Mixing of pigs was carried out between the two pens within a replicate of the same Gender by Timing of Mixing treatment combination. Pens were split into 2 groups of 15 pigs with similar average live weight and variation in live weight to that of the pen. One group from each pen (half of the pigs) was moved to the other pen.

Housing

The study was carried out in a commercial wean-to-finish building that was curtain sided and had tunnel ventilation for control of ambient temperature. The building had fully-slatted concrete floors and a deep (2.4 m) manure pit; pen divisions were of horizontal steel bars. The thermostat was set at 18.3°C throughout the study period, and temperature in the building was maintained using thermostatically controlled heaters and fan ventilation. Each pen was equipped with a 5-space wet-dry box feeder and two cup-type water drinkers. The floor space was 0.67 m^2/pig for all treatments.

Diet Preparation and Feeding

All diets were formulated to meet or exceed the requirements of pigs across the weight range used in this study recommended by NRC (1998). During the study period, a 5-phase dietary feeding program was used as follows:

Phase 1 (fed from 18 to 45 kg live weight).

Phase 2 (fed from 45 to 68 kg live weight).

Phase 3 (fed from 68 to 95 kg live weight).

Phase 4 (fed from 95 to 109 kg live weight).

Phase 5 (fed from 109 to 125 kg live weight).

All experimental diets were manufactured in pellet form at the Griggsville Mill of the Maschhoffs. Diet formulations and calculated and analyzed compositions are presented in Table 2.1. Feed and water were available *ad libitum* throughout the study period.

Study Period and Measurements

The study was carried out from a fixed time (week 9 post-weaning) to a mean pen BW of 130.0 ± 2.15 kg live weight. Pen weights were taken at the start and end of the study and every 2 weeks during the study period. Individual body weights were taken at the start and at the end of the test period, and immediately before the pigs were mixed. All feed additions and the feed remaining in the feeder were recorded at the time of pig weighing and were used to calculate ADFI and G:F.

Animals that died during the study or became morbid and had to be removed from the study were weighed and the date, weight, and possible cause of the morbidity or mortality were recorded using the following categories:

1. Respiratory disease = PRRS, pneumonia, influenza, and thumping
2. Gastrointestinal disease = ileitis, hemorrhagic bowel, obstructed bowel, and ulcers
3. Other disease = *streptococcus swis* and greasy pig *(staphylococcus hyicus*)
4. Injury = broken bones, cannibalism, abscesses, and swollen joints
5. Structural defects = broken top, leg soundness issues, and spraddle legs
6. Hernia = scrotal and umbilical hernias
7. Emaciation = fall out, anorexia, and general unthriftiness
8. NANI = downers and stress related issues
9. Other

When an animal was removed from the pen, the pen floor space was reduced accordingly using metal gates to maintain the same floor space per pig throughout the study period.

Harvest and Carcass Measurements

Intact pens were taken off test and sent for harvest when the pen mean reached 130 ± 2.15 kg live weight. The pigs were weighed individually (harvest live weight) prior to being loaded onto the trailer (with 165 pigs/load). Pigs were transported on the day of harvest on a standard trailer to Cargill Meat Solutions in Beardstown, IL. Upon arrival, pigs were allowed a period in lairage of at least 3 hours prior to harvest which was carried out using standard procedures.

Carcass grading measurements were taken on the slaughter line including hot carcass weight, and Fat-O-Meater® 10th rib backfat thickness and *Longissimus* muscle depth, and predicted carcass lean content.

Statistical Analysis

Two pens of the same gender and Time of Mixing treatment combination (i.e. the 2 pens which pigs were exchanged for the mixing process) were used as the experimental unit for growth and carcass measurements. All variables were checked for normality using the PROC UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, NC). Those meeting the criteria for analysis of variance were analyzed using the PROC MIXED procedure of SAS. The model used included the fixed effects of Gender and Mixing treatments and the two way interaction, and the random effects of block (live weight). The LSMEANS procedure was used to estimate mean values, and the PDIFF option was used to separate treatment means. Mortality and morbidity data were not normally distributed, and, therefore, they were analyzed using a χ^2 rank-based transformation using the PROC RANK procedure of SAS. Transformed mortality and morbidity data was analyzed using the MIXED procedure of SAS.

RESULTS AND DISCUSSION

Least squares means for the effects of Gender and Time of Mixing on the growth performance and carcass characteristics of pigs are presented in Table 2.2 and 2.3, respectively. There were no Gender by Time of Mixing interactions ($P > 0.05$) for any of the measured traits, therefore, only the main effects will be discussed.

Effect of gender

There was no effect ($P > 0.05$) of gender on overall average daily gain, however, overall average daily feed intake of barrows was 7% higher ($P < 0.05$) than that of gilts, resulting in poorer (4.6%; $P < 0.05$) overall G:F for barrows than gilts. Carcass yield was 0.8 percentage units greater ($P < 0.05$) for gilts than barrows. Moreover, gilts had greater ($P < 0.05$) *Longissimus* muscle depth (8.2%) and lower ($P < 0.05$) back fat thickness (12.7%), resulting in gilts being 1.5 percentage units leaner ($P < 0.05$) than barrows. Morbidity and mortality levels were not affected ($P > 0.05$) by gender. In general, the gender differences found in the current study are in line with other studies evaluating the effect of gender on growth performance (Campbell, et al., 1991; Morales et al., 2011; Gispert et al., 2010), carcass characteristics (Cisneros and Ellis, 1996; Hamilton, et al,. 2003; Peinado et al., 2008), and morbidity and mortality (Rodrígez-Sánchez, et al., 2011) of pigs.

Effect of time of mixing

Generally speaking, mixing pigs had no effect ($P > 0.05$) on either interim or overall growth performance or on carcass measures, regardless of the time of mixing. There was a significant ($P < 0.05$) difference in Gain:Feed between mixing treatments for the period between week 11 and 13 of study, however, the differences were small and of little relevance. We are unaware of any study that has been carried out under similar conditions of group size, body weight, length of study, and proportion of pigs mixed to those used in the current study, consequently, comparisons of results between this and other studies should be made with caution.

A lack of effect of mixing on average daily feed intake and Gain:Feed, as found in this study, was consistently reported in all of the studies reviewed (Chapter 1, Table 1.1). Interestingly, with the exception of Anon (1981) showing a positive effect of mixing on growth rate, mixing of pigs has been shown to have either no effect or a negative effect on growth performance (Chapter 1, Table 1.1). Similar to Greer (1987), Heetkamp et al. (2002) and O'Connell et al. (2004), the present study showed no effect of mixing on growth rate. However, our results disagree with those of Hyun et al. (1998a and 1998b), Li and Johnston (2009), and Stookey and Gonyou (1994), where mixed pigs grew between 6 and 20% slower than non-mixed pigs.

The main reason for the absence of effect of mixing on the growth rate of pigs in the present study is not clear. Hyun et al. (1998b) and O'Connell et al. (2005) reported mixing as a transient stressor and, if given sufficient time, pigs can compensate for a short-term reduction in performance. Moreover, it has been suggested that the growth performance response of pigs to mixing can be affected by a number of factors such as the level of aggression (McCort and Graves, 1982; Stookey and Gonyou, 1994), group size (Andersen et al., 2004; Turner and Edwards, 2004), and the proportion of new pigs introduced to the pen (O'Connell et al., 2004). However, with exception of the proportion of pigs introduced (50% of pen), the rest of factors above mentioned were not measured directly on the present study.

Therefore, it is possible that if mixing had any effect on growth performance of pigs in the present study, the effect was short lived (< 2 weeks) such that it was not detected between weigh periods.

CONCLUSIONS

These results suggest that under the current conditions of the study, pigs can be mixed as late as week 17 post-weaning without affecting growth performance, carcass characteristics or morbidity and mortality.

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TABLES

Table 2.1. Diet formulations and calculated composition.

Item	Dietary phase Phase 1[a]	Phase 2[b]	Phase 3[c]	Phase 4[d]	Phase 5[e]
Ingredient, %					
Corn yellow	52.30	62.26	68.26	71.43	72.63
Soybean meal	30.50	20.46	14.46	11.31	10.12
DDGS	15.00	15.00	15.00	15.00	15.00
Limestone, ground	0.947	0.892	0.898	0.924	0.934
Liquid Lysine	0.267	0.353	0.349	0.324	0.316
Salt	0.408	0.408	0.404	0.404	0.404
Fat – yellow grease	0.300	0.405	0.474	0.445	0.427
Trace mineral premix[1]	0.100	0.100	0.075	0.075	0.075
Threonine	0.043	0.035	0.030	0.028	0.027
Monocalcium phosphate	0.109	0.071	0.041	0.058	0.065
Alimet	0.019	0.005	-	-	-
Vitamin premix	0.030	0.030	0.025	0.025	0.025
Optiphos 1000	0.022	0.018	0.012	0.008	0.008
Total, %	100	100	100	100	100
Composition	Calculated	Calculated	Calculated	Calculated	Calculated
ME, Kcal/kg	3305	3303	3303	3298	3295
Crude protein, %	22.05	17.90	15.44	14.14	13.65
Crude fat, %	3.46	3.80	3.99	4.04	4.06
Crude fiber, %	2.82	2.67	2.60	2.55	2.53
Neutral Detergent Fiber, %	10.70	10.78	10.82	10.85	10.86
Acid Detergent Fiber, %	4.38	4.17	4.06	3.98	3.96
Calcium, %	0.55	0.48	0.45	0.45	0.45
Phosphorus, %	0.49	0.44	0.42	0.41	0.40
Available phosphorus, %	0.28	0.24	0.20	0.18	0.18
Calcium:Phosphorus	1.12	1.08	1.08	1.11	1.11
Sodium, %	0.22	0.21	0.21	0.22	0.22
Salt, %	0.30	0.50	0.50	0.50	0.50
Total lysine, %	1.29	1.06	0.89	0.80	0.76
Digestible lysine, %	1.10	0.90	0.75	0.66	0.63
Digestible lysine:ME	3.27	2.72	2.27	2.00	1.90
Methionine + Cystine:Lysine Dig.)	0.57	0.59	0.62	0.58	0.68
Tryptophan:Lysine (Dig.)	0.21	0.19	0.19	0.19	0.19
Threonine:Lysine (Dig.)	0.64	0.62	0.63	0.64	0.66
Isoleucine:Lysine (Dig.)	0.73	0.70	0.71	0.60	0.73
Valine:Lysine (Dig.)	0.81	0.81	0.83	0.70	0.88

[a]Phase 1: 45 kg/pig, 23-45 kg body weight.
[b]Phase 2: 54 kg/pig, 45-68 kg body weight.
[c]Phase 3: 64 kg/pig, 68-91 kg body weight.
[d]Phase 4: 57 kg/pig, 91-109 kg body weight.
[e]Phase 5: 54 kg/pig, 109-125 kg body weight.
[1]Provided per kilogram of final diet: iron, 124 mg as iron sulfate; zinc, 124 mg as zinc oxide; manganese, 29 mg as manganese sulfate; copper, 12 mg as copper sulfate; iodine, 0.2 mg as calcium iodate; and selenium, 0.2 mg as sodium selenite.

Table 2.2. Least squares means for the effects of Gender and Time of mixing on growth performance and incidence of morbidity and mortality in pigs.

	Gender			Time of mixing[1]							*P*-value		
	Barrows	Gilts	SEM	Not-mixed	9	11	13	15	17	SEM	Gender	Mixing	Gender × mixing
Number of experimental units[2]	12	12	-	4	4	4	4	4	4	-	-	-	-
Growth performance[1]													
Body weight, kg													
Start of study (week 9)	33.6	33.3	1.06	33.3	33.7	33.5	33.5	33.6	33.1	1.12	0.52	0.93	0.75
Week 11	48.4	47.9	0.92	48.3	48.0	47.9	48.5	48.4	47.8	0.97	0.15	0.69	0.91
Week 13	60.5[a]	59.3[b]	0.51	60.0	60.1	59.4	60.1	60.5	59.2	0.64	0.01	0.43	0.87
Week 15	73.8[a]	72.5[b]	0.23	73.1	73.7	72.9	73.3	73.4	72.5	0.49	0.01	0.71	0.30
Week 17	87.6[a]	85.6[b]	0.59	86.0	87.6	86.7	86.7	87.0	85.4	0.87	0.01	0.46	0.67
Week 19	102.8[a]	100.1[b]	1.31	100.2	102.4	101.6	101.6	102.6	100.0	1.51	<0.01	0.32	0.82
Week 21	116.2[a]	113.6[b]	1.25	114.4	115.7	114.8	115.7	115.6	113.1	1.53	0.01	0.54	0.95
End of study[3]	129.3	130.8	1.12	129.8	128.7	129.7	131.1	129.4	131.7	1.35	0.08	0.28	0.91
Coefficient of variation (within-pen), %													
Start of study (week 9)	5.3	4.8	0.23	5.4	4.2	5.5	5.3	5.2	4.7	0.41	0.24	0.26	0.70
End of study	3.9	3.9	0.12	4.2	3.7	3.7	4.0	3.9	3.9	0.26	0.97	0.82	0.79
Days on study	45.9[b]	48.2[a]	0.93	47.4	46.2	47.1	46.5	46.2	48.7	1.14	<0.01	0.30	0.92
Average daily gain, kg/d													
Week 9 – 11[5]	0.99	0.97	0.013	1.00	0.96	0.97	1.00	0.98	0.98	0.020	0.22	0.58	0.60
Week 11 – 13	0.86[a]	0.81[b]	0.031	0.83	0.87	0.82	0.83	0.86	0.82	0.033	<0.01	0.09	0.44
Week 13 – 15	0.95	0.94	0.036	0.94	0.97	0.97	0.93	0.92	0.95	0.039	0.68	0.32	0.06
Week 15 – 17	0.98[a]	0.93[b]	0.034	0.93	0.99	0.98	0.95	0.97	0.92	0.040	0.03	0.28	0.41
Week 17 – 19[4]	0.99	0.97	0.044	0.97	0.98	0.98	0.98	1.02	0.97	0.048	0.22	0.61	0.56
Week 19 – 21	0.93	0.95	0.012	0.95	0.93	0.92	0.99	0.93	0.93	0.028	0.42	0.55	0.52
Week 21 – End of study	0.81	0.83	0.039	0.81	0.76	0.79	0.91	0.82	0.82	0.048	0.56	0.12	0.35
Start – End of study	0.93	0.91	0.019	0.91	0.93	0.92	0.94	0.93	0.91	0.022	0.06	0.48	0.75
Average daily feed intake, kg/d													
Week 9 – 11	1.64[a]	1.54[b]	0.015	1.64	1.63	1.56	1.57	1.62	1.51	0.034	0.01	0.20	0.35
Week 11 – 13	2.04[a]	1.87[b]	0.099	1.99	1.97	1.9	1.93	2	1.95	0.102	<0.01	0.30	0.80
Week 13 – 15	2.36[a]	2.16[b]	0.088	2.24	2.41	2.29	2.17	2.21	2.25	0.110	0.01	0.45	0.25
Week 15 – 17	2.74[a]	2.44[b]	0.151	2.54	2.56	2.61	2.62	2.69	2.53	0.162	<0.01	0.70	0.47
Week 17 – 19	3.05[a]	2.74[b]	0.188	2.86	2.92	2.89	2.85	3.03	2.83	0.195	<0.01	0.26	0.43
Week 19 – 21	3.02[a]	2.83[b]	0.061	2.91	2.88	2.88	2.99	2.99	2.88	0.075	<0.01	0.46	0.58
Week 21 – End of study	2.90	2.83	0.023	2.91	2.8	2.84	2.93	2.85	2.86	0.049	0.16	0.54	0.84
Start – End of study	2.53[a]	2.36[b]	0.072	2.45	2.46	2.43	2.44	2.49	2.43	0.076	<0.01	0.60	0.63
Gain:Feed, kg/kg													
Week 9 – 11	0.604	0.633	0.0107	0.610	0.586	0.623	0.634	0.608	0.650	0.0203	0.13	0.41	0.38
Week 11 – 13	0.424[b]	0.435[a]	0.0060	0.420[b]	0.440[a]	0.431[ab]	0.432[ab]	0.434[a]	0.419[b]	0.0071	0.01	0.05	0.54
Week 13 – 15	0.404[b]	0.435[a]	0.0031	0.424	0.406	0.424	0.428	0.413	0.423	0.0068	<0.01	0.34	0.37
Week 15 – 17	0.359[b]	0.381[a]	0.0085	0.364	0.388	0.375	0.366	0.366	0.363	0.0101	<0.01	0.15	0.46
Week 17 – 19	0.327[b]	0.353[a]	0.0073	0.340	0.337	0.339	0.343	0.338	0.344	0.0081	<0.01	0.84	0.16
Week 19 – 21	0.308[b]	0.336[a]	0.0069	0.326	0.321	0.321	0.333	0.311	0.320	0.0097	<0.01	0.63	0.38
Week 21 – End of study	0.279	0.292	0.0128	0.278	0.272	0.279	0.312	0.288	0.287	0.0147	0.11	0.09	0.15
Start – End of study	0.369[b]	0.385[a]	0.0039	0.373	0.377	0.377	0.386	0.375	0.374	0.0045	<0.01	0.07	0.22
Morbidity and mortality, %	5.97	4.31	-	5.02	3.77	7.88	6.22	2.92	5.00	-	0.15	0.18	-

[a,b]Means within a row with different superscripts differ ($P < 0.05$).

[1]Week number is the week post-weaning and refers to the start of each week.

[2]Experimental unit = two pens with the same treatment combination within replicate.

[3]End of study weight = average of all pigs completing the growth study.

[4]Time between weights = 15 days.

Table 2.3. Least squares means for the effects of Gender and Time of mixing on carcass characteristics of pigs.

	Gender			Time of regrouping[1]							*P*-value		
	Barrows	Gilts	SEM	Not-mixed	9	11	13	15	17	SEM	Gender	Mixing	Gender × mixing
Number of experimental units[2]	12	12	-	4	4	4	4	4	4	-	-	-	-
Carcass characteristics													
Harvest live weight, kg[3]	129.2	130.8	1.10	129.7	128.7	129.7	130.9	129.0	131.8	1.33	0.06	0.23	0.79
Hot carcass weight, kg	95.2[b]	97.4[a]	0.68	96.3	94.9	96.7	96.7	95.9	97.5	0.93	<0.01	0.34	0.85
Standard deviation of hot carcass weight, kg	8.52	8.78	0.391	9.83	8.21	8.10	8.42	8.21	8.90	0.676	0.65	0.51	0.71
Carcass yield, %	73.7[b]	74.5[a]	0.15	74.2	73.8	74.5	73.8	74.3	74.0	0.24	<0.01	0.22	0.51
Fat-O-Meater measurements													
Longissimus muscle depth (10^{th} rib), cm	5.33[b]	5.77[a]	0.071	5.664	5.54	5.44	5.49	5.46	5.72	0.122	<0.01	0.49	0.39
Backfat depth (10^{th} rib), cm	1.80[b]	1.57[a]	0.071	1.727	1.70	1.65	1.65	1.70	1.73	0.097	0.01	0.95	0.74
Predicted carcass lean content, %	52.2[b]	53.7[a]	0.29	52.9	53.0	53.0	53.1	52.8	53.0	0.35	<0.01	0.94	0.75

[a,b]Means within a row with different superscripts differ ($P < 0.05$).

[1]Week number is the week post-weaning and refers to the start of each week.

[2]Experimental unit = two pens of the same treatment combination within replicate.

[3]Harvest live weight = average of all pigs that carcass data was collected on (carcass data was not recorded on all the pigs that finished the study).

CHAPTER 3: EFFECT OF FREQUENCY OF MIXING DURING THE MARKETING PHASE OF THE FINISHING PERIOD ON THE GROWTH RATE, CARCASS CHARACTERISTICS, AND MORBIDITY AND MORTALITY LEVELS OF BARROWS AND GILTS REARED IN A COMMERCIAL WEAN-TO-FINISH FACILITY.

ABSTRACT

The effect of frequency of mixing during the marketing phase of the finishing period on the growth rate, carcass characteristics, and morbidity and mortality levels of barrows and gilts in a commercial wean-to-finish facility was investigated in a study involving 6,624 pigs (initial body weight = 108.9 ± 2.01 kg). The study was carried out over a 5 wk period using a RCBD (blocking factor was day of start on test) with a 2 × 3 factorial arrangement of treatments: 1) Gender (Barrows vs. Gilts), and 2) Frequency of Mixing [Control (Not-mixed) vs. Mixed 1 time [mixed at start of study (M1)] vs. Mixed 2 times [mixed at start and d 15 of study (M2)]. A total of 48 single-gender pens of 138 pigs were used. Start of test was immediately after the heaviest 10% of the pen had been removed from each pen. End of test was 5-wk later when the last group of pigs from the pen was shipped for harvest (~20% of pigs from each pen were shipped for harvest each week throughout the study period). The experimental unit was 2 pens of the same gender on the same mixing treatment between which pigs were exchanged. Mixing of pigs was carried out by randomly selecting 31 pigs from each pen and exchanging them between the 2 pens. Pigs were weighed at the start and end of study and every week during the study period. Pigs were harvested at a commercial plant and carcass measures were collected. There was no difference ($P > 0.05$) between genders for morbidity and mortality. Barrows had higher ADG (7.0%; $P < 0.05$), lower carcass yield (0.4 percentage units; $P < 0.05$), and lower predicted lean content (1.6 percentage units; $P < 0.05$) than gilts. Frequency of Mixing had no effect ($P > 0.05$) on morbidity and mortality or carcass characteristics; however, overall ADG was lower ($P <$

0.05) for pigs mixed twice than for the other mixing frequencies (0.78, 0.75, and 0.70 kg for Control, M1, and M2, respectively; SEM 0.037). The results of this study suggest mixing of pigs during finishing had no impact on the morbidity and mortality, and carcass characteristics, however, the reduction in ADG in pigs mixed twice is of concern and needs to be verified.

