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Effects of stocking density on growth performance, carcass grade and immunity of pigs housed in sawdust fermentative pigsties

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Abstract

This study determined the effect of space allowance on performance, carcass grade and physiological variables of pigs reared in sawdust fermentative pigsties. A total of 699 crossbred (Landrace × Yorkshire × Duroc) pigs were housed in sawdust fermentative pigsties and assigned to one of three treatments at different growth stages, namely early grower pigs (EGP), weighing 15 - 40 kg; late grower pigs (LGP), weighing 40 - 75 kg; and finisher pigs (FP), weighing 75 - 110 kg, with three replicates. The three space allowances for each growth stage were 0.40, 0.55 and 0.70 m^2/head for EGP; 0.55, 0.70 and 0.85 m^2/head for LGP; and 0.85, 1.00 and 1.15 m^2/head for FP. The feed intake in EGP was significantly decreased with increased stocking density. In LGP, the average daily gain (ADG) of pigs reared at high stocking density decreased linearly, whereas the feed conversion ratio increased significantly. The final bodyweight, ADG and feed intake in FP were lower with restricting space allowance. The carcass weight and backfat thickness were significantly higher with increased space allowance. The serum immunoglobulin G levels declined significantly with increased stocking density in all growth stages. The results of this study suggest that the space allowance for maximizing the growth performance and stabilizing immune response of pigs in sawdust fermentative pigsties is 0.55, 0.70, and 1.00 m^2/pig for the bodyweight ranges of 15 - 40 kg, 40 - 75 kg, and 75 - 110 kg, respectively.

Keywords: Body weight, cortisol, immunoglobulin G, space allowance, stress
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Introduction

Piglets weaned from their dams are exposed to various stress-related situations, such as mixing with unfamiliar piglets, struggling for hierarchy, and changes in diets and housing environments (Oh *et al*., 2010). These factors cause chronic and acute stress and can result in decreased feed intake, lower growth performance and a decline in immunity (Van Heugten *et al*., 1996; Hyun *et al*., 2005).

Stocking density is closely related to environmental stresses and directly affects the productivity of pigs. Limited space decreases feed intake and weight gain (Kornegay *et al*., 1993). Many researchers have reported that the productivity of pigs reared under high-density conditions declines throughout the entire growth phase (Wolter *et al*., 2000; DeDecker *et al*., 2005; Kerr *et al*., 2005). In addition, limited housing density leads to negative effects such as aggressive behaviour, lesions on the skin and a decrease in immunity (Barnett *et al*., 1992; Weng *et al*., 1998; Salak-Johnson *et al*., 2007).

Additionally, consumer groups have criticized the use of excessive stocking density, which reduces the welfare of pigs on commercial farms. Thus, to prevent excessive density on commercial pig farms, a space allowance per pig has been suggested, based on the Livestock Industry Act in South Korea. The space allowance provided is based on the slot floor as follows: 0.3 m^2/head in the weaning stage (weaning to a bodyweight of 30 kg), 0.45 m^2/head in the growing stage (bodyweight of 30 - 60 kg) and 0.8 m^2/head in the finishing stage (bodyweight greater than 60 kg). However, few studies have attempted to determine the optimal space allowance for pigs in sawdust fermentative pigsties because pig farms that use this type of pigsty are rare. In future, the number of housing systems with sawdust pigsties is likely to increase with growing interest in animal welfare (Hötzel *et al.,* 2009). However, there is no current recommended optimal space allowance for pigs housed in sawdust fermentative pigsties in South Korea. Thus, this study was

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performed to investigate the optimal stocking density for maximizing growth performance, carcass grade and immunity of pigs.

Materials and Methods

The experimental protocols describing the management and care of animals were reviewed and approved by the Animal Care and Use at the National Institute of Animal Science (NIAS). A total of 699 crossbred (Landrace × Yorkshire × Duroc) pigs were housed in sawdust fermentative pigsties and assigned to one of three treatments by each growth stage. The experimental animals consisted of an identical ratio of barrows and gilts in a pen. Pigs at three growth stages were evaluated, namely early grower pigs (EGP) 45 days of age (± 2 days) weighing 15 - 40 kg; late grower pigs (LGP) at 98 days of age (± 3 days) weighing 40 - *75* kg; and finisher pigs (FP) at 140 days of age (± 3 days), weighing 75 - 110 kg, with three replicates. The three space allowances for each growth stage were 0.40 (T1), 0.55 (T2) and 0.70 (T3) m^2/head for EGP; 0.55 (T1), 0.70 (T2) and 0.85 (T3) m^2/head for LGP; and 0.85 (T1), 1.00 (T2) and 1.15 (T3) m^2/head for FP. Space available for each pig was altered by varying the number of pigs in the pen. Detailed assignments of the experimental animals and the values of the space allocation coefficient, κ, corresponding to each space allocation, are presented in Table 1.

Table 1 Area provided to a pig and the space allocation coefficient

Items	T1	T2	T3
Space allowance, m^2/pig			
EGP	0.40	0.55	0.70
LGP	0.55	0.70	0.85
FP	0.85	1.00	1.15
Number of pigs			
EGP	44	32	25
LGP	32	25	21
FP	21	18	15
Space allowance coefficient, κ[1]			
EGP	0.740	0.101	0.130
LGP	0.047	0.060	0.074
FP	0.048	0.056	0.064

EGP: early grower pig with body weight 15 to 40 kg; LGP: late grower pig with body weights of 40 to 75 kg; FP: finisher pig with body weights of 75 to 110 kg.

[1] The allometric expression of the space coefficient is κ, where κ= area in m^2/bodyweight in $kg^{0.667}$.

The diets were formulated with corn and soybean meal, and met or exceeded the recommendations of the Korean Feeding Standard for Swine (KFSS, 2012) (Table 2). A feeder and water nipple were provided per 10 pigs. All pigs were allowed free access to the feeders and water nipples. The bodyweight and feed consumption of the pigs were determined at the beginning and end of the trial, and ADG and feed conversion ratio (FCR) were calculated.

After the end of the 45-day trial, the finisher pigs were shipped to a commercial slaughter house. The live and carcass weights for the pigs were measured before and after slaughter. The dressing rate was calculated as follows: (carcass weight/live weight) × 100. Backfat thickness (BFT) was measured between the 11th and 12th ribs of the left half carcass after slaughter. In South Korea, carcass grades are scored by a quality panellist, using a score of +1, 1 or 2, based on the carcass weight and BFT. The carcasses of the shipped pigs were graded with the Korean carcass grading system for pigs and scored on a scale of 3, 2 and 1 for carcass grades of +1, 1 and 2, respectively (Table 3).

Blood samples were collected via the jugular vein on the last day of the experiment and were divided into EDTA-treated tubes and tubes for serum samples. Whole blood in the EDTA tube was used to analyse the complete blood cell count (CBC). Serum samples were obtained by centrifugation for 15 min at 2000 × *g*. The supernatant serum was then stored at −70 ºC until analysis. The CBC analysis was performed with an automated blood corpuscle analyser (Hemavet HV950FS, Drew Scientific Inc, Miami Lakes, Fl, USA), and the serum glucose (GLU), total cholesterol (T-CHO), total protein (T-PRO), triglyceride (TG) and blood urea nitrogen (BUN) concentrations were analysed using an automated clinical analyser (7180, Hitachi, Japan). The concentrations of IgG, TNF-α and cortisol in the serum were determined using ELISA kits (IgG, E101-104, BETHYL Laboratories Inc., USA; TNF-α, PTA00, R&D Systems, USA; cortisol, CSB-E06811p, CUSABIO, China) according to the manufacturers' instructions.

Table 2 Nutrient composition of the commercial diet used in this study[1]

Items[2]	Weaning	Grower	Finisher
Digestible energy, kJ/kg	14.6	14.2	14.2
Crude protein, g/kg	195	170	160
Lysine, g/kg	12	10	9.0
Calcium, g/kg	6.8	5.3	4.5
Total phosphorus, g/kg	5.8	4.6	4.0

[1] Values are chemical compositions calculated based on the chemical contents of the ingredients.