INTRODUCTION

Current commercial production practices often require that unfamiliar pigs are mixed and this can occur at different stages in the pig production process. For instance, pigs can be mixed at the beginning of growing-finishing period, or when groups of pigs are moved into larger pens to meet their floor space requirements.

A number of studies have evaluated the effect of mixing on the growth performance and morbidity and mortality levels of pigs. Generally speaking, it has been shown that mixing does not affect the levels of morbidity and mortality, and that it has either no effect (Heetkamp et al., 2002; O'Connell et al., 2004) or a negative effect (Tuscherer et al., 1998; Hayne and Gonyou, 2003; Coutellier et al., 2007) on the growth performance of the pigs.

When present, the negative effects of mixing on average daily gain have been reported to be transitory [detected for up to 2 to 6 weeks after mixing (Hyun et al., 1998; and Li and Johnston, 2009)] and that pigs will recover that growth when given enough time. However, due to the different conditions used during these studies (e.g., age at mixing, group size, proportion of pigs mixed, and length of study period), it is difficult to apply these results to commercial conditions. Moreover, practices such as penning barrows and gilts separately, and mixing pigs of similar weight to reduce the within-group variation in slaughter weight require that pigs of the same gender are mixed at a later stage in the production process than those used in most studies. It could be speculated that the stress of mixing would increase at heavier weights; therefore, it is possible that mixing could have a bigger effect on pigs mixed at later stages of the growth period than on those mixed earlier and at lighter weights.

Moreover, in commercial practice, it is possible that pigs could be mixed on several occasions which raise two main questions. Firstly, is not clear what the impact of frequent mixing on growth performance is. Secondly, mixing pigs close to market weight may result in less time for the pigs to overcome the negative effects of mixing before pigs are sent to harvest, or may increase the time needed for pigs to reach market body weight.

Most studies have evaluated just one mixing event and there has been limited research to establish the impact of frequency of mixing at the end of the finishing phase on growth performance of pigs. Therefore, the present study was carried out to evaluate the effect of frequency of mixing at the end of the finishing phase (start of marketing process) on growth rate and morbidity and mortality of barrows and gilts in a commercial wean-to-finish facility.

MATERIALS AND METHODS

This study was carried out to evaluate the effects of Gender and Frequency of Mixing of pigs during the finishing period on growth rate, carcass characteristics, and morbidity and mortality levels of pigs in a commercial wean-to-finish facility. The study was carried out at the Mach 9 Technology Center of the Maschhoffs located near Beardstown, IL, which is a commercial wean-to-finish facility equipped to collect data on growth performance under typical commercial conditions. The experimental protocol for this study was approved by the University of Illinois Institutional Animal Care and Use Committee (IACUC protocol number: 11066).

Experimental Design and Treatments

The study was conducted as a randomized complete block design with a 2 × 3 factorial arrangement of treatments: 1) Gender (Barrows vs. Gilts) and 2) Frequency of Mixing [Control (Not-mixed), vs. Mixed 1 time (pigs mixed at start of study), vs. Mixed 2 times (pigs mixed at start and d 15 of study). Start date was the blocking factor. The study involved a total of 48 pens in 4 replicates. Treatment combinations appeared twice in each replicate to carry out the process of mixing, for a total of 12 pens per replicate (8 pens/treatment interaction subclass). The experimental unit was the 2 pens of the same gender on the same Frequency of Mixing treatment level (between which pigs were exchanged for the mixing process).

Animals and Allotment to Growth Study

The study involved a total of 6,624 pigs (initial BW = 108.9 ± 2.01 kg) that were of progeny of PIC 359 sires mated to PIC C29 dams (PIC USA, Hendersonville, TN). A total of 48 single-gender pens of 138 pigs were allotted to the study to achieve 4 replicates (8 pens per treatment combination). The study was carried out over a 5-wk period, when pigs were being removed from the pens to be shipped for harvest. Pigs were removed from the pens and shipped for harvest on 6 occasions according to the schedule presented in Table 3.1.

The study started after 10% of the pigs had been shipped for harvest, and finished when the last group of pigs was shipped for harvest. The allotment procedure was carried out within gender. Pens were weighed as a group and ranked by mean pen weight within room. The heaviest 3 pens were randomly assigned to one Frequency of Mixing treatment, and the 3 lightest pens were assigned to the Frequency of Mixing treatments such that the average weight of the 2 pens on each Frequency of Mixing treatment combination was similar across treatments. All pens of the same gender within a replicate started trial on the same day, however, because of previous growth difference, the date of start on test for barrows and gilts within a replicate differed.

Mixing process

Mixing of pigs was carried out on day 1 of study for the Mixed 1 time and Mixed 2 times treatments, and on day 15 of study for the Mixed 2 times. Within a replicate, 31 pigs were exchanged between two pens of the same treatment combination. Pigs that were exchanged had a similar body weight (± 0.7 kg) to that of the mean body weight of the pen that they were moved from.

Housing

The study was carried out in a commercial wean-to-finish facility that consisted of two buildings with different designs. One building was curtain sided with tunnel ventilation, and the other building had an equal pressure ventilation system (SKOV A/S®, Denmark). Each building had two rooms with 15 pens/room. Both buildings had fully-slatted concrete floors, deep manure pits, and pen divisions were of horizontal steel bars. In both buildings, the thermostat was set at 18.3°C throughout the study period and temperature was maintained using heaters and fan ventilation. Each pen was equipped with two standard 4-hole wet-dry feeder with access to both sides, and four cup-type water drinkers. Feed and water were available ad libitum throughout the study period. The floor space was 0.62 m^2/pig for all treatments at start of the study, however, floor space increased throughout the study period due to removal of pigs for harvest and morbidity & mortality (Table 3.1).

Diet Preparation and Feeding

The diet used in the study was formulated to meet or exceed the nutrients recommendations of NRC (1998), and was manufactured in pellet form at a mill of the

Maschhoffs (Griggsville, IL). Diet formulation and calculated and analyzed composition is presented in Table 3.2.

Study Period and Measurements

The study was carried out from a fixed mean pen weight of 108.9 ± 2.01 kg to a fixed time (5 weeks after start). Pens were weighed as a group at the start and every week during the study period. Additionally, group weights were taken on pigs before mixing, and before shipping for harvest (harvest live weight). The research facility was not set up to collect feed intake data and so this was not recorded.

Animals that died during the study or became morbid and had to be removed from the study were weighed and the date, weight, and possible cause of the morbidity or mortality were recorded using the following categories:

1. Respiratory disease = PRRS, pneumonia, influenza, and thumping
2. Gastrointestinal disease = ileitis, hemorrhagic bowel, obstructed bowel, and ulcers
3. Other disease = *streptococcus swis* and greasy pig *(staphylococcus hyicus*)
4. Injury = broken bones, cannibalism, abscesses, and swollen joints
5. Structural defects = broken top, leg soundness issues, and spraddle legs
6. Hernia = scrotal and umbilical hernias
7. Emaciation = fall out, anorexia, and general unthriftiness
8. NANI = downers and stress related issues
9. Other

Harvest and Carcass Measurements

Pigs were sent for harvest based on the schedule on Table 3.1. The group of pigs to be shipped from each pen were weighed (harvest live weight) and pre-sorted ~16 hours before shipping and held in sort pens with access to feed and water. Pigs were transported for harvest on a standard trailer (with 165 pigs/trailer) to Cargill Meat Solutions in Beardstown, IL. Upon arrival, pigs were allowed a period in lairage of at least 3 hours prior to harvest which was carried out using standard procedures.

Carcass grading measurements were taken on the slaughter line including hot carcass weight, and Fat-O-Meater® 10^{th} rib backfat thickness and *Longissimus* muscle depth, and predicted carcass lean content.

Statistical Analysis

Two pens of the treatment combination (i.e. the 2 pens between which pigs were exchanged for the mixing process) were used as the experimental unit for growth and carcass measurements. All variables were checked for normality using the PROC UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, NC). Those meeting the criteria for analysis of variance were analyzed using the PROC MIXED procedure of SAS. The model used included the fixed effects of Gender and Frequency of Mixing treatments and the two way interaction, and the random effects of block (date of start). The LSMEANS procedure was used to estimate mean values, and the PDIFF option was used to separate treatment means. Mortality and morbidity data were not normally distributed, and, therefore, they were analyzed using a χ^2 rank-based transformation using the PROC RANK procedure of SAS. Transformed mortality and morbidity data was analyzed using the MIXED procedure of SAS.

RESULTS AND DISCUSSION

Least squares means for the effects of Gender and Frequency of Mixing on the growth performance of pigs and carcass characteristics are presented in Table 3.3 and 3.4, respectively.

There were no Gender by Frequency of Mixing interactions (*P* > 0.05) for any of the measured traits, therefore, only the main effects will be discussed.

Effects of Gender

Overall average daily gain of barrows was 7% higher (*P* < 0.05) than that of gilts (Table 3.3). Carcass yield was 0.4 percentage units lower (*P* < 0.05) for barrows than gilts (Table 3.4). Moreover, barrows had smaller (3.7 %; *P* < 0.05) *Longissimus* muscle depth and bigger (16.7 %; *P* < 0.05) back fat thickness, resulting in barrows having 1.6 percentage units lower (*P* < 0.05) predicted lean content than gilts (Table 3.4). Morbidity and mortality levels were not affected (*P* > 0.05) by gender (Table 3.3). In general, the gender differences found in the current study are in line with other studies evaluating the effect of gender on growth performance (Campbell, et al., 1991; Morales et al., 2011; Gispert et al., 2010), carcass characteristics (Cisneros and Ellis, 1996; Hamilton, et al,. 2003; Peinado et al., 2008), and morbidity and mortality (Rodrígez-Sánchez, et al., 2011) of pigs.

Effects of Frequency of Mixing

There was no effect (*P* > 0.05) of mixing on the morbidity and mortality levels of pigs (Table 3.3), which is in agreement with most of the published literature (Chapter 1, Table 1.1). Frequency of Mixing had no effect (*P* > 0.05) on body weight or interim growth rate (Table 3.3). In addition, there was no effect (*P* > 0.05) of Frequency of Mixing on carcass measures. However, overall average daily gain of pigs that were mixed on two occasions was lower (*P* < 0.05) than that for the Control pigs or the pigs that were mixed once only (0.78, 0.75, 0.70 kg/day, for Control, Mixed 1 time, and Mixed 2 times treatments, respectively, Table 3.3). There is no published study that has been carried out with similar treatments under similar conditions of group size, body weight, length of study, and proportion of pigs mixed to those used in the current study, consequently, comparisons of results between this and other studies should be made with caution.

The response to mixing observed in pigs mixed only once is similar to that reported by Sherritt et al. (1974), Greer (1987) Heetkamp et al. (1995), Coutellier et al. (2007), and Li and Johnston (2009), where mixing had no effect on the growth rate. However, the response of pigs mixed twice suggests that pigs were unable to recover their growth rate to levels similar of the control treatment. There were no statistically significant differences ($P > 0.05$) in growth between the mixing treatments for the interim periods (Table 3.3) and numerical differences between the three treatments were relatively small and inconsistent. It is therefore not possible to establish either the short term effects of mixing or the effects of multiple mixing on growth performance from this study. Further research is required to address these important questions.

CONCLUSIONS

These results suggest that no major effect on growth performance, carcass characteristics or morbidity and mortality should be expected when pigs are mixed one time during the marketing period when pigs are being removed from pens and shipped for harvest. However, any negative effect of mixing can be increased with increased number of mixings.

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TABLES

Table 3.1. Schedule of pigs shipped for harvest, pigs per pen, and available floor space throughout study period.

Week of study[1]	Pigs shipped for harvest (% of pigs in pen)	Pigs per pen[4]	Estimated pen floor space (m2/pig)
Before start of study	~15 (~10%)[2]	~155	0.55
Start (Week 1)[3]	0	138	0.62
Week 2	31 (20%)	~107	0.80
Week 3	31 (20%)	~76	1.13
Week 4	31 (20%)	~45	1.91
Week 5	15 (10%)[2]	~30	2.87
Week 6	Remaining pigs[5]	-	-

[1]Week number is the week of study and relates to the start of each week.
[2]Number of pigs shipped for harvest before the start of test varied across pens to have 138 pigs remaining in the pen at the start of the study.
[3]Study started immediately after the first group of pigs was shipped for harvest.
[4]Approximated number of pigs per pen; pigs removed for morbidity and mortality reasons are not being included.
[5]Any morbidities and mortalities that occurred after the start of the study were accounted for by having fewer pigs in the last group (week 6 of study).

Table 3.2. Diet formulations and calculated composition.

Item	Dietary phase 1[a]
Ingredient, %	
Corn	73.41
Soybean meal	16.60
Corn germ meal	7.28
Limestone ground	0.81
Salt	0.49
Fat – yellow grease	1.00
Trace mineral mix[2]	0.06
Monocalcium phosphate	0.32
Vitamins premix	0.02
Optiphos 1000	0.01
Total, %	100
Composition	Calculated
ME, Kcal/kg	3329
Crude protein, %	14.62
Crude fat, %	3.61
Crude fiber, %	2.27
Neutral Detergent Fiber, %	9.75
Acid Detergent Fiber, %	3.35
Calcium, %	0.45
Phosphorus, %	0.43
Available phosphorus, %	0.18
Calcium:Phosphorus	1.05
Sodium, %	0.20
Salt, %	0.56
Total lysine, %	0.75
Digestible lysine, %	0.62
Digestible lysine:ME	1.87
Met + Cys:Lysine (Dig.)	0.69
Tryptophan:Lysine (Dig.)	0.23
Threonine:Lysine (Dig.)	0.73
Isoleucine:Lysine (Dig.)	0.83
Valine:Lysine (Dig.)	0.98

[a]Phase 1: 54 kg/pig, 109-125 kg body weight.
[2]Provided per kilogram of final diet: iron, 124 mg as iron sulfate; zinc, 124 mg as zinc oxide; manganese, 29 mg as manganese sulfate; copper, 12 mg as copper sulfate; iodine, 0.2 mg as calcium iodate; and selenium, 0.2 mg as sodium selenite.

Table 3.3. Least squares means for the effects of Gender and Frequency of Mixing on the growth performance and morbidity and mortality levels of pigs.

	Gender (G)			Frequency of Mixing (M)				*P*-value		
Item	Barrows	Gilts	SEM	Not-Mixed	M1	M2	SEM	G	M	G × M
Number of experimental units[1]	12	12	-	8	8	8	-	-	-	-
Body weight, kg[2]										
Week 1 (Start,~138 pigs/pen)	108.4	109.0	0.52	108.5	108.7	108.8	0.68	0.24	0.90	0.69
Week 2										
Before shipping heaviest pigs of the pen for harvest (~138 pigs/pen)	112.6	112.4	0.65	112.9	112.4	112.1	0.71	0.70	0.51	0.71
After shipping heaviest pigs of the pen for harvest (~107 pigs/pen)	108.9	108.5	0.66	109.2	108.5	108.4	0.73	0.50	0.55	0.79
Week 3										
Before shipping heaviest pigs of the pen for harvest (~107 pigs/pen)	114.3	114.8	0.83	114.9	114.5	114.3	0.89	0.47	0.72	0.78
After shipping heaviest pigs of the pen for harvest (~76 pigs/pen)	110.4	110.7	0.80	110.9	110.4	110.2	0.88	0.79	0.66	0.73
Week 4										
Before shipping heaviest pigs of the pen for harvest (~76 pigs/pen)	117.2	116.4	0.89	117.1	116.9	116.4	0.97	0.28	0.79	0.50
After shipping heaviest pigs of the pen for harvest (~45 pigs/pen)	111.5	110.3	0.95	111.1	111.1	110.6	1.04	0.19	0.85	0.62
Week 5										
Before shipping heaviest pigs of the pen for harvest (~45 pigs/pen)	117.7	116.5	0.80	117.4	117.5	116.5	0.86	0.08	0.41	0.41
After shipping heaviest pigs of the pen for harvest (~30 pigs/pen)	113.4[a]	111.7[b]	0.67	112.7	112.9	112.0	0.76	0.03	0.57	0.30
Week 6										
Before shipping heaviest pigs of the pen for harvest (~30 pigs/pen)	120.3[a]	118.1[b]	0.84	120.3	119.0	118.3	0.98	0.04	0.28	0.68
Body weight of pigs shipped for harvest, kg[2]										
Week 2 (~31 pigs shipped)	125.4	125.8	0.79	126.1	125.9	124.9	0.88	0.58	0.42	0.59
Week 3 (~31 pigs shipped)	123.9	124.8	0.99	124.8	124.5	123.9	1.06	0.25	0.60	0.53
Week 4 (~31 pigs shipped)	125.2	124.9	1.00	125.5	125.1	124.6	1.06	0.65	0.55	0.37
Week 5 (~15 pigs shipped)	125.1	125.0	1.25	125.6	125.5	124.0	1.29	0.86	0.12	0.17
Week 6 (Remaining pigs)	120.3[a]	118.1[b]	0.84	120.3	119.0	118.3	0.98	0.04	0.28	0.68
End of test weight[3]	124.0	123.7	0.81	124.5	124.0	123.1	0.86	0.64	0.19	0.44
Average daily gain, kg[4]										
Week 1 – 2	0.60	0.48	0.090	0.63	0.53	0.47	0.090	0.17	0.33	0.91
Week 2 – 3	0.76[b]	0.90[a]	0.040	0.82	0.86	0.81	0.050	0.03	0.78	0.80
Week 3 – 4	0.97[a]	0.81[b]	0.071	0.88	0.92	0.88	0.072	<0.01	0.45	0.13
Week 4 – 5	0.88	0.88	0.050	0.89	0.92	0.83	0.059	0.98	0.56	0.56
Week 5 – 6	0.91	0.81	0.077	0.96	0.81	0.81	0.089	0.28	0.33	0.73
Overall (Week 1 – Week 6)[5]	0.77[a]	0.72[b]	0.035	0.78[a]	0.75[a]	0.70[b]	0.037	0.01	0.01	0.13
Morbidity and mortality, %[6]	1.8	2.1	-	2.1	1.5	2.2	-	0.51	0.15	0.84

M1 = Pigs mixed at start of study

M2 = Pigs mixed at start of study and start of week 3.

[a,b]Means within a row with different superscripts differ ($P < 0.05$).

[1]Experimental unit = two pens with the same treatment combination within replicate.

[2]Week number is the week of study and relates to the start of each week.

[3]End of test weight = average weight of pigs shipped for harvest (Not-Mixed = 2163; One Mixing = 2174; Two Mixings = 2156; Barrows = 3252; Gilts = 3241).

[4]Average daily gain = (Pen weight before shipping pigs for harvest of current period – Pen weight after shipping pigs for harvest of previous period + mortality weight)/pig days.

[5]Overall live daily gain = [(Sum of weight of pigs shipped for harvest + mortality weights) – start pen weight]/total pig days.

[6]Analyzed using ranks transformation.

Table 3.4. Least squares means for the effects of Gender and Frequency of Mixing on the carcass characteristics of pigs.

Item	Gender (G)		SEM	Frequency of Mixing (M)			SEM	*P*-value		
	Barrows	Gilts		Not-Mixed	M1	M2		G	M	G × M
Number of experimental units[1]	12	12	-	8	8	8	-	-	-	-
Carcass characteristics										
Harvest live weight, kg[2]	123.7	123.6	0.85	124.4	123.6	123.0	0.89	0.80	0.17	0.35
Hot carcass weight, kg	90.7	91.1	0.77	91.3	91.0	90.5	0.79	0.31	0.31	0.65
Standard deviation of hot carcass weight, kg	5.0	4.9	0.12	4.9	5.1	4.9	0.14	0.21	0.52	0.96
Carcass yield, %	73.3[b]	73.7[a]	0.15	73.4	73.6	73.6	0.16	0.003	0.36	0.32
Longissimus muscle depth (10^{th} rib), cm	5.4[b]	5.6[a]	0.05	5.5	5.5	5.5	0.05	<0.01	0.44	0.50
Backfat depth (10^{th} rib), cm	1.8[b]	1.5[a]	0.05	1.7	1.7	1.7	0.05	<0.01	0.29	0.75
Predicted carcass lean content, %	52.3[b]	53.9[a]	0.15	53	53.1	53.1	0.16	<0.01	0.74	0.16

M1 = Pigs mixed at start of study

M2 = Pigs mixed at start and d 15 of study

[1]Experimental unit = two pens within the same treatment combination within replicate.

[2]Harvest live weight = final farm live weight; average of all pigs that carcass data was collected on (Not-mixed = 2021; One mixing = 2094; Two mixings = 2153; Barrows = 3031; Gilts = 3237).

CHAPTER 4: EFFECT OF BODYWEIGHT AT MIXING AT THE START OF THE FINISHING PHASE ON GROWTH RATE, LEVELS OF AGGRESSION, AND MORBIDITY AND MORTALITY OF BARROWS AND GILTS IN A COMMERCIAL WEAN-TO-FINISH FACILITY

ABSTRACT

The effect of bodyweight at mixing at the start of the finishing phase on growth rate and morbidity and mortality of barrows and gilts was investigated in 2 studies carried out in a commercial wean-to-finish facility. Study 1 was carried out from wk 16 (82.7 ± 10.8 kg BW) to wk 22 post-weaning (120.9 ± 11.8 kg BW) with a total of 6,618 pigs. Study 2 was carried out from wk 15 (73.2 ± 9.1 kg) to 2 end points, namely fixed-time end (week 22 post-weaning) and to a fixed-weight end of 126 kg with a total of 1,765 pigs. Both studies were carried out as a RCBD (blocking factor was day of start on test) with a 2 × 2 × 3 factorial arrangement of treatments: 1) Gender (Barrows vs. Gilts), 2) Mixing [Control (Not-mixed) vs. Mixed at start of study], and 3) BW Category (Heavy, Medium, and Light). Within pen, pigs were assigned to one of the following Body Weight Categories: Heavy (heaviest 1/3 in the pen), Medium (middle weight 1/3 in the pen), and Light (lightest 1/3 in the pen). Mixing treatment was randomly assigned to 6 pens within gender and replicate (3 Control and 3 Mixed for each gender). The Control pens were kept intact (i.e., not-mixed). For the 3 pens on the Mixing treatment within gender, groups of pigs of the same BW Category were moved into a new pen, resulting in 3 new pens (i.e., 1 Mixed pen for each BW Category). Individual pig BW was collected at the start and end of study and every 2 wk (Study 1) and every wk (Study 2) during the study period.

For Study 1 there was a Mixing × Gender interaction ($P \leq 0.05$) for wk 18 BW and for wk 16-18 ADG; Mixing had a negative impact on the ADG of gilts, but not of barrows, resulting in lighter BW for gilts in the Mixed treatment. There was a Mixing × BW Category interaction ($P \leq 0.05$) for wk 18 BW; Mixing had no effect on BW of pigs on the Light BW Category,

however, mixed pigs on the Heavy and Medium BW Category were lighter than their Control counterpart. Barrows had higher (9.6%; $P \leq 0.05$) overall ADG than gilts. Mixing reduced ($P \leq 0.05$) the ADG of pigs during the first 4 wks after mixing but not during the last 2 weeks, resulting in lower (4.6%; $P \leq 0.05$) overall ADG than control pigs. Overall ADG increased ($P \leq 0.05$) across BW Category. Morbidity and mortality levels were not affected ($P > 0.05$) by Gender or Mixing; however, pigs on the Light BW Category had a higher ($P \leq 0.05$) incidence of morbidity and mortality than pigs on the Medium or Heavy BW categories.

For Study 2 there was a Mixing × BW Category treatment interaction ($P \leq 0.05$) for ADG from wk 20−22 post-weaning and for the overall study period (wk 15−22 post-weaning). Mixing had a negative effect on ADG of pigs on the Heavy BW Category, but not on the Light and Medium Categories. Mixing had no effect ($P > 0.05$) on carcass characteristics. During the first wk post-mixing, pigs on the Mixed treatment had lower (11.5%; $P \leq 0.05$) ADG and lower (6.0%; $P \leq 0.05$) ADFI than pigs on the Control treatment, resulting in lower (5.2%; $P \leq 0.05$) G:F for pigs on the Mixed treatment. However, Mixing had no effect ($P > 0.05$) on growth performance for subsequent interim periods or for the overall study period. Pigs in the Mixed treatment had 27 times more fights ($P \leq 0.05$) during the first 3 days after mixing than the Control. For Mixed pens, there were 3.3 fights/pig on the day of mixing, but only 0.6 fights/pig on day 2 post-mixing. Increasing Body Weight Category increased ($P \leq 0.05$) overall (week 15 to 22 post-weaning) ADG. Barrows were heavier ($P \leq 0.05$) and had higher ($P \leq 0.05$) overall ADFI than gilts throughout the study. However, gilts grew faster ($P \leq 0.05$) and had greater ($P \leq 0.05$) G:F than barrows. Morbidity and mortality levels were not affected ($P > 0.05$) by Gender or Mixing; however, pigs on the Light BW Category had a higher ($P \leq 0.05$) incidence of morbidity and mortality than pigs on the Heavy BW Category, with pigs on the Medium BW

Category being intermediate. These results suggest that the short-term response to mixing pigs on late finishing may be affected by other factors such as gender and live weight of pigs, but that no major long-term effect should be expected for growth performance and morbidity and mortality levels.

INTRODUCTION

Current commercial production practices often require the mixing of unfamiliar pigs at different stages in the production process. For instance, pigs can be mixed at the beginning of growing-finishing period, when groups of pigs are moved into larger pens to meet their floor space requirements, or when pigs of similar weight are moved into a different pen to reduce the within-group variation in weight.

A number of studies have evaluated the effect of mixing on the growth performance, levels of aggression, and morbidity and mortality levels of pigs. Generally speaking, it has been shown that mixing increases the levels of aggression between pigs, but does not affect the levels of morbidity and mortality, and that it has either no effect (Heetkamp et al., 2002; O'Connell et al., 2004) or a negative effect (Tuscherer et al., 1998; Hayne and Gonyou, 2003; Coutellier et al., 2007) on the growth performance of pigs.

When present, the negative effects of mixing on ADG have been reported to be transitory [detected up to 2 to 6 weeks after mixing (Hyun et al., 1998b; and Li and Johnston, 2009) and that pigs will recover that growth if given enough time after mixing. However, due to the different conditions used during these studies (e.g., age at mixing, group size, proportion of pigs mixed, and length of study period), it is difficult to apply these results to commercial conditions.

Moreover, practices such as penning barrows and gilts separately, moving pigs into larger pens to meet their space requirements, and mixing pigs of similar weight to reduce the within-group variation in slaughter weight, require pigs of the same gender to be mixed at later stages in the production process than those used in most studies. It could be speculated that the level of aggressive behaviors and stress of mixing would increase at heavier weights; therefore, it is possible that mixing can have a bigger effect on pigs mixed at later stages of the growth period than on those mixed earlier at lighter weights.

However, this raises three main concerns: First, it could be suggested that that mixing can have a bigger effect on pigs mixed at later stages of their growth period (based on the assumption that stress of mixing would increase at heavier weights). Second, it is not clear if pigs of different body weight (e.g., heavy, medium or light pigs) respond differently to mixing when they are sorted by weight at later stages of the growth period. Third, mixing pigs close to market BW may result in less time for the pigs to overcome the negative effects of mixing before pigs are send to harvest, or in more time needed to reach market BW.

To our knowledge, no study has evaluated these three questions, therefore, the present studies were carried out to evaluate the effect of bodyweight at mixing at the start of the finishing phase on growth rate, levels of aggression, and morbidity and mortality of barrows and gilts in a commercial wean-to-finish facility.

MATERIALS AND METHODS

Two studies were carried out in a commercial wean-to-finish facility to evaluate the effect of mixing of barrows and gilts of different body weights at the start of the finishing phase on growth performance, morbidity and mortality, and aggressive behavior. A summary of the key materials and methods for both studies is shown in Table 4.1. The studies were conducted at two research units of The Maschhoffs LLC. (Carlyle, IL). Study 1 was conducted at the Mach 9 research farm, located near Beardstown, IL; Study 2 was conducted at the Georgia Technology Center research farm, located near Carlyle, IL. Both units are commercial wean-to-finish facilities that were equipped to collect data on growth performance under typical commercial conditions. The experimental protocol for these studies was approved by the University of Illinois Institutional Animal Care and Use Committee (IACUC protocol number: 11194).

Experimental Design and Treatments

Both studies were carried out as randomized complete block designs with a 2 × 2 × 3 factorial arrangement of treatments: 1) Gender (barrows vs. gilts), 2) Mixing [Control (Not-mixed) vs. Mixed at start of study], and 3) Body Weight Category (Heavy vs. Medium vs. Light). Date of start on test was the blocking factor.

Animals and Allotment to Growth Study

All pigs were progeny of PIC 359 sires mated to PIC C29 dams (PIC USA, Hendersonville, TN). For Study 1, a total of 6,618 pigs (initial BW = 82.7 ± 10.8 kg) were allotted to the study at week 16 post-weaning, and for Study 2 a total of 1,765 pigs (initial BW = 73.2 ± 9.1 kg) were allotted to the study at week 15 post-weaning. For both studies, replicates consisted of 12 single-gender pens (6 pens of barrows and 6 pens of gilts), with a total of 48 pens for Study 1 (average of 138 pigs per pen) and 72 pens for Study 2 (average of 24 pigs per pen).

Allotment and mixing procedures were similar for both studies and were carried out within gender as follows:

Allotment: An experimental unit consisted of 3 groups of pigs (each group consisted of part of a pen as described below) of the same Body Weight Category within Mixing treatment (Figure 4.1). Mixing treatments were randomly assigned to 6 pens of similar mean BW within gender and replicate [3 Control (Not-mixed) and 3 Mixed pens per gender]. Pigs were weighed individually and classified within pen to one of the following Body Weight Category groups based on their individuals weights: 1) Heavy (heaviest 1/3 of pigs in the pen); 2) Medium (middle weight 1/3 of pigs in the pen); and 3) Light (lightest 1/3 of pigs in the pen).

Mixing procedure (Figure 4.1): Mixing of pigs was carried out immediately after allotment as follows: The 3 control pens were kept intact (i.e., pigs were not mixed). For the 3 pens on the mixing treatment, groups of pigs of the same Body Weight Category from the 3 original pens were moved and mixed into a new pen, resulting in 3 new pens (1 pen per Body Weight Category). As a result, the experimental unit (i.e., 3 groups of the same Body Weight Category and Mixing treatment) of the Mixed treatments was located in the same pen. Conversely, the 3 groups forming the experimental unit of the Control treatments were not mixed together, therefore, the experimental unit in the Control treatments was located across 3 different pens (Figure 4.1). Pigs were started on test immediately after mixing.

In Study 1, different group sizes were used for each of the Body Weight Categories to prevent the confounding of Body Weight Category treatment with available floor space by unit of live weight (details below). This resulted in group sizes as follows: Heavy group = 43 pigs; Medium group = 46 pigs; and Light group = 49 pigs. The resulting number of pigs per pen after mixing was 138 pigs in the Control pens (43 Heavy, 46 Medium, and 49 Light pigs), 129 pigs in the Mixed-Heavy pens (3 groups of 43 pigs), 138 pigs in the Mixed-Medium pens (3 groups of 46 pigs), and 147 pigs in the Mixed-Light pens (3 groups of 49 pigs).

For Study 2, the number of pigs per group at the start of study (week 15 post-weaning) varied between pens due to having less numbers of gilts than barrows available at placement (which was carried out at week 8 post-weaning) and due to differences in removal and mortality rates between pens before the start of the study. As a result, the size of the groups forming the experimental units in Study 2 ranged from 7 to 9 pigs, resulting in pens of 21 to 26 pigs (the number of pigs per pen was kept constant within replicate and within gender).

Housing

Facilities for Study 1 consisted of two buildings with different designs. One building was curtain sided with tunnel ventilation, and the other building had an equal pressure ventilation system (SKOV A/S ®, Denmark). Each pen was equipped with two 4-hole wet-dry feeder with access to both sides, and four cup-type water drinkers.

Study 2 was carried out in two rooms of a curtain sided building with tunnel ventilation. Each pen was equipped with a 5-space wet-dry box feeder and two cup-type water drinkers.

The buildings used for both studies had fully-slatted concrete floors and deep manure pits (2.4 m deep), and pen divisions were of horizontal steel bars. The thermostat was set at 18.3°C throughout the study period, and temperature was maintained using thermostatically controlled heaters and fan ventilation in both studies.

Different approaches were used in the 2 studies to avoid confounding the treatment effect of body weight with space available per unit of body weight:

For Study 1, as previously described, the number of pigs in the pens that were mixed was varied across Body Weight Category treatments to achieve the same floor space per pig relative to body weight based on the following formula (adapted from Petherick, 1983):

$$\text{Floor space per pig} = k\,(\text{BW})^{0.67}$$

where $k = 0.026$, and BW = predicted body weight at end of study. The BW at end of study was used based on the assumption that the biggest restriction in growth due to reduced available floor space available per unit of weight would be found at end of study. Predicted body weight at end of study was calculated as follows:

Start weight + [42 days of study × 0.86 kg/day predicted average daily gain (predicted average daily gain was based on growth recorded in previous studies with similar pigs in the same facilities)].

Based on previous studies, it was assumed that no major differences in overall growth rate would occur between mixing treatments and gender, therefore, the same predicted average daily gain was used for mixed and non-mixed groups and for barrows and gilts. The resulting number of pigs per pen and floor space per treatment, and the space allowance coefficient (*k*) by Gender and Mixing by Body Weight Category treatments at start and end of study are presented in Table 4.1.

For study 2, the number of pigs per pen was kept the same across treatments and pigs were allowed a floor space of 0.82 m^2. As suggested by Gonyou et al. (2006), such floor space was considered to have little or no impact on growth performance (i.e., growth would not be restricted) despite differences in the available space per unit of weight between Body Weight Categories.

Diet Preparation and Feeding

Diet preparation and feeding was similar for both studies. All diets were formulated to meet or exceed the requirements of pigs across the weight range used in this study recommended by NRC (1998). On Study 1, a 2-phase feeding program was used as follows:

Phase 1 (fed from 68 to 91 kg body weight).

Phase 2 (fed from 91 to 125 kg body weight).

On study 2, a 5-phase feeding program was used as follows:

Phase 1 (fed from 27 to 54 kg body weight).

Phase 2 (fed from 54 to 73 kg body weight).

Phase 3 (fed from 73 to 91 kg body weight).

Phase 4 (fed from 91 to 108 kg body weight).

Phase 5 (fed from 108 to 127 kg body weight).

All experimental diets were manufactured in pellet form at the Griggsville Mill of The Maschhoffs LLC. Diet formulations and calculated and analyzed compositions are presented in Tables 4.2 and 4.3 for Studies 1 and 2, respectively. Feed and water were available *ad libitum* throughout the study period.

Study Period and Measurements

Study 1 was carried out on a fixed-time basis, from week 16 to week 22 post-weaning. Study 2 was carried out in two parts; a fixed-time period from week 15 to week 22 post-weaning), and to a fixed weight of 126 kg (harvest). For both studies individual body weights were taken at the start and end of the study, and either every 2 weeks (Study 1) or every week (Study 2) during the study period. Feed intake was recorded (in Study 2 only) every time that the pigs were weighed.

The process to record animals that died during the study or became morbid and had to be removed from the study was the same for both studies. Such pigs were weighed and the date, weight, and possible cause of the morbidity or mortality were recorded using the following categories:

1. Respiratory disease = PRRS, pneumonia, influenza, and thumping
2. Gastrointestinal disease = ileitis, hemorrhagic bowel, obstructed bowel, and ulcers
3. Other disease = *streptococcus suis* and greasy pig *(staphylococcus hyicus*)
4. Injury = broken bones, cannibalism, abscesses, and swollen joints
5. Structural defects = broken top, leg soundness issues, and spraddle legs
6. Hernia = scrotal and umbilical hernias
7. Emaciation = fall out, anorexia, and general unthriftiness
8. NANI = downers and stress related issues
9. Other

Aggressive behavior

Aggressive behavior was recorded in one replicate (i.e., 12 pens) of Study 2 on the day of mixing, and on day 1 and 2 after mixing. Observations were carried out from 0600h to 1800h on each day. The level of aggression in the pens was estimated by recording the number and duration of fights, with a fight being defined as any biting, chasing or head butting occurring for more than 2 seconds between two or more pigs. In addition, the location of the start of the fight within the pen (i.e., at feeder, drinker or at other location in the pen) was recorded to determine if fights related to competition for access to feed and water.

Harvest and Carcass Measurements

Intact pens were taken off test and sent for harvest when the pen mean reached 126 ± 3.67 kg live weight. The pigs were weighed individually (harvest live weight) prior to being loaded onto the trailer (with 165 pigs/load). Pigs were transported on the day of harvest on a standard trailer to Cargill Meat Solutions in Beardstown, IL. Upon arrival, pigs were allowed a period in lairage of at least 3 hours prior to harvest which was carried out using standard procedures.

Carcass grading measurements were taken on the slaughter line including hot carcass weight, and Fat-O-Meater® 10^{th} rib backfat thickness and *Longissimus* muscle depth, and predicted carcass lean content.

Additional measurements

For Study 2, feed intake could only be recorded on a pen-basis level, therefore, two additional analyses were carried out:

To evaluate the effect of Mixing and Gender on body weight, growth rate, feed intake and feed efficiency, within replicate and within gender, data from 3 pens with the same Mixing treatment combination [i.e., 3 Control pens vs. 3 Mixed pens (1 Mixed-Light, 1 Mixed-Medium, and 1 Mixed-Heavy) of the same gender] was pooled together for analysis.

For Studies 1 and 2, the within-pen variation of body weight was measured on a pen-basis throughout the study period, therefore, the comparisons could only be made between Control pens vs. Mixed pens, resulting in 3 Control pens vs. 1 Mixed-Light pen vs. 1 Mixed-Medium pen vs. 1 Mixed-Heavy pen per replicate.

Statistical Analysis

For both studies, growth performance variables were checked for normality using the PROC UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, NC). Those meeting the criteria for analysis of variance were analyzed using the PROC MIXED procedure of SAS. The model used included the fixed effects of Gender, Mixing, and Body Weight Category treatments and two- and three-way interactions, and the random effects of block (date of start) and replicate. The LSMEANS procedure was used to estimate mean values, and the PDIFF option was used to separate treatment means. The incidence of mortality and morbidity and the number of fights did not conform to the normal distribution, consequently, the Kruskal-Wallis rank-based nonparametric test (Steel and Torrie, 1980) was carried out using the PROC RANKS and PROC MIXED procedures of SAS, with means being analyzed using the MIXED procedure of SAS using the same model as for the growth performance data.

RESULTS AND DISCUSSION

Results of Studies 1 and 2 are presented and discussed separately. Least squares means for the effects of Mixing, Body Weight Category, and Gender on the growth performance and morbidity and mortality (Studies 1 and 2), and on the aggressive behavior of pigs (Study 2) are presented in Tables 4.4 to 4.11.

Study 1

There was a significant ($P \leq 0.05$) Mixing × Body Weight Category treatment interaction for week 18 body weight (Table 4.4). Mixing had no effect on BW of pigs in the Light Body Weight Category, however, for the Heavy and Medium Body Weight Category, pigs on the Mixed treatment were lighter than those on the Control treatment. To our knowledge, no other study has evaluated the response to mixing of finishing pigs of different BW. However, Rushen (1987) and Andersen et al. (2000) suggested that groups of pigs with large differences in weight establish a social hierarchy more easily than groups of pigs of similar weight. This would result in lower levels of aggressions between pigs following mixing in groups with large weight variation than with small weight variation. The distribution of body weight of the population on the current study was slightly skewed to the left (skewness = -0.19), therefore the Light Body Weight Category treatment had a higher ($P \leq 0.05$) within-group live weight coefficient of variation (CV = 10.7 %) compared to the Heavy and Medium Body Weight Categories (CV = 6.6, and 4.9 %, respectively). Therefore, it could be speculated that the smaller differences in body weight variation of the Heavy and Medium Body Weight Category treatment resulted in higher levels of aggressions compared to the Light Body Weight Category, which could partially explain the different response between treatments in BW to mixing. However, levels of aggression were not measured and it is not possible to separate the effects of Body Weight Category from those of variation in live weight.

A Mixing × Gender treatment interaction was found for Body Weight at week 18 ($P \leq 0.05$) and for average daily gain from week 16−18 ($P \leq 0.05$; Table 4.4). Mixing had a negative impact on the growth rate of gilts, but not barrows, during the first two weeks post-mixing, resulting in lighter body weight for gilts at week 18 on the Mixed treatment. However, there was no Mixing × Gender treatment interaction in subsequent periods, suggesting that the effect of mixing was similar for the two genders. No other studies have reported the growth rate of barrows and gilts when mixed under similar conditions to those of the current study. However, Stookey and Gonyou (1994) reported that gilts spent more time fighting after mixing than barrows in the first two days post-mixing (0.37 vs. 0.05 min/h, for gilts and barrows, respectively). In addition, Stookey and Gonyou (1994) concluded that the levels of aggression at the moment of mixing have an impact on the subsequent growth performance of pigs. Therefore, it could be argued that the differences in growth rate between genders in the first 2 weeks after mixing observed in the present study might be related, at least in part, to the different levels of aggression experienced in the two genders. However, as previously discussed, aggression was not measured in the current study. In addition, Stookey and Gonyou (1994) found no Mixing × Gender treatment interactions for growth rate. Further research is needed to determine if the

Mixing × Gender treatment interactions found in the current study can be repeated, and to understand what factors, if any, influence the different responses to mixing between barrows and gilts.

Effect of Mixing.

There was no effect of mixing on the morbidity and mortality levels of pigs (Tables 4.4 and 4.10), which is in agreement with most published studies (Chapter 1, Table 1.1). The average daily gain of pigs in the Mixed treatment was lower ($P \leq 0.05$) than that of the Control treatment (Not-Mixed) during the first 4 weeks of study (weeks 1 to 4 post-mixing), but not in the last 2 weeks of study (weeks 4 to 6 post-mixing). As a result, compared to the Control pigs, pigs in the Mixed treatment had lower (4.6%; $P \leq 0.05$) overall average daily gain and were lighter (1.7%; $P \leq 0.05$) throughout the study period. These results are in agreement with those of Francis et al. (1996), Hyun et al. (1998a and 1998b), and Stookey and Gonyou (1994), which found that the growth rate of pigs that had been mixed was between 7 and 20 % lower than non-mixed pigs for the overall study periods. Conversely, studies by Greer (1987), Heetkamp et al. (2002), and O'Connell et al. (2004) showed no effect of mixing on growth rate. Generally speaking, mixing has been considered to have a negative but transitory effect and, when given sufficient time, pigs are able to compensate from a short-term reduction in performance (O’Connell et al., 2005).