Table 3 Carcass grading system for pigs in South Korea

Grade	Carcass weight, kg	Backfat thickness, mm	Score used in this study[1]
+1	83 - 93	17 - 25	3
1	83 - 93	15 - 17	2
1	83 - 93	25 - 28	2
1	80 - 83	15 - 28	2
1	93 - 98	15 - 28	2
2	Neither +1 nor 1 grade		1

[1]The voluntary score was used to express the carcass grade in this study.

All of the growth performance, carcass grade and biochemical and physiological parameter data were analysed statistically in accordance with the GLM (general linear model) procedure, using SPSS version 17.0. The individual pen for the pigs was considered the experimental unit for the statistical analysis in this experiment. The means of all of the measured variables were compared via the polynomial regression method to demonstrate the linear and quadratic effects of the space allowance. Differences were considered significant at P <0.05 level, and Duncan's multiple range test (1955) was used to compare treatment means.

Results and Discussion

The growth performances of the pigs housed in sawdust fermented pigsties are presented in Table 4. At the EGP stage, the average daily feed intake (ADFI) was 14% and 11% lower in T1 than in T2 and T3, respectively (P <0.01), although the final bodyweight, ADG and FCR did not differ among treatments (P >0.05). Each treatment in the LGP had similar ADFIs, whereas the ADG of pigs reared at high density decreased linearly (P <0.01). Accordingly, the FCR was found to be significantly increased in the high density group compared with the low stocking density group (P <0.01). The final bodyweight, ADG (P <0.05) and ADFI (P <0.01) in FP were lower with the small space allowance than the large space allowance.

Although no significant effect of stocking density on FCR in FP was observed, the FCR was highest in the T1 group (*P* >0.1). Most researchers have demonstrated that a restricted space allowance decreases daily gain and feed intake in grower-finisher pigs (Edmonds *et al*., 1998; Brumm *et al*., 2001; Wolter *et al*., 2002; Zhang *et al*., 2013). Brumm & Gonyou (2001) asserted that a decrease in feed intake is a major response to space restrictions. In the present study, the ADFI in EGP and FP was decreased with increasing stocking density, although the ADFI in LGP was not affected by the restricted space. It is thought that the designed space allowance for LGP in this study might be insufficient to decrease the feed intake compared to the other growth stages. The space allowance coefficient of T1 in LGP was 0.047, which was similar to that in FP. Thus, LGPs, which are smaller than FPs, may experience negligible effects of stocking density under equal space allowance (coefficient 0.047). Street & Gonyou (2007) reported no significant difference in ADFI between uncrowded pigs (0.78 m^2/pig) and crowded pigs (0.52 m^2/pig) in grower-finisher pigs. Nevertheless, ADG and FCR in LGP decreased linearly with high stocking density (*P* <0.01). The results of this study are supported by the report of Brumm & Miller (1996). These results suggest that a high density could retard the growth rate due to lower nutrient availability and chronic stress caused by the social hierarchy and interaction among individuals. Paterson & Pearce (1991) suggested that an impaired efficiency of feed utilization due to chronic stress is one mechanism by which crowding reduces growth. Serum cortisol, as a marker of stress, increased as the stocking density increased in LGP (Table 7) (*P* = 0.063). The increase in serum cortisol concentration reflects that an experimental animal reared at a high density was placed in a stressful condition in LGP. Although the authors did not investigate nutrient availability in this study, the increase in FCR and serum cortisol level supports the assertions of Brumm & Miller (1996) and Paterson & Pearce (1991). In contrast, there was no significant difference in FCR in FP, although ADFI and ADG

Table 4 Effects of stocking density on the growth performance of pigs reared in sawdust fermentative pigsties