In the current study, there were no differences in growth rate between mixing treatments for the last 2 weeks of study (weeks 4 to 6 post-mixing), which suggest that the effect of mixing on growth rate were transitory. However, the differences in overall growth rate suggests that pigs on the Mixed treatment did not have enough time to compensate for the reduction in growth experienced during the first 4 weeks post-mixing.

In addition, the variation in body weight of the population at the end of the study was 1.9 percentage units lower ($P \leq 0.05$) for the Mixed treatment than for the Control (Table 4.4). We are unaware of other studies reporting a reduction in variation in the BW of the population due to mixing. We believed that the difference in body weight variation found in the current study between Mixing treatments was due to random chance and had little biological implications.

Effects of Body Weight Category

Least squares means for the effects of Body Weight Category on the growth performance of pigs are presented in Table 4.4. By design, body weight between Categories differed ($P \leq 0.05$) throughout the study period. In addition, overall average daily gain increased ($P \leq 0.05$) with increasing Body Weight Category. Similar effects of Body Weight Category on growth performance to those found in the present study were also observed by Brumm et al. (2002) and O'Quinn et al. (2001).

Pigs on the Heavy and Medium Body Weight Category treatment had a lower ($P \leq 0.05$) incidence of morbidity and mortality than pigs on the Light Body Weight Category (2.9, 1.2, and 1.5 % for Light, Medium and Heavy Categories, respectively; Table 4.4 and 4.9). However, the interpretation of the morbidity and mortality results should be carried out with care due to the way the Body Weight Categories were created. At start of the study, Body Weight Categories were formed based solely on the live weight of pigs and it is possible that some pigs in the Light Body Weight category had previous or existing health issues. For example, from a total of 69 morbid or dead pigs recorded on the Light Body Weight Category (Table 4.9), 43 of these had conditions that could potentially affect their growth (i.e., respiratory disease, gastrointestinal disease, or emaciation). However, the presence of such health issues and the number of pigs assigned to each Body Weight Category at the start of the study was not assessed. Therefore, it is not possible to determine if differences in morbidity and mortality rates between Body Weight Category treatments are due to health issues prior to allotment, or if light pigs are innately more prone to be morbid or to die than heavier ones.

Effects of Gender

Least squares means for the effects of Gender on the growth performance of pigs are presented in Table 4.4. Differences in live weight between genders were present at the start of the test, reflecting differences in pre-test growth rates between barrows and gilts. Nevertheless, growth performance prior to the start of test was not measured in the current study.

Barrows were heavier ($P \leq 0.05$) and grew faster ($P \leq 0.05$) than gilts throughout the study period. Morbidity and mortality levels were not affected ($P > 0.05$) by gender. Generally speaking, differences between the genders were in line with previous studies that have evaluated the effect of gender on growth performance (Cisneros et al., 1996; Dunshea et al., 2001; Hamilton et al., 2003; Fàbrega et al., 2010), and morbidity and mortality (Rodrígez-Sánchez, et al., 2011) of pigs.

Within-pen variation of body weight

Least squares means for the effects of Body Weight Category and Gender on within-pen variation in live weight are presented in Table 4.7. Pens on the Control treatment (not-mixed) had a higher ($P \leq 0.05$) within-pen standard deviation and within-pen coefficient of variation of body weight than pens on Mixed treatment for the Light, Medium and Heavy Body Weight Category treatments (pens that were formed by mixing pigs of the same Body Weight Category from 3 original pens) at each weighing time throughout the study period. These results are in disagreement to those of O'Quinn et al. (2001) and Wolter et al. (2002) which showed that, over time, the coefficient of variation of weight within pens of pigs mixed to form homogenous weight groups reaches a level similar to that of unmixed groups (i.e., groups not mixed by weight). In contrast, the current study mixing pigs of similar weight successfully reduced the within-pen coefficient of variation of final body weight. The major difference between this current study and those of O'Quinn et al. (2001) and Wolter et al. (2002) was the time between forming of groups and the end of study. Therefore, the results of the current study suggest that forming groups of pigs with similar weight at week 16 post-weaning can reduce the within-pen coefficient of variation of body weight at the end of the finishing period (i.e., week 22 post-weaning).

Study 2

There was a significant ($P \leq 0.05$) Mixing × Body Weight Category treatment interaction for body weight at week 22, and for average daily gain from week 20−22 post-weaning and from week 15−22 post-weaning (Table 4.5). For all treatment interactions, mixing had a negative effect on the growth rate of pigs in the Heavy Body Weight Category, but not in the Light and Medium Categories. It is possible that the different response to mixing between Body Weight Category treatments is related to differences in the levels of aggression in the pens (Rushen, 1987; Andersen et al., 2000), which for the current study will be presented and discussed below.

Effect of Mixing

Growth performance

Mixing had no effect ($P > 0.05$) on the incidence of morbidity and mortality (Tables 4.5 and 10), which is in agreement with most published studies (Chapter 1, Table 1.1). During the first week following mixing, the average daily gain of pigs on the Mixed treatment was 11.5% lower ($P \leq 0.05$; Table 4.5) than that of the Control treatment, but feed intake was only 6.0% lower ($P \leq 0.05$; Table 4.6), resulting in a 5.2% lower ($P \leq 0.05$) feed efficiency for pigs on the Mixed treatment compared to the Control (Table 4.6). However, mixing had no effect ($P > 0.05$) on growth performance during the subsequent interim periods. These results are in agreement with those of Stookey and Gonyou (1994) and Hyun et al. (1998b) who showed significant effects of mixing on growth performance during the first two weeks after mixing, but not on later periods.

In addition, there was no effect ($P > 0.05$) of mixing on the overall growth performance of pigs. These results are similar to those reported by Greer (1987), Heetkamp et al. (1995 and 2002), O'Connell et al. (2004), and Li and Johnston (2009), which showed that mixing had no effect on the overall growth rate of pigs. In contrast, Study 1 and the studies of Francis et al. (1996), Hyun et al. (1998a and 1998b), and Stookey and Gonyou (1994) showed that the growth rate of pigs that had been mixed was between 7 and 20% lower than non-mixed pigs for the overall study periods.

The effect of mixing on growth performance has often been considered to be negative and transitory and, when given sufficient time, pigs are able to compensate from a short-term reduction in performance (Hyun et al., 1998b; O’Connell et al., 2005; Li and Johnston, 2009).

Results of the current study suggest that pigs on the Mixed treatment had enough time to compensate for the reduction in growth experienced during the first week post-mixing.

Carcass characteristics.

The effect of Mixing on carcass characteristics is presented in Table 4.8. Mixing pigs had no effect ($P > 0.05$) on most of the carcass variables with the exception that the standard deviation of hot carcass weight was 34% lower ($P \leq 0.05$) for pigs on the Mixed treatment than that of the Control. Because entire pens were sent for harvest, this reduction in standard deviation of hot carcass weight was mainly due to a reduction in within-pen coefficient variation of body weight, due to the approach used to form the pens described below (Table 4.8).

Aggressive behavior.

The effect of Mixing on the total number of fights and the number of fights per pig is presented in Figures 4.2 and 4.3, respectively. On average, the number of fights per pig during the first 3 days after mixing was 27 times greater ($P \leq 0.05$) for pigs on the Mixed treatment than that of the Control. Pigs on the Mixed treatment had the greatest number of fights per pig on the day of mixing (3.3 fights per pig), and this decreased to 1.4 and 0.6 fights per pig on days 1 and 2 post-mixing, respectively. Similar results found the studies of O'Connell et al. (2005) and Li and Johnston (2009), which showed that pigs that had been mixed had 8 to 40 times more fights per pig than pigs not mixed. Moreover, Li and Johnston (2009) also reported a reduction in the number of fights per pig from 1.6 at day of mixing to 0.2 fights/pig/day at 2 days post-mixing, and these authors suggested that familiarity was the major factor determining aggression within groups of pigs.

Effects of Body Weight Category

Growth performance

Least squares means for the effects of Body Weight Category on the growth performance of pigs are presented in Table 4.5. By design, body weight between Categories differed ($P \leq 0.05$) at the start of the study, and this difference was maintained throughout the study period. In addition, overall (week 15 to 22 post-weaning) average daily gain increased ($P \leq 0.05$) with increasing Body Weight Category. These results were expected and are in agreement with those found in Study 1 and in studies by Brumm et al. (2002) and O'Quinn et al. (2001).

Pigs on the Heavy and Medium Body Weight Category treatment had a lower ($P \leq 0.05$) incidence of morbidity and mortality than pigs on the Light Body Weight Category (Table 4.5 and 4.10). However, similar to Study 1, the interpretation of the morbidity and mortality results should be carried out with care due to approach used to form the Body Weight Category treatment groups were created. At start of the study, Body Weight Categories were formed based solely on the live weight of pigs and it is possible that some pigs in the Light Body Weight category had previous or existing health issues. For example, from a total of 26 morbid or dead pigs recorded for the Light Body Weight Category (Table 4.10), 18 of these had conditions that could potentially affect their growth (i.e., respiratory disease, gastrointestinal disease, or emaciation). However, the presence of such health issues and the number of pigs assigned to each Body Weight Category was not assessed at the start of the study. Therefore, it is not possible to determine if differences in morbidity and mortality rates between Body Weight Category treatments are due to health issues prior to allotment, or if light weight pigs are innately more prone to become morbid or to die than heavier ones. Further research is warranted to investigate this commercially important question.

Aggressive behavior

The effect of Body Weight Category on the number of fights per pig is presented in Figure 4.3. There were no significant ($P > 0.05$) differences in the number of fights per pig between Body Weight Categories. However, pigs on the Heavy Body Weight Category treatment tended ($P = 0.12$) to have a higher number of fights per pig than those on the Medium and Light Categories on the day of mixing but not on days 2 and 3 post-mixing (Figure 4.3). It should be noted that only aggressive interactions (i.e., biting, head butting, and chasing) lasting for more than 3 seconds were recorded as a fight, leaving a large number of shorter aggressive interactions unrecorded, and, therefore, potentially underestimating the levels of aggression in the pens. Stookey and Gonyou (1994) concluded that the levels of aggression during mixing had an impact on the growth performance of pigs. Therefore, it is possible that the Mixing × Body Weight Category treatment interaction described above for growth performance was due, at least in part, to differences in the levels of aggression between Body Weight Categories. However, further research is needed to understand the relationship between the levels of aggression and the effect of mixing on growth performance, and to determine the factors that influence this response between pigs of different Body Weight Category.

Effects of Gender

Least squares means for the effects of Gender on the growth performance of pigs are presented in Table 4.5 and 4.10. Differences in live weight between genders were present at the start of the test, probably reflecting differences in pre-test growth rates between barrows and gilts. Nevertheless, growth performance prior to the start of test was not measured in the current study. Morbidity and mortality, and aggression levels were not affected ($P > 0.05$) by gender, which is in line with previous studies (Colson et al., 2006; Rodríguez-Sánchez, et al., 2011) of pigs.

Barrows were heavier ($P \leq 0.05$) and had higher ($P \leq 0.05$) overall feed intake than gilts throughout the study. However, gilts grew faster ($P \leq 0.05$) and had greater ($P \leq 0.05$) feed efficiency than barrows. The results for feed intake and feed efficiency are generally in line with previous research (Cisneros et al., 1996; Dunshea et al., 2001; Hamilton et al., 2003; Fàbrega et al., 2010). However, the greater growth rate of gilts was unexpected and is difficult to explain.

Within-pen variation of body weight.

Least square means for the effects of Body Weight Category and Gender in within-pen variation are presented in Table 4.8. Pens on the Control treatment (not-mixed) had a higher ($P \leq 0.05$) within-pen standard deviation and within-pen coefficient of variation of body weight than pens on the mixed treatment for Light, Medium and Heavy Body Weight Category (pens that were formed by mixing pigs of the same Body Weight Category from 3 original pens) at each weighing time throughout the study period**.** These results are in disagreement to those of O'Quinn et al. (2001) and Wolter et al. (2002) which showed that over time, the coefficient of variation of weight within pens of pigs mixed to form homogenous groups reaches a level similar to that of unmixed groups (i.e., groups not mixed by weight). In contrast, the current study and Study 1, mixing pigs of similar weight successfully reduced the within-pen coefficient of variation of final body weight. The major difference between Studies 1 and 2, and those of

O'Quinn et al. (2001) and Wolter et al. (2002) was the time between forming of groups and the end of study. Therefore, the current results suggest that forming groups of pigs with similar weight at week 15 post-weaning can reduce the within-pen variation in body weight at harvest (i.e., 126 kg BW).

CONCLUSIONS

Generally speaking, both studies showed similar results, and it can be concluded that mixing pigs on the basis of body weight as late as 16 weeks post-weaning has little or no impact on morbidity and mortality levels of pigs, and can effectively reduce within-pen variation in BW at the end of the finishing period. However, mixing pigs by weight can also have a transitory (1 to 4 weeks) negative impact on growth performance and aggression, particularly in the heavier pigs.

Nevertheless, it still remains unclear how different factors (e.g., gender, body weight, group size, etc.) affect the response of pigs to mixing, in terms of growth performance and aggression, and further research is needed in this area.

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TABLES

Table 4.1. Summary of materials and methods for Study 1 and 2.

Item	Study 1	Study 2
Experimental design and treatments		
Design	Randomized complete block	Randomized complete block
Arrangement of treatments	2 × 2 × 3 factorial	2 × 2 × 3 factorial
Treatments:		
Gender	Barrows vs. Gilts	Barrows vs. Gilts
Mixing	Control (Not-mixed) vs. Mixed	Control (Not-mixed) vs. Mixed
Body Weight Category	Heavy vs. Medium vs. Light	Heavy vs. Medium vs. Light
Animals		
Genotype	PIC 359 Sires mated to PIC C29 dams	PIC 359 Sires mated to PIC C29 dams
Number of pigs on study	6,618 pigs	1,765 pigs
Initial Body Weight	82.7 ± 10.8 kg	73.2 ± 9.1 kg
Start of study	Week 16 post-weaning	Week 15 post-weaning
Number of pens on study	48	72
Pens per replicate	12	12
Number of replicates	4	6
Housing		
Location of study	Mach 9 Research Farm, Beardstown, IL	Georgia Technology Center, Carlyle, IL
Building design	Curtain sided with tunnel ventilation & Equal pressure ventilation system (SKOV A/S®, Denmark)	Curtain sided with tunnel ventilation
Feeder type	4-hole wet-dry feeder with access to both sides	5-space wet-dry box
Number of feeders per pen	2	1
Water drinkers type	Cup-type	Cup-type
Number of water drinkers	4	2
Moveable gates for floor space adjustment	No	Yes
Single gender pens	Yes	Yes
Pigs per Body Weight Category group		
Heavy	43	7-9
Medium	46	7-9
Light	49	7-9

Pigs per pen/Floor space per pig[a]	Pigs/pen	m^2/pig	*k* start	*k* end[b]	Pigs/pen[c,d]	m^2/pig[e]	*k* start	*k* end[f]
Barrows								
Control	138	0.62	0.033	0.025	23-26	0.82	0.045	0.032
Mixed-Heavy	129	0.67	0.032	0.026	23-26	0.82	0.042	0.032
Mixed-Medium	138	0.62	0.033	0.026	23-26	0.82	0.045	0.032
Mixed-Light	147	0.59	0.034	0.026	23-26	0.82	0.049	0.032
Gilts								
Control	138	0.62	0.033	0.025	21-24	0.82	0.047	0.032
Mixed-Heavy	129	0.67	0.032	0.026	21-24	0.82	0.044	0.032
Mixed-Medium	138	0.62	0.033	0.026	21-24	0.82	0.047	0.032
Mixed-Light	147	0.59	0.034	0.026	21-24	0.82	0.051	0.032

[a] k = Space allowance coefficient = Floor space per pig/(body weight)$^{0.67}$

[b] Fixed time end of study (week 22 post-weaning)

[c] Number of pigs per pen at start of study (week 15 post-weaning) varied between pens due to availability of pigs at placement (week 8 post-weaning) and to differences in removal and mortality rates between pens.

[d] Number of pigs per pen were kept constant within replicate for each gender.

[e] Available floor space in the pen was adjusted by moving back gates to provide the same floor space/pig despite differences in number of pigs per pen

[f] Fixed end weight = 126 kg.

Table 4.1(Continued). Summary of materials and methods for Study 1 and 2.

Item	Study 1	Study 2
Study period		
Start	Week 16 post-weaning	Week 15 post-weaning
End:		
Fixed time	Week 22 post-weaning	Week 22 post-weaning
Fixed weight	No	126 kg (harvest)
Measurements		
Individual weights	Start, End and every 2 weeks	Start, End, and every week
Feed intake	Not recorded	Recorded when pigs were weighed
Aggressive behavior	Not recorded	- Recorded the day of mixing, and on days 1, and 2 post-mixing - Number, duration and locations of fights

Table 4.2. Study 1: Diet formulations and calculated composition.

	Dietary phase	
Item	Phase 1[a]	Phase 2[b]
Ingredient, %		
Corn	63.80	76.25
DDGS	16.03	1.99
Soybean meal	9.41	11.87
Corn germ meal	7.50	7.50
Limestone	1.26	1.00
Dry Lysine	0.25	0.15
Salt	0.44	0.45
Fat–yellow grease	0.70	0.70
Trace mineral premix[1]	0.08	0.06
Surfactant	0.50	-
Trace minerals	0.08	0.06
Vitamins	0.03	0.02
Optiphos 1000	0.01	0.02
Total	100	100
Calculated composition	Calculated	Calculated
ME, Kcal/kg	3222	3282
Crude protein, %	15.18	13.51
Crude fat, %	4.19	3.52
Crude fiber, %	3.00	2.33
NDF, %	12.75	9.75
ADF, %	4.82	3.64
Calcium, %	0.56	0.47
Phosphorus, %	0.43	0.36
Available phosphorus, %	0.18	0.18
Calcium:Phosphorus	1.30	1.30
Sodium, %	0.22	0.20
Salt, %	0.53	0.52
Total lysine, %	0.82	0.73
Digestible lysine, %	0.67	0.61
Digestible lysine:ME	2.09	1.87
Met + Cys:Lysine ratio (Dig.)	0.64	0.63
Tryptophan:Lysine ratio (Dig.)	0.19	0.20
Threonine:Lysine ratio (Dig.)	0.63	0.64
Isoleucine:Lysine ratio (Dig.)	0.68	0.70
Valine:Lysine ratio (Dig.)	0.88	0.85

[a]Phase 1 was fed at 64 kg of feed/pig, over the body weight range of 68-90 kg.
[b]Phase 2 was fed at 111 kg of feed/pig, over the body weight range of 90-125 kg.
[1]Provided per kilogram of final diet: iron, 124 mg as iron sulfate; zinc, 124 mg as zinc oxide; manganese, 29 mg as manganese sulfate; copper, 12 mg as copper sulfate; iodine, 0.2 mg as calcium iodate; and selenium, 0.2 mg as sodium selenite.

Table 4.3. Study 2: Diet formulations and calculated composition.

Item	Dietary phase				
	Phase 1[a]	Phase 2[b]	Phase 3[c]	Phase 4[d]	Phase 5[e]
Ingredient, %					
Corn	48.38	59.92	66.49	71.07	73.26
DDGS	15.00	15.00	15.00	15.00	15.00
Soybean meal	33.99	22.60	16.13	11.61	9.45
Limestone	1.28	1.14	1.07	1.01	0.99
Dry Lysine	0.00	0.11	0.17	0.21	0.23
Salt	0.43	0.41	0.39	0.38	0.38
Fat–yellow grease	0.75	0.67	0.63	0.60	0.59
Trace mineral premix[1]	0.10	0.09	0.08	0.08	0.08
Vitamins	0.03	0.03	0.03	0.03	0.03
Monocal	0.03	0.02	0.01	0.00	0.00
Optiphos 1000	0.02	0.02	0.01	0.01	0.01
Total	100	100	100	100	100
Composition					
ME, Kcal/kg	3252	3252	3252	3252	3252
Crude protein, %	23.96	19.47	16.92	15.14	14.29
Crude fat, %	3.47	3.67	3.79	3.87	3.91
Crude fiber, %	2.54	2.42	2.36	2.31	2.29
NDF, %	9.52	9.59	9.63	9.66	9.67
ADF, %	4.69	4.44	4.30	4.21	4.16
Calcium, %	0.65	0.56	0.50	0.47	0.45
Phosphorus, %	0.50	0.45	0.42	0.40	0.39
Available phosphorus, %	0.28	0.23	0.21	0.19	0.18
Calcium:Phosphorus	1.30	1.24	1.20	1.17	1.16
Sodium, %	0.20	0.19	0.19	0.18	0.18
Salt, %	0.53	0.51	0.50	0.49	0.48
Total lysine, %	1.20	0.99	0.86	0.78	0.74
Digestible lysine, %	1.02	0.83	0.72	0.65	0.61
Digestible lysine:ME	3.14	2.56	2.23	2.00	1.89
Met + Cys:Lysine ratio (Dig.)	0.61	0.64	0.66	0.67	0.68
Tryptophan:Lysine ratio (Dig.)	0.23	0.21	0.19	0.18	0.18
Threonine:Lysine ratio (Dig.)	0.73	0.69	0.67	0.66	0.65
Isoleucine:Lysine ratio (Dig.)	0.82	0.77	0.74	0.72	0.71
Valine:Lysine ratio (Dig.)	0.89	0.87	0.85	0.84	0.84

[a]Phase 1 was fed at 54 kg of feed/pig, over the body weight range of 27-54 kg.
[b]Phase 2 was fed at 45 kg of feed/pig, over the body weight range of 54-73 kg.
[c]Phase 3 was fed at 50 kg of feed/pig, over the body weight range of 73-91 kg.
[d]Phase 4 was fed at 57 kg of feed/pig, over the Body weight range of 91-108 kg.
[e]Phase 5 was fed at 62 kg of feed/pig, over the Body weight range of 108-127 kg.
[1]Provided per kilogram of final diet: iron, 124 mg as iron sulfate; zinc, 124 mg as zinc oxide; manganese, 29 mg as manganese sulfate; copper, 12 mg as copper sulfate; iodine, 0.2 mg as calcium iodate; and selenium, 0.2 mg as sodium selenite.