Items	T1	T2	T3	SEM	Linear	Quadratic
EGP						
Initial BW, kg	12.5	12.6	12.5	0.2	0.995	0.695
Final BW, kg	38.4	38.3	40.3	0.8	0.308	0.521
ADG, g	447	450	474	10	0.282	0.638
ADFI, g	870^b	1005^a	982^a	11	< 0.01	< 0.01
FCR	2.41	2.49	2.29	0.10	0.654	0.518
LGP						
Initial BW, kg	39.7	40.0	39.2	0.6	0.724	0.699
Final BW, kg	73.0	75.0	75.6	0.7	0.153	0.658
ADG, g	659^b	697^{ab}	724^a	9	0.004	0.769
ADFI, g	2020	2011	2043	11	0.429	0.408
FCR	3.21^a	2.99^{ab}	2.90^b	0.05	0.008	0.525
FP						
Initial BW, kg	75.5	75.9	75.7	0.6	0.937	0.840
Final BW, kg	106.1^b	109.9^a	108.5^{ab}	0.6	0.097	0.038
ADG, g	716^b	807^a	776^{ab}	12	0.043	0.016
ADFI, g	2624^b	2904^a	2831^{ab}	20	< 0.01	< 0.01
FCR	3.95	3.65	3.75	0.08	0.320	0.242

T1, T2 and T3: stocking densities as given in Table 1.
EGP: early grower pig with body weight 15 to 40 kg; LGP: late grower pig with body weight 40 to 75 kg;
FP: finisher pig with body weights of 75 to 110 kg.
BW: bodyweight; ADG: average daily gain; ADFI: average daily feed intake; FCR: feed conversion ratio.
$^{a, b}$ Means in the same row with different superscripts differ significantly at *P* <0.05. SEM: standard error of the means.

Table 5 Effects of stocking density on carcass characteristics of finisher pigs reared in sawdust fermentative pigsties

Items	T1	T2	T3	SEM	Linear	Quadratic
Live weight, kg	109.8	111.9	112.9	0.64	0.061	0.709
Carcass weight, kg	83.9[b]	84.4[ab]	86.8[a]	0.54	0.037	0.381
Dressing rate, %	76.3	75.4	76.9	0.16	0.177	0.156
BFT, mm	19.2[b]	20.5[ab]	21.5[a]	0.39	0.024	0.786
Carcass grade, score	2.22	2.29	2.04	0.08	0.384	0.346

T1, T2 and T3: stocking densities as given in Table 1.
BFT: backfat thickness; SEM: standard error of the means.
[a, b] Means without the same superscript in a row are significantly different (P <0.05).

decreased with the high density. This result is in agreement with other trials (Jensen *et al.*, 1973; Randolph *et al*., 1981; Ward *et al*., 1997), which showed no significant differences in FCR in pigs because of limited space allowance.

The results for the serum biochemical components are shown in Table 6. The serum biochemical concentrations were within normal ranges (Klem *et al*., 2010). The significant effect of stocking density on the biochemical parameters was observed only in the FP group. The authors did not present the results for the biochemical parameters in EGP and LGP because those results were not significant. The glucose concentration was significantly lower (P <0.05) in T1 than in T2 and T3 by 5.8 and 13.6 mg/dL, respectively. The other parameters did not differ among treatment groups. The hematologic results, such as the leukocyte and erythrocyte levels, showed similar levels among all of the treatment groups in all of the growth stages (data not shown).

Table 6 Effects of stocking density on serum biochemical components of pigs reared in sawdust fermentative pigsties

Items	T1	T2	T3	SEM	Linear	Quadratic
FP						
Glucose, mg/dL	67.0[b]	72.8[ab]	80.6[a]	2.0	0.016	0.005
Total cholesterol, mg/dL	84.1	83.6	90.6	1.9	0.243	0.164
Total protein, g/dL	6.9	6.9	6.7	0.1	0.159	0.097
Triglyceride, IU/L	44.0	53.1	45.2	2.5	0.271	0.839
Urea nitrogen, mg/dL	16.4	17.4	18.9	0.9	0.531	0.269
Non-esterified fatty acid, μEq/L	52.2	48.9	51.2	2.2	0.824	0.857

T1, T2 and T3: stocking densities as given in Table 1.
FP, finisher pig with body weights of 75 to 110 kg; SEM: standard error of means.
[a, b] Means without the same superscript in a row are significantly different (P <0.05).