Table 4.4. Study 1: Least-squares means for the effects of Mixing, Body Weight Category, and Gender treatments in body weight, average daily gain, and morbidity and mortality levels of pigs.[1]

	Mixing (M)			Body Weight Category (BWC)				Gender (G)			*P*-value						
Item	Control	Mixed	SEM	Light	Medium	Heavy	SEM	Barrows	Gilts	SEM	M	BWC	G	G × M	G × BWC	BWC × M	G × BWC × M
Number of experimental units	24	24	-	16	16	16	-	24	24	-	-	-	-	-	-	-	-
Number of pigs	3298	3321	-	2368	2186	2065	-	3308	3311	-	-	-	-	-	-	-	-
Growth performance[2]																	
Body weight, kg																	
Start (Week 16)[3]	82.8	82.6	0.81	70.2[c]	83.3[b]	94.6[a]	0.82	84.9[a]	80.5[b]	0.81	0.49	<0.001	<0.001	0.84	0.93	0.16	0.87
Week 18	95.7[a]	94.5[b]	1.05	82.7[c]	95.6[b]	106.9[a]	1.06	98.3[a]	91.9[b]	1.05	<0.001	<0.001	<0.001	0.02	0.62	0.01	0.063
Gender																	
Barrows	98.6[a]	97.9[a]	1.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gilts	92.9[b]	91.0[c]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mixing																	
Control	-	-	-	82.8[e]	96.4[c]	107.9[a]	1.08	-	-	-	-	-	-	-	-	-	-
Mixing	-	-	-	82.6[e]	94.8[d]	106.0[b]	-	-	-	-	-	-	-	-	-	-	-
Week 20	108.3[a]	105.9[b]	1.08	94.1[c]	107.9[b]	119.2[a]	1.09	110.7[a]	103.5[b]	1.08	<0.001	<0.001	<0.001	0.09	0.27	0.17	0.29
End of test (Week 22)	121.9[a]	120.0[b]	0.86	108.0[c]	121.4[b]	133.4[a]	0.88	125.1[a]	116.8[b]	0.86	<0.001	<0.001	<0.001	0.61	0.88	0.32	0.08
Within experimental-unit CV, %																	
Week 16	7.6	7.2	0.24	10.7[a]	4.9[c]	6.6[b]	0.26	7.2	7.5	0.24	0.06	<0.001	0.06	0.14	0.45	0.53	0.96
Week 22	14.1[b]	12.2[a]	0.71	17.9[a]	10.6[b]	11.0[b]	0.84	13.0[a]	13.3[b]	0.71	0.04	<0.001	0.04	0.06	0.77	0.96	0.30
Average daily gain, kg[4]																	
Week 16 – 18[2]	0.92[a]	0.85[b]	0.035	0.89	0.88	0.88	0.036	0.95[a]	0.81[b]	0.035	<0.001	0.90	<0.001	0.02	0.44	0.42	0.08
Gender																	
Barrows	0.97[a]	0.94[a]	0.037	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gilts	0.87[b]	0.75[c]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Week 18 – 20	0.89[a]	0.81[b]	0.032	0.80[b]	0.87[a]	0.87[a]	0.034	0.88[a]	0.82[b]	0.032	<0.001	0.009	0.006	0.93	0.18	0.24	0.65
Week 20 – 22[5]	0.87	0.90	0.057	0.88	0.86	0.91	0.058	0.92[a]	0.85[b]	0.057	0.16	0.14	0.001	0.30	0.46	0.37	0.12
Overall (Week 16 – 22)[6]	0.89[a]	0.85[b]	0.008	0.86[b]	0.87[ab]	0.89[a]	0.009	0.92[a]	0.83[b]	0.008	<0.001	0.007	<0.001	0.41	0.72	0.92	0.08
Morbidity and Mortality, %	2.1	1.7	-	2.9[b]	1.2[a]	1.5[a]	-	1.9	1.9	-	0.18	<0.001	0.77	0.64	0.63	0.69	0.24

[a,b,c,d,e]Means within a row with different superscripts differ ($P < 0.05$).

[1]Experimental unit =3 groups (of approximately 1/3 of a pen) of the same Mixing, Body Weight Category and Gender treatment combination.

[2]Week number is the week post-weaning and relates to the start of each week.

[3]Pigs were mixed at the start of the study at week 16 post-weaning.

[4]Average daily gain = (Weight of current period + Mortality weight on current period – Weight of previous period)/Total pig days.

[5]Week 20 to 22 period averaged 15.5 days

[6]Overall average daily gain = (Weight at end of study + Mortality weight – Weight at start of study)/Total pig days in study.

Table 4.5. Study 2: Least-squares means for the effects of Mixing, Body Weight Category, and Gender treatments in body weight, average daily gain, and morbidity and mortality levels of pigs[1]

Item	Mixing (M)			Body Weight Category (BWC)				Gender (G)			*P*-value						
	Control	Mixed	SEM	Light	Medium	Heavy	SEM	Barrows	Gilts	SEM	M	BWC	G	G × M	G × BWC	BWC × M	G × BWC × M
Number of experimental units	36	36	-	24	24	24	-	36	36	-	-	-	-	-	-	-	-
Number of animals	892	872	-	584	592	588	-	916	848	-	-	-	-	-	-	-	-
Growth performance[2]																	
Body weight, kg																	
Start (Week 15)[3]	73.5	73.2	0.86	64.6^{c}	73.3^{b}	82.2^{a}	0.88	75.6^{a}	71.1^{b}	0.86	0.49	<0.001	<0.001	0.99	0.61	0.77	0.14
Week 16	80.7^{a}	79.6^{b}	1.04	71.2^{c}	80.1^{b}	89.2^{a}	1.06	82.4^{a}	77.9^{b}	1.04	0.005	<0.001	<0.001	0.98	0.81	0.24	0.06
Week 17	87.1^{a}	86.2^{b}	1.00	77.4^{c}	86.5^{b}	96.0^{a}	1.02	89.1^{a}	84.2^{b}	1.00	0.02	<0.001	<0.001	0.83	0.97	0.53	0.10
Week 18	94.6	93.7	1.05	84.7^{c}	94.1^{b}	103.7^{a}	1.07	96.4^{a}	91.9^{b}	1.05	0.06	<0.001	<0.001	0.57	1.00	0.17	0.19
Week 19	98.5	97.8	0.75	89.2^{c}	97.9^{b}	107.4^{a}	0.79	100.4^{a}	96.0^{b}	0.76	0.11	<0.001	<0.001	0.45	0.85	0.11	0.58
Week 20	106.5	105.7	0.96	96.9^{c}	105.8^{b}	115.7^{a}	0.99	108.2^{a}	104.1^{b}	0.96	0.12	<0.001	<0.001	0.58	0.92	0.09	0.20
Week 21[4]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Week 22 (Fixed-time end)	116.1	115.3	0.71	106.4^{c}	115.5^{b}	125.1^{a}	0.76	117.3^{a}	114.0^{b}	0.71	0.11	<0.001	<0.001	0.44	0.95	0.007	0.41
Control	-	-	-	105.9^{d}	115.7^{c}	126.6^{a}	0.88	-	-	-	-	-	-	-	-	-	-
Mixed	-	-	-	106.9^{d}	115.3^{c}	123.5^{b}	-	-	-	-	-	-	-	-	-	-	-
Within experimental-unit CV of Body Weight, %																	
Week 15	6.3	6.0	0.26	7.9^{a}	4.6^{c}	6.0^{b}	0.30	6.3	6.1	0.26	0.30	<0.001	0.52	0.43	0.38	0.006	0.46
Week 22	6.2	6.1	0.29	7.3^{a}	5.3^{b}	5.9^{b}	0.33	6.1	6.2	0.29	0.63	<0.001	0.76	0.47	0.65	0.12	0.95
Average daily gain, kg[5]																	
Week 15 – 16	0.96^{a}	0.85^{b}	0.016	0.88	0.91	0.93	0.018	0.91	0.91	0.016	<0.001	0.06	0.94	0.99	0.53	0.08	0.73
Week 16 – 17	0.95	0.96	0.024	0.90^{b}	0.95^{b}	1.00^{a}	0.026	0.98^{a}	0.92^{b}	0.024	0.60	0.002	0.007	0.51	0.45	0.26	0.99
Week 17 – 18	1.03	1.04	0.026	1.01	1.04	1.06	0.028	1.01^{b}	1.07^{a}	0.026	0.73	0.07	0.009	0.24	0.32	0.08	0.70
Week 18 – 19	0.56	0.57	0.056	0.63^{b}	0.54^{a}	0.53^{a}	0.057	0.56	0.58	0.056	0.51	<0.001	0.37	0.34	0.07	0.14	0.17
Week 19 – 20	1.14	1.13	0.035	1.10^{b}	1.12^{b}	1.19^{a}	0.037	1.12	1.15	0.035	0.78	0.006	0.13	0.60	0.03	0.50	0.02
Barrows:																	
Control	-	-	-	1.10^{cd}	1.08^{d}	1.20^{abc}	0.049	-	-	-	-	-	-	-	-	-	-
Mixed	-	-	-	1.15^{bcd}	1.11^{bcd}	1.07^{d}	-	-	-	-	-	-	-	-	-	-	-
Gilts:																	
Control	-	-	-	1.10^{cd}	1.14^{bcd}	1.21^{ab}	-	-	-	-	-	-	-	-	-	-	-
Mixed	-	-	-	1.06^{d}	1.14^{bcd}	1.26^{a}	-	-	-	-	-	-	-	-	-	-	-
Week 20 – 22[4]	0.68	0.68	0.028	0.68	0.69	0.66	0.029	0.65^{b}	0.71^{a}	0.028	0.77	0.31	<0.001	0.65	0.36	0.03	0.34
Control	-	-	-	0.67^{ab}	0.68^{ab}	0.69^{a}	0.032	-	-	-	-	-	-	-	-	-	-
Mixed	-	-	-	0.69^{a}	0.70^{a}	0.63^{b}	-	-	-	-	-	-	-	-	-	-	-
Week 15 – Week 22[6]	0.86	0.84	0.012	0.84^{b}	0.85^{ab}	0.87^{a}	0.013	0.84^{b}	0.86^{a}	0.012	0.10	0.04	0.010	0.28	0.61	0.01	0.94
Control	-	-	-	0.83^{b}	0.85^{b}	0.89^{a}	0.014	-	-	-	-	-	-	-	-	-	-
Mixed	-	-	-	0.85^{b}	0.84^{b}	0.84^{b}	-	-	-	-	-	-	-	-	-	-	-
Morbidity and Mortality, %	2.1	3.2	-	4.5^{b}	2.7^{a}	0.9^{a}	-	2.5	2.8	-	0.76	<0.001	0.84	0.54	0.95	0.15	0.21

[a,b,c,d]Means within a row with different superscripts differ ($P < 0.05$).

[1]Experimental unit =3 groups (of approximately 1/3 of a pen) of the same Mixing, Body Weight Category and Gender treatment combination. The experimental unit used in the present analysis did not allow for a measurement of feed intake.

[2]Week number is the week post-weaning and relates to the start of each week.

[3]Pigs were mixed at the start of the study at week 15 post-weaning.

[4]Pigs were not weighed at week 21 due to feed outages at the farm during that weighing period.

[5]Average daily gain = (Weight at end of period + Mortality weight at end of period – Weight at start of period)/Total pig days in period.

[6]Start – Week 22 average daily gain = (Weight at week 22 + Mortality weight – Weight at start of study)/Total pig days from start to week 22.

Table 4.6. Study 2: Least-squares means of the effects of Mixing and Gender treatments in body weight, average daily gain, feed intake, feed conversion rate, and morbidity and mortality levels of pigs[1].

	Mixing (M)			Gender (G)			*P*-value		
Item	Control	Mixed	SEM	Barrows	Gilts	SEM	M	G	G × M
Number of experimental units	12	12	-	12	12	-	-	-	-
Number of animals	892	872	-	916	848	-	-	-	-
Growth performance[2]									
Body weight, kg									
Start (Week 15)[3]	73.5	73.2	0.89	75.6^{a}	71.1^{b}	0.89	0.72	<0.001	0.99
Week 16	80.7	79.6	1.05	82.4^{a}	77.9^{b}	1.05	0.07	<0.001	0.94
Week 17	87.2	86.2	1.01	89.1^{a}	84.2^{b}	1.01	0.12	<0.001	0.95
Week 18	94.6	93.7	0.82	96.4^{a}	91.9^{b}	0.82	0.49	<0.001	0.87
Week 19	98.6	97.8	0.77	100.4^{a}	96.0^{b}	0.77	0.29	<0.001	0.70
Week 20	106.6	105.7	0.97	108.2^{a}	104.1^{b}	0.97	0.29	<0.001	0.79
Week 21[4]	-	-	-	-	-	-	-	-	-
Week 22 (Fixed-time end)	116.1	115.3	0.72	117.4^{a}	114.0^{b}	0.72	0.25	<0.001	0.63
Fixed-weight end (126 kg)[5]	126.1	125.9	0.36	126.2	125.8	0.36	0.82	0.50	0.88
Days to 126 kg	63.9	64.5	1.31	61.7^{b}	66.7^{a}	1.31	0.74	0.009	0.63
Average daily gain, kg[6]									
Week 15 – 16	0.96^{a}	0.85^{b}	0.017	0.90	0.91	0.017	<0.001	0.95	0.98
Week 16 – 17	0.95	0.96	0.025	0.98^{a}	0.92^{b}	0.025	0.66	0.026	0.58
Week 17 – 18	1.04	1.04	0.027	1.01^{b}	1.07^{a}	0.027	0.81	0.030	0.32
Week 18 – 19	0.56	0.57	0.056	0.56	0.58	0.056	0.55	0.41	0.37
Week 19 – 20	1.14	1.13	0.035	1.12	1.15	0.035	0.76	0.10	0.54
Week 20 – 22	0.68	0.68	0.028	0.65^{b}	0.71^{a}	0.028	0.76	0.003	0.68
Week 15 – Week 22[7]	0.86	0.85	0.012	0.84^{b}	0.86^{a}	0.012	0.11	0.016	0.32
Week 15 – 126 kg[8]	0.82	0.81	0.013	0.81	0.82	0.013	0.36	0.63	0.12
Average daily feed intake, kg									
Week 15 – 16	2.50^{a}	2.35^{b}	0.033	2.55^{a}	2.30^{b}	0.033	0.001	<0.001	0.62
Week 16 – 17	2.58	2.54	0.022	2.66^{a}	2.46^{b}	0.022	0.12	<0.001	0.88
Week 17 – 18	2.52	2.55	0.051	2.66^{a}	2.42^{b}	0.051	0.34	<0.001	0.36
Week 18 – 19	2.63	2.63	0.066	2.78^{a}	2.48^{b}	0.066	0.92	<0.001	0.37
Week 19 – 20	2.70	2.71	0.039	2.80^{a}	2.61^{b}	0.039	0.64	<0.001	0.84
Week 20 – 22	2.51	2.49	0.038	2.56^{a}	2.44^{b}	0.038	0.44	<0.001	0.37
Week 15 – Week 22[7]	2.56	2.54	0.030	2.65^{a}	2.45^{b}	0.030	0.23	<0.001	0.56
Week 15 – 126 kg[8]	2.54	2.54	0.035	2.64^{a}	2.44^{b}	0.035	0.67	<0.001	0.54
Gain:Feed, kg:kg									
Week 15 – 16	0.385^{a}	0.365^{b}	0.0078	0.356^{b}	0.394^{a}	0.0078	0.038	<0.001	0.80
Week 16 – 17	0.366	0.376	0.0082	0.369	0.373	0.0082	0.22	0.61	0.56
Week 17 – 18	0.412	0.410	0.0093	0.380^{a}	0.442^{b}	0.0093	0.72	<0.001	0.55
Week 18 – 19	0.212	0.218	0.0178	0.200^{b}	0.231^{a}	0.0178	0.45	<0.001	0.53
Week 19 – 20	0.423	0.419	0.0134	0.400^{b}	0.441^{a}	0.0134	0.51	<0.001	0.62
Week 20 – 22	0.272	0.271	0.0081	0.254^{b}	0.290^{a}	0.0081	0.95	<0.001	0.95
Week 15 – Week 22[7]	0.336	0.334	0.0031	0.318^{b}	0.353^{a}	0.0031	0.51	<0.001	0.58
Week 15 – 126 kg[8]	0.323	0.321	0.0036	0.308^{b}	0.336^{a}	0.0036	0.51	<0.001	0.17
Carcass characteristics									
Hot carcass weight, kg	92.5	92.7	0.31	92.6	92.6	0.31	0.63	0.92	0.55
Standard deviation of hot carcass weight, kg	8.84	5.75	0.269	7.20	7.40	0.269	<0.001	0.62	0.57
Carcass yield, %	73.4	73.6	0.13	73.4	73.6	0.13	0.18	0.17	0.16
Longissimus muscle depth (10th rib), cm	5.78	5.81	0.077	5.66	5.92	0.77	0.84	0.06	0.37
Backfat depth (10th rib), cm	1.54	1.59	0.268	1.71	1.42	0.028	0.32	<0.001	0.52
Predicted carcass lean content, %	54.13	53.99	0.109	53.23	54.89	0.109	0.04	<0.001	0.57
Morbidity and Mortality, %	2.1	3.2	-	2.5	2.8	-	0.45	0.78	0.92

[a,b]Means within a row with different superscripts differ ($P < 0.05$).
[1]Experimental unit = 3 pens of the same Mixing and Gender treatment combination.
[2]Week number is the week post-weaning and relates to the start of each week.
[3]Pigs were mixed at the start of the study at week 15 post-weaning.
[4]Pigs were not weighed at week 21 due to feed outages at the farm during that weighing period.
[5]Entire pens were shipped for harvest at an average pen body weight of 126 kg.
[6]Average daily gain = (Weight at end of period + Mortality weight at end of period – Weight at start of period)/Total pig days in period.
[7]Week 15 – Week 22 average daily gain = (Weight at start of week 22 + Mortality weight – Weight at start of week 15)/Total pig days from week 15 to week 22.
[8]Week 15 – 126 kg average daily gain = (Weight at end of study + Mortality weight – Weight at start of study)/Total pig days in study.

Table 4.7. Study 1: Least-squares means of the effects of Body Weight Category and Gender treatments in within pen variation for body weight.[1]

	Body Weight Category (BWC)					Gender (G)			*P*-value		
Item	Control	Light[2]	Medium[2]	Heavy[2]	SEM	Barrows	Gilts	SEM	BWC	G	G × BWC
Number of experimental units	24	8	8	8	-	24	24	-	-	-	-
Number of pigs	3298	1182	1094	1034	-	3308	3311	-	-	-	-
Body weight, kg[3]											
Start (Week 16)[4]	82.2[b]	70.4[c]	83.1[b]	94.3[a]	1.02	84.7[a]	80.4[b]	0.88	<0.001	<0.001	1.00
Fixed-time end (Week 22)	121.4[b]	107.5[c]	120.2[b]	132.3[a]	1.05	124.5[a]	116.1[b]	0.92	<0.001	<0.001	0.88
Within-pen standard deviation for BW, kg[3]											
Week 16	11.68[a]	7.31[b]	4.00[d]	5.93[c]	0.295	7.15	7.31	0.231	<0.001	0.57	0.98
Week 18	12.42[a]	8.38[b]	5.29[d]	6.61[c]	0.321	8.25	8.10	0.270	<0.001	0.56	0.45
Week 20	13.12[a]	9.26[b]	5.94[d]	7.71[c]	0.308	9.03	8.98	0.256	<0.001	0.86	0.18
Fixed-time end (Week 22)	13.79[a]	9.94[b]	6.50[d]	8.36[c]	0.374	9.58	9.72	0.318	<0.001	0.62	0.73
Within-pen coefficient of variation for BW, %[3]											
Week 16	14.2[a]	10.4[b]	4.8[d]	6.3[c]	0.43	8.6	9.3	0.36	<0.001	0.06	0.97
Week 18	13.1[a]	10.2[b]	5.6[c]	6.2[c]	0.45	8.6	9.0	0.40	<0.001	0.16	0.35
Week 20	12.2[a]	10.0[b]	5.6[d]	6.6[c]	0.38	8.3[b]	8.9[a]	0.33	<0.001	0.04	0.15
Fixed-time end (Week 22)	11.4[a]	9.3[b]	5.4[d]	6.3[c]	0.35	7.8[b]	8.4[a]	0.30	<0.001	0.01	0.48

[a,b,c]Means within a row with different superscripts differ ($P < 0.05$).
[1]Experimental unit = pen.
[2]Includes pens of pigs from the Mixed treatment only.
[3]Week number is the week post-weaning and relates to the start of each week.
[4]Pigs were mixed at the start of the study at week 16 post-weaning.

Table 4.8. Study 2: Least-squares means of the effects of Body Weight Category and Gender treatments in within pen variation for body weight, and carcass characteristics of pigs[1].

	Body Weight Category (BWC)					Gender (G)			*P*-value		
Item	Control	Light[2]	Medium[2]	Heavy[2]	SEM	Barrows	Gilts	SEM	BWC	G	G × BWC
Number of experimental units	36	12	12	12	-	36	36	-	-	-	-
Number of animals	892	288	292	292	-	916	848	-	-	-	-
Body weight, kg[4]											
Start (Week 15)[5]	73.5^{b}	64.7^{c}	73.2^{b}	81.8^{a}	0.94	75.5^{a}	71.1^{b}	0.87	<0.001	<0.001	0.94
Week 22 (Fixed-time end)	116.1^{b}	106.9^{c}	115.3^{b}	123.5^{a}	0.85	117.3^{a}	113.7^{b}	0.74	<0.001	<0.001	0.74
Fixed-weight end (126 kg)[6]	126.1	125.2	126.8	125.9	0.54	126.1	125.8	0.39	0.33	0.56	0.66
Days to 126 kg	63.9^{b}	75.4^{a}	65.3^{b}	52.8^{c}	1.23	61.6^{b}	67.1^{a}	1.03	<0.001	<0.001	0.51
Within-pen standard deviation for BW, kg[4]											
Week 15	8.65^{a}	4.53^{bc}	3.50^{c}	5.11^{b}	0.312	5.69	5.21	0.225	<0.001	0.13	0.17
Week 16	9.15^{a}	5.15^{b}	4.07^{c}	5.45^{b}	0.344	6.13	5.77	0.264	<0.001	0.27	0.15
Week 17	9.48^{a}	5.68^{b}	4.37^{c}	5.72^{b}	0.387	6.46	6.17	0.298	<0.001	0.43	0.30
Week 18	9.92^{a}	5.65^{b}	4.43^{c}	5.72^{b}	0.373	6.48	6.38	0.287	<0.001	0.77	0.21
Week 19	9.90^{a}	5.79^{bc}	4.71^{c}	5.96^{b}	0.383	6.64	6.54	0.299	<0.001	0.76	0.20
Week 20	10.46^{a}	6.29^{b}	5.25^{b}	6.43^{b}	0.422	7.11	7.10	0.331	<0.001	0.97	0.16
Week 21[7]	-	-	-	-	-	-	-	-	-	-	-
Week 22 (Fixed-time end)	11.09^{a}	7.24^{bc}	6.12^{c}	7.52^{b}	0.485	8.01	7.97	0.391	<0.001	0.92	0.61
Fixed-weight end (126 kg)[8]	11.55^{a}	8.44^{b}	6.71^{c}	7.48^{bc}	0.498	8.32	8.77	0.382	<0.001	0.34	0.92
Within-pen coefficient of variation for BW, %[4]											
Week 15	11.8^{a}	7.0^{b}	4.8^{c}	6.3^{b}	0.43	7.6	7.4	0.31	<0.001	0.61	0.35
Week 16	11.3^{a}	7.3^{b}	5.1^{c}	6.2^{bc}	0.42	7.5	7.4	0.32	<0.001	0.94	0.28
Week 17	10.9^{a}	7.4^{b}	5.1^{c}	6.0^{c}	0.46	7.3	7.4	0.36	<0.001	0.82	0.40
Week 18	10.5^{a}	6.7^{b}	4.7^{c}	5.6^{bc}	0.40	6.8	7.0	0.30	<0.001	0.58	0.43
Week 19	10.0^{a}	6.5^{b}	4.8^{c}	5.6^{bc}	0.40	6.7	6.8	0.31	<0.001	0.61	0.33
Week 20	9.8^{a}	6.5^{b}	5.0^{c}	5.6^{bc}	0.41	6.6	6.8	0.33	<0.001	0.51	0.29
Week 21[7]	-	-	-	-	-	-	-	-	-	-	-
Week 22 (Fixed-time end)	9.6^{a}	6.8^{b}	5.3^{c}	6.1^{bc}	0.44	6.9	7.0	0.36	<0.001	0.66	0.73
Fixed-weight end (126 kg)[6]	9.2^{a}	6.8^{b}	5.3^{c}	6.0^{bc}	0.40	6.6	7.0	0.31	<0.001	0.32	0.90
Carcass characteristics											
Hot carcass weight, kg	92.5	92.2	93.5	92.5	0.49	92.7	92.6	0.37	0.33	0.88	0.65
Standard deviation of hot carcass weight, kg	8.84^{a}	6.35^{b}	5.06^{c}	5.85^{bc}	0.379	6.37	6.68	0.279	<0.001	0.42	0.82
Carcass yield, %	73.4	73.5	73.6	73.8	0.19	73.5	73.6	0.145	0.44	0.56	0.48
Longissimus muscle depth (10th rib), cm	5.78	5.77	5.68	5.98	0.108	5.70	5.90	0.076	0.39	0.09	0.29
Backfat depth (10th rib), cm	1.55	1.55	1.59	1.62	0.036	1.73^{a}	1.42^{b}	0.026	0.36	<0.001	0.36
Predicted carcass lean content, %	54.1^{a}	54.2^{a}	53.7^{b}	54.2^{ab}	0.14	53.2^{b}	54.8^{a}	0.12	0.046	<0.001	0.71

[a,b,c]Means within a row with different superscripts differ ($P < 0.05$).
[1]Experimental unit = pen.
[2]Includes pens of pigs from the Mixed treatment only.
[3]Control vs. (Light, Medium and Heavy)
[4]Week number is the week post-weaning and relates to the start of each week.
[5]Pigs were mixed at the start of the study at week 15 post-weaning.
[6]Entire pens were shipped for harvest at an average pen Body weight of 126 kg.
[7]Pigs were not weighed at week 21 due to feed outages at the farm on that weighing period.

Table 4.9. Study 1: Effects of Mixing, Body Weight Category and Gender treatments on the incidence of morbidity and mortality.

	Mixing[1]		Body Weight Category			Gender	
Item	Control	Mixed	Light	Medium	Heavy	Barrows	Gilts
Total number of pigs	3289	3321	2368	2186	2065	3308	3311
Total morbidity and mortality							
Number of pigs	70	56	69	26	31	63	63
Percentage of pigs, %	2.1	1.7	2.9	1.2	1.5	1.9	1.9
Total mortality							
Number of pigs	33	21	24	15	15	23	31
Percentage of pigs, %	1.0	0.6	1.0	0.7	0.7	0.7	0.9
Total morbidity							
Number of pigs	37	35	45	11	16	40	32
Percentage of pigs, %	1.1	1.1	1.9	0.5	0.8	1.2	1.0
Causes of morbidity and mortality, number of pigs							
Respiratory disease[2]	18	9	15	6	6	11	16
Gastrointestinal disease[3]	15	17	10	8	14	17	15
Other disease[4]	2	2	3	0	1	1	3
Injury[5]	19	12	16	8	7	19	12
Structural defect[6]	0	0	0	0	0	0	0
Hernia[7]	0	2	1	1	0	0	2
Emaciation[8]	13	9	18	3	1	12	10
NANI[9]	0	0	0	0	0	0	0
Other[10]	2	5	5	0	2	3	4
Light at harvest[11]	1	0	1	0	0	0	1
Timing of morbidity and mortality, number of pigs[12]							
Week 16 – 18	19	8	17	7	3	15	12
Week 18 – 20	27	28	28	12	15	25	30
Week 20 – 22	24	20	24	7	13	23	21

[1]Pigs were mixed at the start of the study at week 16 post-weaning.
[2]Respiratory disease = PRRS, pneumonia, influenza, and thumping.
[3]Gastrointestinal disease = ileitis, hemorrhagic bowel, obstructed bowel, and ulcers.
[4]Other disease = neurological signs, and exudative epidermitis (*Staphylococcus hyicus*).
[5]Injury = broken bones, cannibalism, abscesses, and swollen joints.
[6]Structural defects = broken top, leg soundness issues, and spraddle legs.
[7]Hernia = scrotal and umbilical hernias.
[8]Emaciation = fall out, anorexia, and general unthriftiness.
[9]NANI = downers and stress related issues.
[10]Other = all other reasons for morbidity or mortality.
[11]Pigs under 95 kg body weight at marketing.
[12]Week number is the week post-weaning and relates to the start of each week.

Table 4.10. Study 2: Effects of Mixing, Body Weight Category, and Gender on the incidence of morbidity and mortality of pigs.

	Mixing[1]		Body Weight Category			Gender	
Item	Control	Mixed	Light	Medium	Heavy	Barrows	Gilts
Total number of pigs	892	872	584	592	588	916	848
Total morbidity and mortality							
Number of pigs	19	28	26	16	5	23	24
Percentage of pigs, %	2.1	3.2	4.5	2.7	0.9	2.5	2.8
Total mortality							
Number of pigs	9	13	13	7	2	12	10
Percentage of pigs, %	1.0	1.5	2.2	1.2	0.3	1.3	1.2
Total morbidity							
Number of pigs	10	15	13	9	3	11	14
Percentage of pigs, %	1.1	1.7	2.2	1.5	0.5	1.2	1.7
Causes of morbidity and mortality, number of pigs							
Respiratory disease[2]	4	8	9	3	0	6	6
Gastrointestinal disease[3]	1	5	2	3	1	4	2
Other disease[4]	0	0	0	0	0	0	0
Injury[5]	3	3	1	3	2	2	4
Structural defect[6]	0	0	0	0	0	0	0
Hernia[7]	2	1	3	0	0	2	1
Emaciation[8]	2	1	3	0	0	3	0
NANI[9]	0	0	0	0	0	0	0
Other[10]	3	6	4	5	0	4	5
Light at harvest[11]	4	4	4	2	2	2	6
Timing of morbidity and mortality, number of pigs[12]							
Week 15 – 16	2	0	1	1	0	2	0
Week 16 – 17	1	3	3	0	1	3	1
Week 17 – 18	0	4	2	2	0	2	2
Week 18 – 19	4	4	3	5	0	4	4
Week 19 – 20	1	0	0	0	1	0	1
Week 20 – 21	1	1	1	0	1	2	0
Week 21 – 22	0	3	2	1	0	3	0
Week 21 – 23	0	0	0	0	0	0	0
Week 21 – 24	5	4	8	1	0	5	4
Week 21 – 25	3	4	1	5	1	1	6
Week 21 – 26	2	5	5	1	1	1	6

[1]Pigs were mixed at the start of the study at week 15 post-weaning.
[2]Respiratory disease = PRRS, pneumonia, influenza, and thumping.
[3]Gastrointestinal disease = ileitis, hemorrhagic bowel, obstructed bowel, and ulcers.
[4]Other disease = neurological signs and exudative epidermitis (*Staphylococcus hyicus*).
[5]Injury = broken bones, cannibalism, abscesses, and swollen joints.
[6]Structural defects = broken top, leg soundness issues, and spraddle legs.
[7]Hernia = scrotal and umbilical hernias.
[8]Emaciation = fall out, anorexia, and general unthriftiness.
[9]NANI = downers and stress related issues.
[10]Other = all other reasons for morbidity or mortality.
[11]Pigs under 95 kg Body weight at marketing.
[12]Week number is the week post-weaning and relates to the start of each week.

FIGURES

Figure 4.1: Diagram of experimental units and mixing procedure for Studies 1 and 2.[1,2]

Before mixing

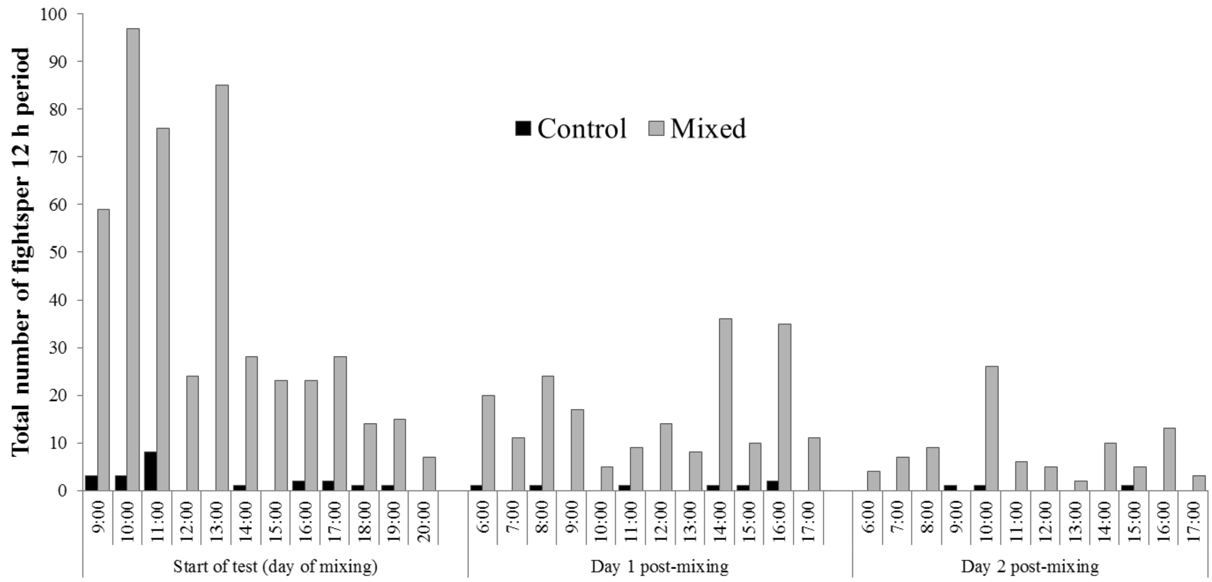
		Experimental units[3]
Mixed	Pen 1	
	Heaviest 1/3	A
	Medium 1/3	B
	Lightest 1/3	C
	Pen 2	
	Heaviest 1/3	A
	Medium 1/3	B
	Lightest 1/3	C
	Pen 3	
	Heaviest 1/3	A
	Medium 1/3	B
	Lightest 1/3	C
Control (Not-mixed)	Pen 4	
	Heaviest 1/3	D
	Medium 1/3	E
	Lightest 1/3	F
	Pen 5	
	Heaviest 1/3	D
	Medium 1/3	E
	Lightest 1/3	F
	Pen 6	
	Heaviest 1/3	D
	Medium 1/3	E
	Lightest 1/3	F

After mixing

Experimental units[3]	
	Pen 1 – Heavy Mixed
A	Heaviest 1/3 from pen 1
A	Heaviest 1/3 from pen 2
A	Heaviest 1/3 from pen 3
	Pen 2 – Medium Mixed
B	Medium 1/3 from pen 1
B	Medium 1/3 from pen 2
B	Medium 1/3 from pen 3
	Pen 3 – Light Mixed
C	Lightest 1/3 from pen 1
C	Lightest 1/3 from pen 2
C	Lightest 1/3 from pen 3
	Pen 4 – Control (Not-Mixed)
D	Heaviest 1/3 from Pen 4
E	Medium 1/3 from Pen 4
F	Lightest 1/3 from Pen 4
	Pen 5 – Control (Not-Mixed)
D	Heaviest 1/3 from Pen 5
E	Medium 1/3 from Pen 5
F	Lightest 1/3 from Pen 5
	Pen 6 – Control (Not-Mixed)
D	Heaviest 1/3 from Pen 6
E	Medium 1/3 from Pen 6
F	Lightest 1/3 from Pen 6

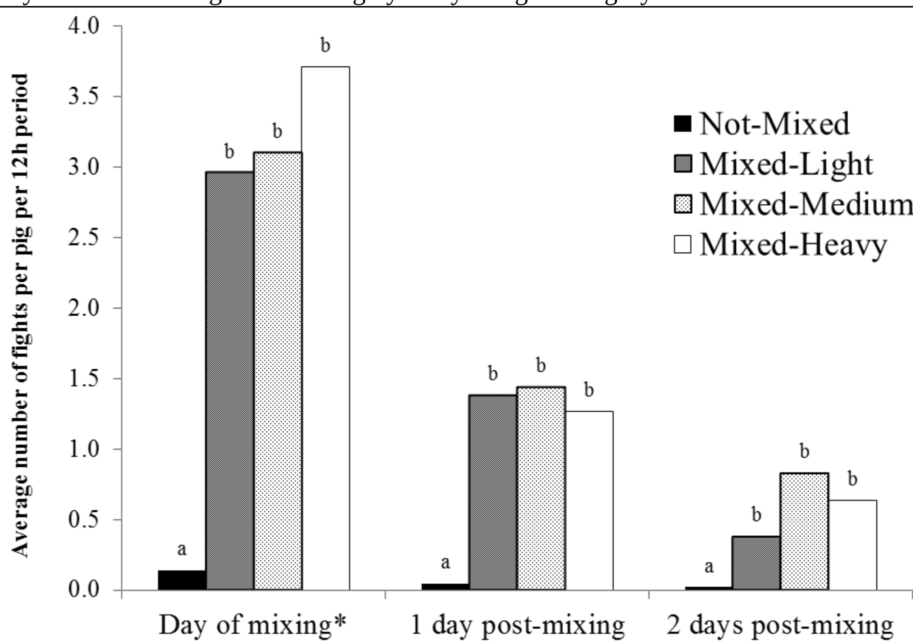
[1]Diagram only shows the mixing procedure and experimental units of one gender.
[2]Arrows indicate movement of groups of pigs (only Heavy Mixed treatment and Control treatment are shown)
[3]Groups with same experimental unit letters correspond to the same experimental unit (One letter per treatment combination).

Figure 4.2. Study 2: Frequency of fights during the behavior recording period for Mixed and Control (Not-Mixed) treatments.[1,2]



[1]Pigs mixed at week 15 post-weaning.
[2]Recording period = 12 hours per day, on day of mixing, and day 1 and 2 post-mixing.

Figure 4.3. Study 2: Number of fight for Mixing by Body Weight Category treatment subclasses.



*Pigs mixed at week 15 post-weaning
[a,b]Means within day with different superscripts differ ($P < 0.05$).

CHAPTER 5: EVALUATION OF THE GROWTH PERFORMANCE, FEEDING AND ACTIVITY PATTERNS, AND AGGRESSIVE BEHAVIOR OF BARROWS MIXED TWICE DURING THE FINISHING PERIOD.

ABSTRACT

The effect of mixing pigs twice during the finishing phase on growth performance, feeding and activity patterns, and aggressive behavior was investigated in a study involving 48 barrows. The study was carried out over a 10-wk period from 65.2 ± 4.5 kg to 136.5 ± 7.6 kg BW as a generalized randomized block design (blocking factor day of start on test) with 2 treatments: 1) Control (Not-mixed); 2) Mixed (mixed at start and at wk 5 of the study). The study involved 4 pens of 12 pigs; pens were equipped with an electronic feed station that recorded the time and duration of visits to the feeder and the weight of feed consumed/visit for each animal in the group. For the first mixing event, the 12 pigs in the 2 pens on the Mixed treatment were divided into 2 subgroups of 6 pigs with the same mean and variation in BW and one subgroup from each pen was exchanged with the subgroup from the other pen. For the second mixing event, the subgroups of 6 that were mixed had not previously been mixed together. Activity (number of pigs lying, standing, eating, and drinking) and aggressive interactions (number of bites and fights of greater than 3 seconds duration) were recorded on the d before and d of mixing, and d 1, 2, and 3 post-mixing. There was no effect ($P > 0.05$) of mixing on growth performance or feeding patterns for the periods immediately after mixing or for the overall study period. Mixing increased ($P \leq 0.05$) the number of pigs standing (6.9 vs. 9.7% for Control and Mixed, respectively) and reduced ($P \leq 0.05$) the number of pigs lying (85 vs. 82%, respectively) for the 3 days following the first mixing event, but not following the second mixing event ($P > 0.05$). For both mixing events, mixing increased ($P \leq 0.05$) the

number of bites/pig during the 3 d post-mixing, however, the number of bites/pig declined from the d of mixing (1.1 vs. 10.5, respectively), to d 3 post-mixing (1.6 vs. 4.7, respectively). Mixing increased ($P \leq 0.05$) the number of fights/pig (0.04 vs. 1.75, respectively) on the day of mixing for the first mixing event only. These results suggest that mixing pigs in the finishing period can increase the level of aggression for a short period of time, with no impact on growth performance or feeding patterns.

INTRODUCTION

Current commercial production practices often require the mixing of unfamiliar pigs at different stages in the pig production process. For instance, pigs are commonly mixed at weaning and/or at the beginning of growing-finishing period, when groups of pigs are moved into larger pens to meet their floor space requirements as pigs grow, or when pigs of similar weight are moved into a different pen to reduce the within-group variation in weight.

The effect of mixing on the growth performance and behavior of pigs has been evaluated in a number of studies (Chapter 1, Tables 1.1 and 1.2). Generally speaking, it has been shown that mixing increases the level of aggression of pigs (Rushen, 1987; Barnett et al., 1994; Stookey and Gonyou, 1994; Giersing and Andersson, 1998; Andersen et al., 2000; O'Connell et al., 2004; O'Connell et al., 2005; Li and Johnston, 2009) and that it has either no effect (Heetkamp et al., 2002; O'Connell et al., 2004) or a negative effect (Tuscherer et al., 1998; Hayne and Gonyou, 2003; Coutellier et al., 2007) on the growth performance of pigs.

When present, the negative effects of mixing on aggressive behavior and growth performance have been reported to be transitory and that pigs will recover that growth when given enough time. However, most previous research has been carried out mainly in the early part of the growth period (i.e., at weaning or when moving pigs from the nursery to grow-finish), and focused more on behavioral responses than on production parameters. Moreover, a limited number of studies have evaluated the effect of mixing on feeding patterns of pigs and their relation to changes in aggressive behavior and growth performance.

Therefore, the present study was carried out to evaluate the effect of mixing at two times in the finishing phase on the feeding behavior, aggressive behavior, level of activity, and growth performance of pigs.

MATERIALS AND METHODS

This study was carried out at the Isolation Facility of the University of Illinois to evaluate the effect of mixing finishing weight barrows on growth performance and feeding and aggressive behavior. The experimental protocol for this study was approved by the University of Illinois Institutional Animal Care and Use Committee.

Experimental Design and Treatments

The study was carried out as generalized randomized complete block designs with 2 treatments [Control (Not-mixed) vs. Mixing pigs two times]. Date of start on test was the blocking factor. There were 2 pens in each treatment and a total of 4 pens for the study.

Animals, Allotment to Growth Study, and Mixing Procedure

A total of 48 hybrid pigs (PIC 359 sires × PIC C29 dams; PIC USA, Hendersonville, TN) were selected from a pool of pigs at an outside source (commercial wean-to-finish facility) of pigs at week 6 post-weaning (30.0 ± 2.1 kg BW). Outcome groups of 4 barrows of similar body weight were formed and pigs were randomly allotted to 4 pens from within outcome group until there were 12 pigs/pen with similar average BW and variation in weight. Pigs were moved to the test facility and were allowed a 7-week acclimation period, at which stage all the pigs were fitted with an electronic ear tag transponder and treatments were randomly assigned to pens. After the acclimation period, pigs were individually weighed and the Mixing treatment was randomly assigned to pens and pigs started on test immediately. The study was carried out over a 10-wk period between body weights of 65.2 ± 4.5 and 136.5 ± 7.6 kg. Mixing of pigs was carried out at the start of the study (week 13 post-weaning) and at week 18 post-weaning as follows. For the first mixing event, the 12 pigs in the 2 pens on the Mixed treatment were divided into 2 subgroups of 6 pigs with the same mean and variation in BW and one subgroup from each pen was exchanged with the subgroup from the other pen. For the second mixing event (week 6 of study), the subgroups of 6 that were mixed had not previously been mixed together (Table 5.1). Control pens were kept intact (i.e., not mixed) throughout the study period.

Housing

The study was carried out in one room of a mechanically ventilated wean-to-finish facility at the University of Illinois' Grein Farm, which is located in Savoy, IL. The room temperature was regulated by mechanical ventilation and heater suspended in the room linked to a thermostat set at 21°C throughout the study period. The pens had fully-slatted floors and the floor space allowance (total area minus space taken by the feeder) was kept constant throughout the study at 0.98 m^2 per pig. The room had 24-h lighting, and water was continuously available from two cup drinkers/pen mounted on the pen partition. Pigs had access to feed via electronic feed intake recording equipment feeders (FIRE; Osborne Industries, Osborne, KS).

Diet and Feeding

All diets were formulated to meet or exceed the requirements of pigs of the weight range used in this study recommended by NRC (2012). During the study period, a 4-phase feeding program was used as follows:

Phase 1: fed from 54 to 73 kg body weight.

Phase 2: fed from 73 to 91 kg body weight.

Phase 3: fed from 91 to 108 kg body weight.

Phase 4: fed from 108 to 127 kg body weight.

All experimental diets were manufactured in pellet form at the Effingham Mill of Effingham Equity. Diet formulations and calculated and analyzed compositions are presented in Table 5.2. Feed and water were available *ad libitum* throughout the study period.

Body Weight and Feed Intake Recording

Pigs were weighed at the start and end of the study and weekly throughout the study period. The FIRE feeders consisted of a feed trough connected to a load cell and equipment to receive radio signals from the ear tag transponder carried by the animal. Pigs had 24-h access to the feed station, which was equipped with a full-length protective crate in front of the feeder to prevent access to the trough by more than one animal at any time. The FIRE feeders recorded the time and duration of each feeder visit and the weight of the feed trough at the start and end of each visit (which was used to calculate the weight of feed consumed per visit). Recording of feed intake started 6 days before the start of the study. All feeders were calibrated at the start of recordings and weekly using a 500 g test weight. Data on feed intake traits for individual animals were summarized on a daily basis and accumulated over the study period. These data were used to estimate mean values for each pig for daily feed intake, number of feeder visits per day, feed intake per visit, feeder occupation time per visit and per day, and feed consumption rate, defined as feed intake per visit divided by feeder occupation time per visit.

General and Aggressive Behavior

General behavior and aggressive behavior were recorded in all pens over a 12-h period starting at 0600h on each day of mixing (day 0) and days 1 to 4 post-mixing by research personnel. For general behavior, the number of pigs lying, sitting, standing, eating, and drinking was recorded every 10 minutes. Aggressive behavior was measured by constantly recording the number of bites occurring between pigs, and recording the number and duration of fights, with a fight being defined as any biting, chasing, or head butting lasting for more than 2 seconds between two or more pigs.

Statistical Analysis

Growth performance variables were checked for normality using the PROC UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, NC). Those meeting the criteria for analysis of variance were analyzed using the PROC MIXED procedure of SAS. The individual pig was considered the experimental unit and the model included the fixed effects of treatment, and the random effects of block (date of start), replicate, and the interaction of block × treatment. For feeding patterns, the individual animal was considered the experimental unit. Diurnal patterns for feed intake traits for each pen were evaluated by totaling the number of feeder visits, total feeder occupation time, mean feeder occupation per visit, and feed consumption rate for each hour of the 24-h period and for each day for the 10-wk study. Comparison of the daily means for the treatments was carried out using PROC MIXED procedure of SAS and the model included the fixed effects of treatment, and a compound symmetry covariance matrix structure within pig was incorporated for the repeated measurements of pigs for each day.

General and aggressive behavior observations were totaled for the 12-h period for each pen. The percentage of animals lying, sitting, standing, drinking, and eating was calculated for general behavior, and the percentage of bites and mean number of fight per pig was calculated for aggressive behavior. Comparison of the daily means for the treatments was carried out using

PROC MIXED procedure of SAS and the model included the fixed effects of treatment, and a compound symmetry covariance matrix structure within pig was incorporated for the repeated measurements of pigs for each hour.

RESULTS AND DISCUSSION

Growth performance

Least squares means for the effects of Mixing on growth performance are presented in Table 5.3. There was no effect ($P > 0.05$) of mixing on growth performance for the period immediately after the two mixing events, or for any of the interim periods, or the overall study period. These results are in agreement with a number of studies that showed no effect of mixing on the growth performance of pigs (Graves et al., 1978; Greer, 1987; Heetkamp et al., 2002; O'Connell et al., 2004). However, contrary to the results of the current study, other studies (Hyun et al.,1998; O'Connell et al., 2005; Li and Johnston, 2009) have shown that mixing had a negative effect on growth performance. Nevertheless, Hyun et al. (1998) and O'Connell et al. (2005) reported mixing as a transient stressor and, if given sufficient time, pigs can compensate from a short-term reduction in performance.

A number of factors such as feeding behavior and the level of aggression following mixing are likely to affect the growth performance response of pigs and these will be discussed in the following sections.

Feeding behavior

The effect of mixing on feeding behavior is summarized in Figures 5.1 to 5.5. Generally speaking, pigs on both treatments showed similar ($P > 0.05$) feeding behavior patterns. Regardless of treatment, average daily feed intake, feed intake per visit, and feed consumption rate increased over time (Figures 5.1, 5.2, and 5.3, respectively), and the number and duration of visits decreased over time (Figures 5.4 and 5.5, respectively). These results are generally in line with those reported by Hyun et al. (1997) and Hyun and Ellis (2000).

There were a number of significant ($P \leq 0.05$) differences between treatments for a number of the feeding behavior measures throughout the study period. However, there was no clear pattern to these differences that could indicate an effect of the mixing treatment on feeding behavior. Therefore, it is likely that the observed differences between mixed and unmixed pigs were due to chance and are of limited biological relevance.

General and aggressive behavior

The effect of mixing on general behavior is shown in Figures 5.6 and 5.7. The effect of mixing on aggressive behavior is shown in Figures 5.8 and 5.9. There was no effect ($P > 0.05$) of mixing on the percentage of pigs at the feeder (0.70 vs. 0.68% for Control and Mixed, respectively) or at the water drinker (0.15 vs. 0.18%, respectively). On average, pens on the Mixed treatment had a greater ($P \leq 0.05$) percentage of pigs standing (5.6 vs. 9.4% for Control and Mixed, respectively; Figure 5.6) and a lower ($P \leq 0.05$) percentage of pigs lying (87 vs. 82%; Figure 5.7) compared to the control during the recording periods for both mixing events. However, mixing increased the number of pigs standing and decreased the number of pigs lying only for the first mixing event. On the other hand, there was no effect of mixing on the number of pigs standing and lying for the second mixing event, and the differences between treatments were already present on the day before mixing.

A meta-analysis by Averós et al. (2010) showed a wide range of the percentage of time pigs spent lying (75 ± 15.9% of time) and standing (17 ± 14.4 % of time) for growing-finishing pigs. In the current study, both treatments fell within the range shown by Averós et al. (2010), which could suggest that the effect of mixing on behavior of pigs in the current study was relatively small.

After both mixing events, pigs in the Mixed treatment had more ($P \leq 0.05$) bites/pig compared to the Control on the day of mixing and days 1, 2, and 3 post-mixing (Figure 5.8). After the first mixing event, mixing increased the number of bites per/pig from 0.8 on the day before mixing to a maximum of 13.2 on day 1 post-mixing, and the number of bites subsequently declined to 4.8 bites/pig on day 3 post-mixing, with the Control pens averaging 1.6 bites/pig during the same period. After the second mixing event, mixing increased the number of bites from 1.2 on the day before mixing, to a maximum of 11.9 on the day of mixing, and the number of bites subsequently declined to 4.6 on day 3 post-mixing, with the Control pens averaging 1.0 bites/pig during the same period (Figure 5.8).

The effect of mixing on the number of fights per pig differed between the first and the second mixing event (Figure 5.9). After the first mixing event, mixed pigs had more fights/pig (0.0 vs. 1.8, for Control and Mixed, respectively; $P \leq 0.05$) on the day of mixing but not for the subsequent days. On the second mixing event, mixing did not increase ($P > 0.05$) the number of fights/pig for any of the days when aggressive behavior was recorded.

As previously discussed in Chapter 1 (Table 1.1), the most common consequence of mixing is an increase in the level of aggression. Generally speaking, the treatment differences found in the present study are in line with previous research that has evaluated the effect of mixing on the aggressive behavior of pigs (Meese and Ewbank, 1973; Couret et al., 2009; Puppe et al., 2008). Most authors attributed the increase in aggression (such as fights and biting among others) to the formation of a new dominance hierarchy-based social structure between the unfamiliar pigs when they are brought together. Moreover, Meese and Ewbank (1973), Jensen (1982), McCort and Graves (1982), and Luescher et al. (1990) reported that once the hierarchy order is established within the first 24 to 48 h post-mixing, fighting is replaced by quick bites and submissive acts for longer periods (more than 48 h post-mixing). This could explain the sharp reduction on the number of fights (within 24 h post mixing), and a more gradual decline in the number of bites found in the present study.

Moreover, the lack of a significant ($P > 0.05$) increase in the number of fights during the second mixing event was unexpected and is difficult to explain. However, a number of studies have suggested that the probability of pigs getting involved in fights is related to victories or defeats experienced in previous aggressive interactions (van de Poll et al., 1982; Rushen, 1988; Chase et al., 1994; Mendl and Erhard, 1997; Hsu and Wolf, 1999; Ruis et al., 2001; D'Eath, 2004). Therefore, it is possible that less aggression (i.e. fights) was required to establish the dominance hierarchy of the second compared to the first mixing.

CONCLUSIONS

Based on these results, it could be suggested that mixing increases the level of aggression in the pen within 48 h of mixing, but that it rapidly declines to relatively low levels by the third day after mixing. Also, current results suggest that mixing has little or no effect on growth performance and feeding behavior of pigs.

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TABLES

Table 5.1. Mixing procedure for first and second mixing[1]

Before Mixing		1st Mixing (Week 1 of study)		2nd Mixing (Week 6 of study)	
Pen 1	Pen 2	Pen 1	Pen 2	Pen 1	Pen 2
Original Pen 1/ Group A	Original Pen 2/ Group A	Original Pen 1/ Group A	Original Pen 2/ Group B	Original Pen 1/ Group A	Original Pen 2/ Group A
Original Pen 1/ Group B	Original Pen 2/ Group B	Original Pen 2/ Group A	Original Pen 1/ Group B	Original Pen 2/ Group B	Original Pen 1/ Group B

[1]Groups within a pen (i.e., A and B) represent half of original population of pigs from each pen at start of the study

Table 5.2. Diet formulations and calculated composition.

Item	Dietary phase			
	Phase 1[a]	Phase 2[b]	Phase 3[c]	Phase 4[d]
Ingredient, %				
Corn	65.76	68.01	71.00	72.08
DDGS	15.00	15.00	15.00	15.00
Soybean meal	15.85	14.40	11.37	10.25
Fat-yellow grease	1.08	0.92	0.94	0.96
Limestone	1.06	0.93	0.96	0.97
Lysine	0.38	0.24	0.22	0.21
Salt	0.40	0.40	0.40	0.40
Monocal	0.29	0.00	0.00	0.00
Trace mineral premix[1]	0.09	0.08	0.08	0.08
Threonine	0.05	0.00	0.00	0.00
Alimet	0.01	0.00	0.00	0.00
Phyzyme TPT 2500	0.00	0.00	0.00	0.02
Vitamins	0.03	0.03	0.03	0.03
Optiphos 2000	0.01	0.01	0.01	0.00
Total	100	100	100	100
Composition, %				
ME, Kcal/kg	3252	3257	3257	3257
Crude protein	17.47	16.80	15.59	15.14
Crude fat	3.83	3.73	3.81	3.84
Crude fiber	2.56	2.54	2.49	2.47
NDF	8.85	8.89	8.86	8.84
ADF	4.30	4.28	4.19	4.16
Calcium	0.55	0.44	0.44	0.44
Phosphorus	0.42	0.36	0.35	0.34
Available phosphorus	0.24	0.20	0.18	0.18
Calcium:Phosphorus	1.30	1.24	1.28	1.30
Sodium	0.20	0.20	0.20	0.20
Salt	0.50	0.50	0.50	0.50
Total lysine	1.03	0.88	0.79	0.75
Digestible lysine	0.88	0.74	0.65	0.62
Digestible lysine:ME ratio	2.72	2.27	2.01	1.91
Met + Cys:Lysine ratio (Dig.)	0.57	0.65	0.70	0.72
Tryptophan:Lysine ratio (Dig.)	0.16	0.18	0.18	0.18
Threonine:Lysine ratio (Dig.)	0.62	0.65	0.68	0.69
Isoleucine:Lysine ratio (Dig.)	0.64	0.73	0.75	0.76
Valine:Lysine ratio (Dig.)	0.72	0.83	0.87	0.89

[a]Phase 1 was fed at 45 kg of feed/pig, over the body weight range of 54-73 kg.
[b]Phase 2 was fed at 50 kg of feed/pig, over the body weight range of 73-91 kg.
[c]Phase 3 was fed at 57 kg of feed/pig, over the Body weight range of 91-108 kg.
[d]Phase 4 was fed at 62 kg of feed/pig, over the Body weight range of 108-127 kg.
[1]Provided per kilogram of final diet: iron, 124 mg as iron sulfate; zinc, 124 mg as zinc oxide; manganese, 29 mg as manganese sulfate; copper, 12 mg as copper sulfate; iodine, 0.2 mg as calcium iodate; and selenium, 0.2 mg as sodium selenite.

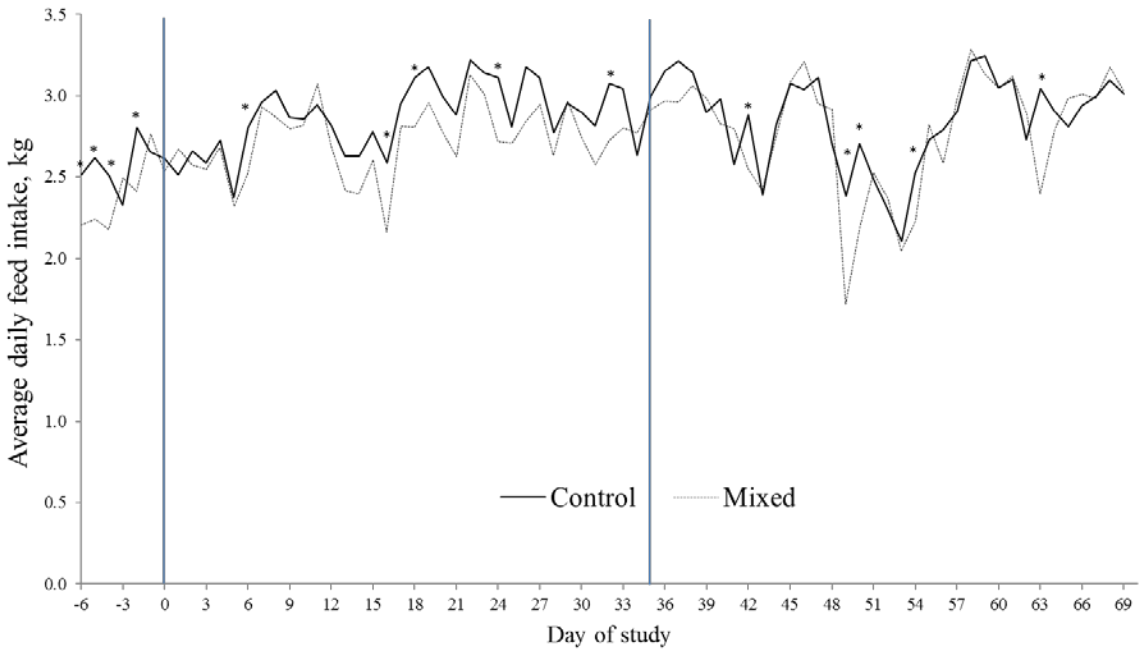
Table 5.3. Least-squares means of the effects of mixing on the growth performance of pigs.

Item	Treatment		SEM	*P*-value
	Control	Mixed		
Number of animals	24	24	-	-
Growth performance[1]				
Body weight, kg				
Start (Week 1; First mixing)	65.9	64.6	0.90	0.49
Week 2	75.1	73.8	1.15	0.57
Week 3	81.2	79.5	1.12	0.49
Week 4	90.2	88.3	1.09	0.43
Week 5	97.9	95.7	1.27	0.44
Week 6 (Second mixing)	102.8	100.7	1.17	0.42
Week 7	110.2	107.3	1.20	0.34
Week 8	118.2	116.2	1.35	0.48
Week 9	123.0	121.7	1.53	0.64
Week 10	127.9	126.5	1.48	0.63
Week 11 (Fixed-time end of test)	136.6	136.3	1.65	0.94
Average daily gain, kg				
Week 1 – 2	1.33	1.31	0.054	0.89
Week 2 – 3	0.87	0.75	0.038	0.28
Week 3 – 4	1.30	1.26	0.054	0.71
Week 4 – 5	1.09	1.06	0.056	0.71
Week 5 – 6	0.70	0.71	0.067	0.95
Week 6 – 7	1.06	0.95	0.069	0.38
Week 7 – 8	1.14	1.22	0.095	0.58
Week 8 – 9	0.69	0.79	0.050	0.38
Week 9 – 10	0.69	0.68	0.066	0.91
Week 10 – 11	1.25	1.41	0.082	0.39
First to second mixing	1.06	1.03	0.025	0.61
Second mixing to end of test	0.97	1.01	0.026	0.41
Start to en of test	1.01	1.02	0.024	0.78
Average daily feed intake, kg				
Week 1 – 2	2.60	2.55	0.087	0.77
Week 2 – 3	2.88	2.80	0.070	0.56
Week 3 – 4	2.90	2.67	0.068	0.26
Week 4 – 5	3.08	2.80	0.106	0.32
Week 5 – 6	2.89	2.78	0.052	0.37
Week 6 – 7	2.99	2.97	0.083	0.89
Week 7 – 8	2.87	2.79	0.104	0.66
Week 8 – 9	2.44	2.33	0.172	0.67
Week 9 – 10	3.02	3.05	0.090	0.84
Week 10 – 11	3.30	3.29	0.128	0.96
First to second mixing	2.87	2.77	0.058	0.42
Second mixing to end of test	2.92	2.91	0.089	0.95
Start to en of test	2.90	2.84	0.054	0.57
Gain:Feed, kg:kg				
Week 1 – 2	0.510	0.514	0.0202	0.91
Week 2 – 3	0.303	0.264	0.0138	0.30
Week 3 – 4	0.451	0.472	0.0187	0.57
Week 4 – 5	0.355	0.366	0.0144	0.70
Week 5 – 6	0.245	0.257	0.0232	0.77
Week 6 – 7	0.354	0.318	0.0183	0.38
Week 7 – 8	0.392	0.419	0.0382	0.67
Week 8 – 9	0.271	0.345	0.0200	0.23
Week 9 – 10	0.229	0.223	0.0173	0.82
Week 10 – 11	0.375	0.433	0.0267	0.26
First to second mixing	0.370	0.376	0.0102	0.76
Second mixing to end of test	0.329	0.349	0.0066	0.26
Start to en of test	0.349	0.361	0.0059	0.37

[1]Week number is the week of the study, and it refers to the start of the week.

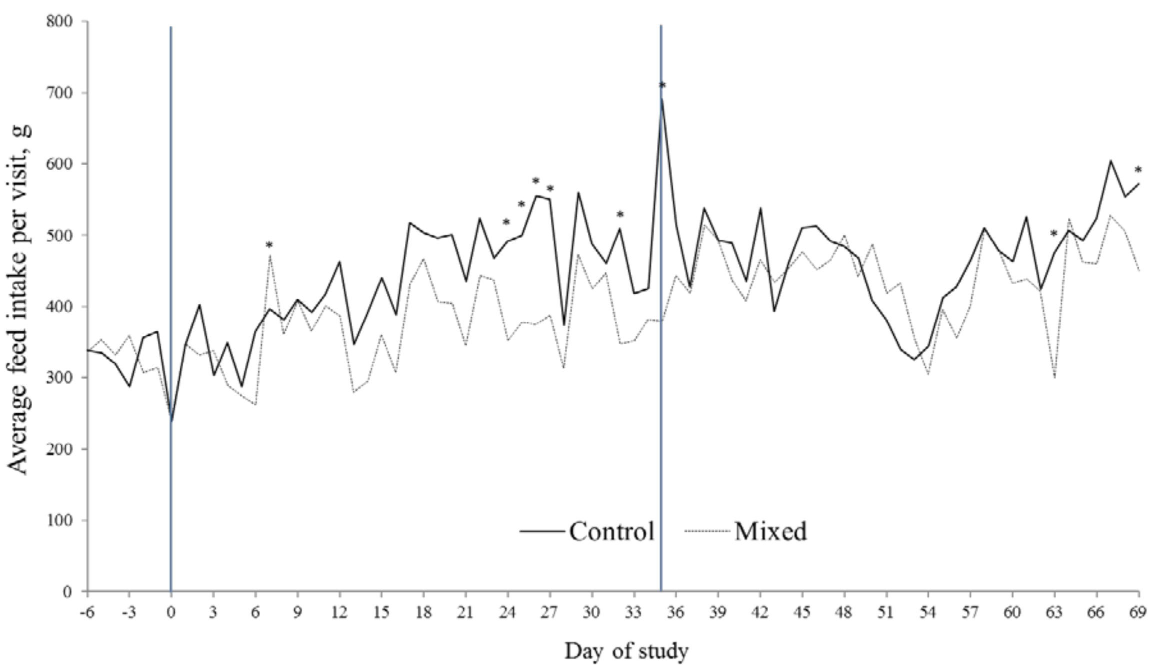
FIGURES

Figure 5.1. Effect of mixing on average daily feed intake.[1]



*Means differ between Control and Mixed treatment ($P \leq 0.05$).
[1]Recording of feed intake started 6 days before the start of the study.
Vertical lines indicate days when pigs were mixed (i.e., day 0 and 35 of study).

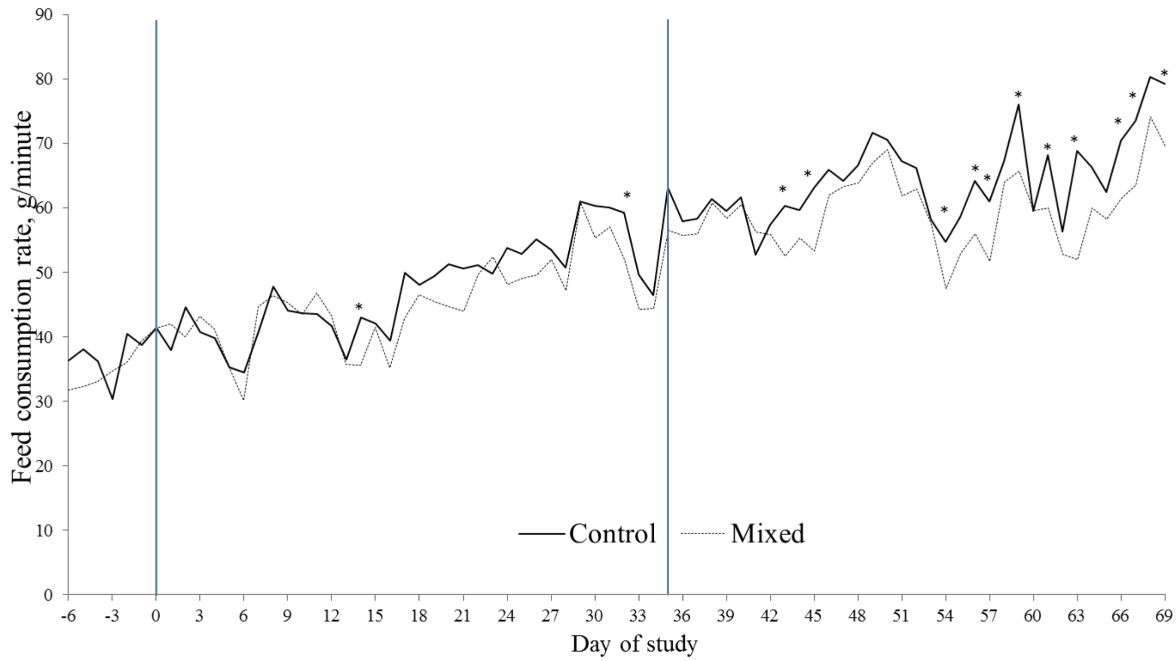
Figure 5.2. Effect of mixing on the average feed intake per visit.[1]



*Means differ between Control and Mixed treatment ($P \leq 0.05$).
[1]Recording of feed intake started 6 days before the start of the study.

Vertical lines indicate days when pigs were mixed (i.e., day 0 and 35 of study).

Figure 5.3. Effect of mixing on the feed consumption rate of pigs.[1]

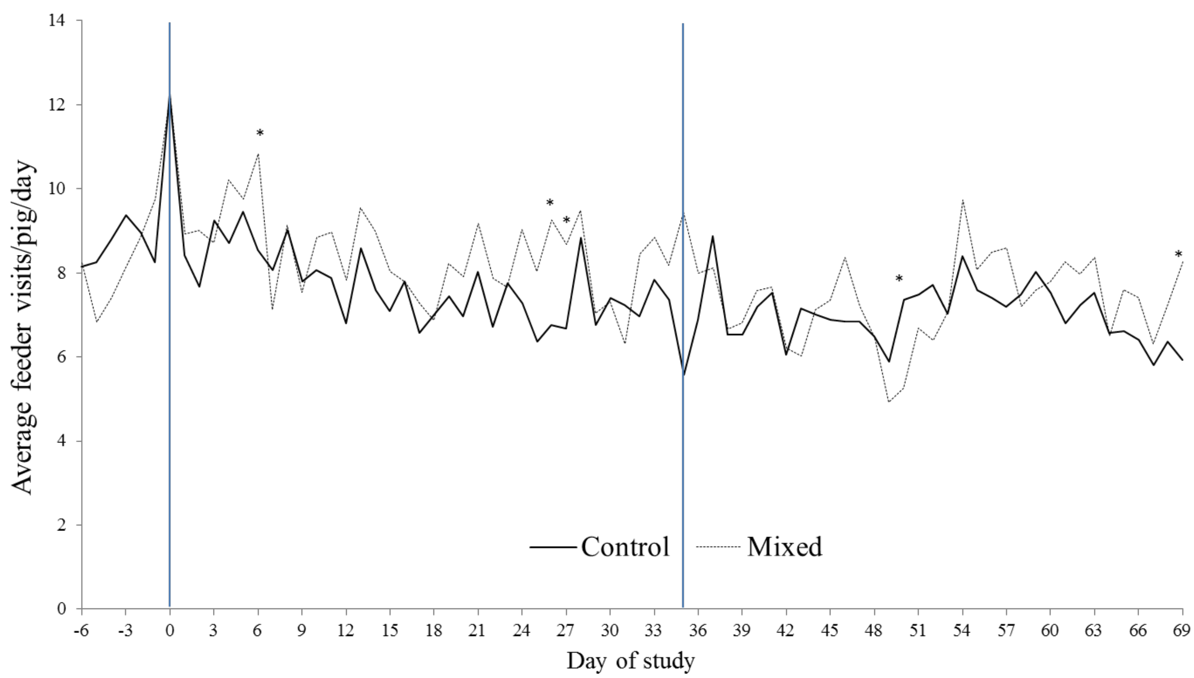


*Means differ between Control and Mixed treatment ($P \leq 0.05$).

[1]Recording of feed intake started 6 days before the start of the study.

Vertical lines indicate days when pigs were mixed (i.e., day 0 and 35 of study).

Figure 5.4. Effect of mixing on the average number of feeder visits.[1]

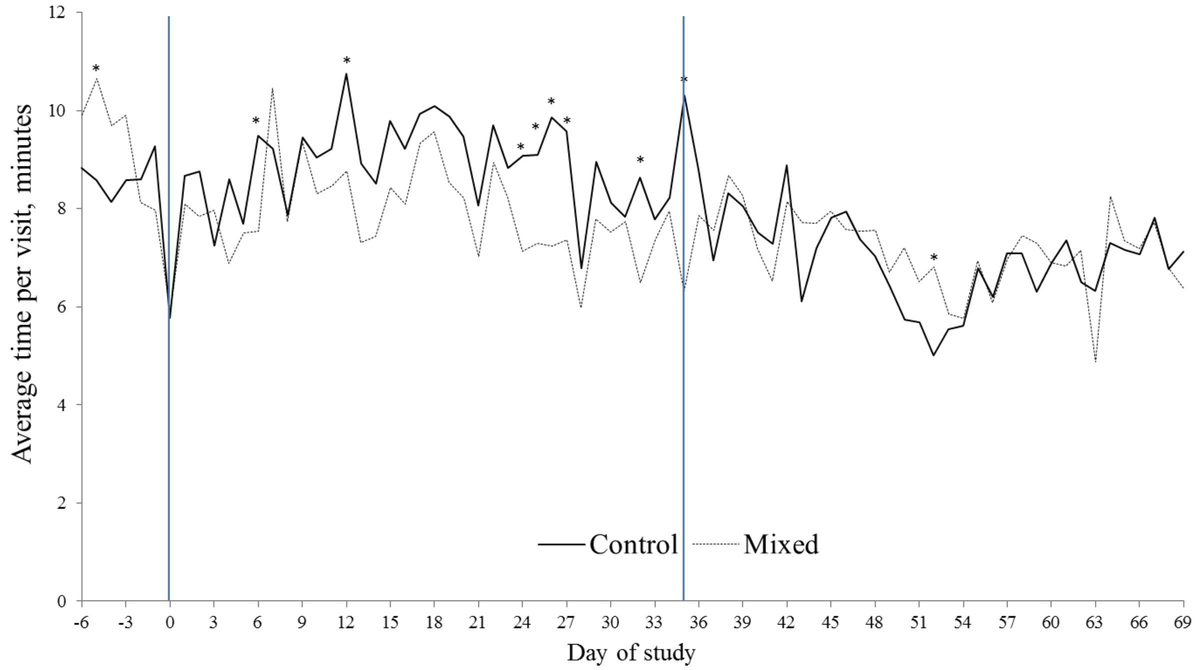


*Means differ between Control and Mixed treatment ($P \leq 0.05$).

[1]Recording of feed intake started 6 days before the start of the study.

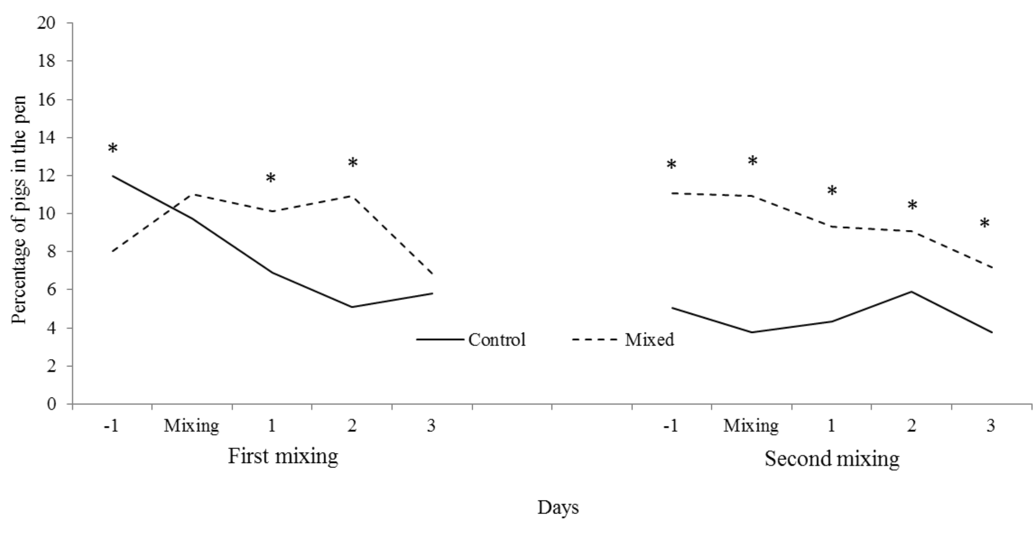
Vertical lines indicate days when pigs were mixed (i.e. day 0 and 35 of study).

Figure 5.5. Effect of mixing on the average time at the feeder per visit.



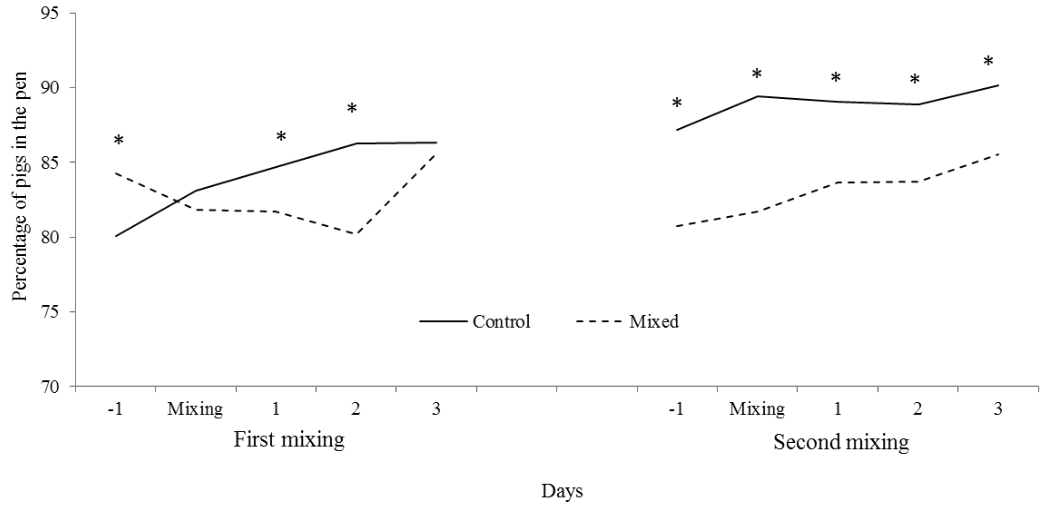
*Means differ between Control and Mixed treatment ($P \leq 0.05$).
[1]Recording of feed intake started 6 days before the start of the study.
Vertical lines indicate days when pigs were mixed (i.e., day 0 and 35 of study).

Figure 5.6. Effect of mixing on percentage of pigs standing.



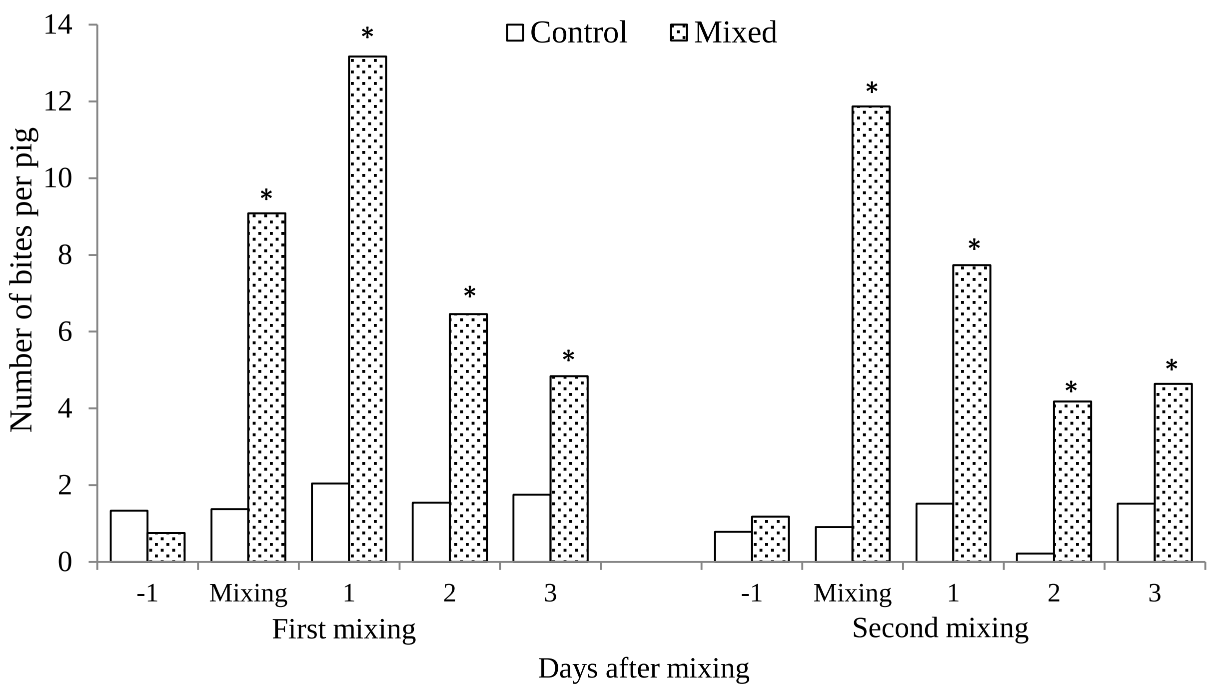
*Means differ between Control and Mixed treatment ($P \leq 0.05$).

Figure 5.7. Effect of mixing on percentage of pigs lying.



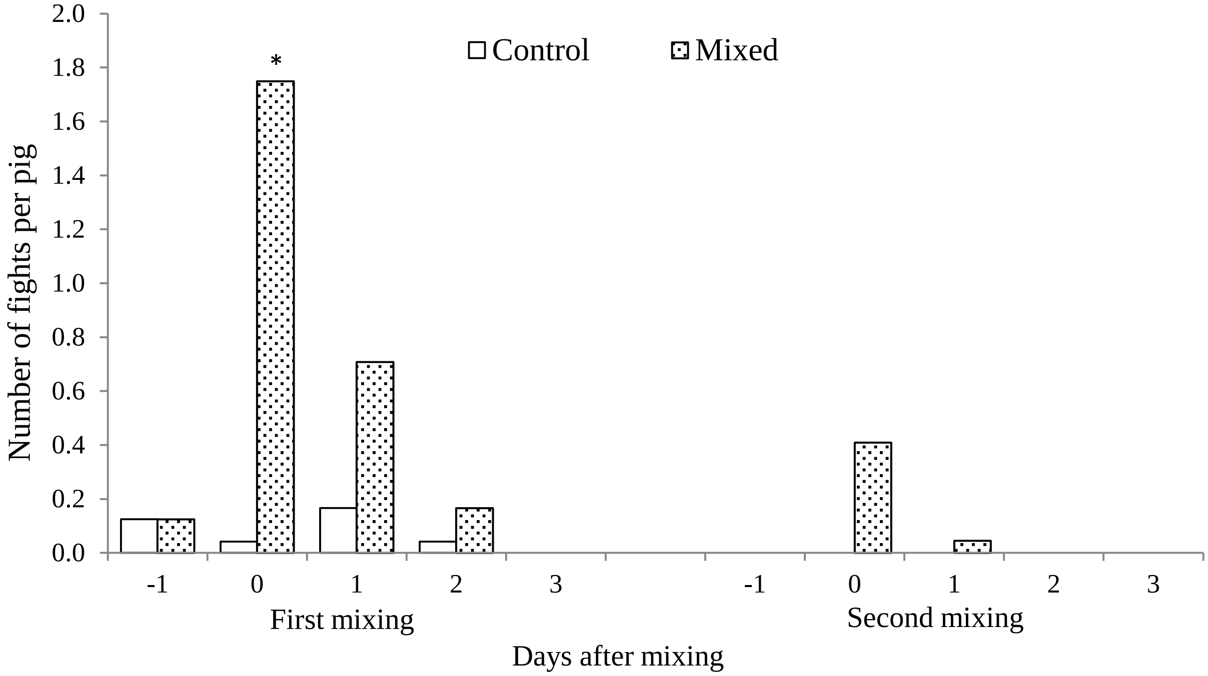
*Means differ between Control and Mixed treatment ($P \leq 0.05$).

Figure 5.8. Effect of mixing on the average number of bites per pig.



*Means differ between Control and Mixed treatment ($P \leq 0.05$).

Figure 5.9. Effect of mixing on the average number of fights per pig.



*Means differ between Control and Mixed treatment ($P \leq 0.05$).