Serum glucose concentration generally decreased with low feed intake. In this study, ADFI in FP decreased at the high density. Thus, it is thought that the decreased serum glucose was caused by the low feed intake in pigs housed at high density. Similarly, Pearce *et al.* (2013) demonstrated that stress reduces intestinal glucose transport in growing pigs. Low glucose concentration at the limited space allowance might be caused by restricted glucose transport in this present study. Additionally, Hemsworth *et al.* (2002) and Bryer *et al.* (2011) found that pigs under acute stress had higher glucose levels. Serum glucose is influenced by factors such as stress conditions (intensity, phase, acute and chronic), animals' physiological conditions and nutritional conditions (Pearce *et al.*, 2013). However, these differences have not been clear, and additional research is required to elucidate these results.

The effects of the space allowance on the serum IgG, TNF-α and cortisol levels in the growth stages are shown in Table 7. The serum IgG concentrations for all growth stages were significantly reduced with increased stocking density. The T1 group had the lowest value compared with the others (P <0.05 in the EGP and LGP and P <0.01 in the FP). Because the differences in T1 and T3 for serum IgG level were 58%, 53% and 45% in EGP, LGP and FP, respectively, the heavier pigs had a wider range of decrease than the lighter pigs. However, there were no effects of stocking density on the serum TNF-α in all the growth stages. The serum cortisol level did not differ in the EGP (P >0.05), although the authors observed an increase in the higher stocking density groups in LGP and FP (P = 0.063 in LGP; P = 0.103 in FP).

Table 7 Effects of stocking density on serum IgG, TNF-α and cortisol levels of pigs reared in sawdust fermentative pigsties

Items	T1	T2	T3	SEM	Linear	Quadratic
EGP						
IgG, mg/mL	54.7^{b}	78.6^{ab}	93.0^{a}	6.3	0.010	0.684
TNF-α, pg/mL	100.2	111.8	118.9	7.7	0.348	0.885
Cortisol, ng/mL	51.4	48.9	29.3	7.25	0.197	0.661
LGP						
IgG, mg/mL	52.8^{b}	66.2^{ab}	97.8^{a}	8.6	0.033	0.604
TNF-α, pg/mL	63.1	74.6	73.4	5.1	0.427	0.570
Cortisol, ng/mL	58.2	43.0	35.9	4.64	0.063	0.674
FP						
IgG, mg/mL	45.4^{b}	73.5^{ab}	98.2^{a}	8.3	0.008	0.915
TNF-α, pg/mL	44.9	55.3	54.2	5.0	0.461	0.608
Cortisol, ng/mL	77.5	67.3	38.0	9.98	0.103	0.653

T1, T2 and T3: stocking densities as given in Table 1.
EGP: early grower pig with body weights of 15 to 40 kg; LGP: late grower pig with body weights of 40 to 75 kg;
FP: finisher pig with body weights of 75 to 110 kg.
IgG: immunoglobulin G; TNF-α: tumour necrosis factor-alpha; SEM: standard error of means.
[b] Means without the same superscript in a row are significantly different (P <0.05).

Serum IgG, which plays a major role in defending against antigens in the body, is a typical marker representing the immune system (Deng *et al*., 2007). Serum IgG is affected by heat stress and social stress. Stress caused by high density impairs the immune function and reduces antibody synthesis (Kelly, 1980). Moreover, activation of the immune system could result in a reduction of feed intake and weight gain (Van Heugten *et al*., 1996). The observed results, which indicate that high density suppressed the serum IgG content, are sufficient to support this assertion. The decreased growth performance in pigs housed at high density indirectly verifies this assertion. Cortisol, which is commonly used as a marker of stress, is a steroid hormone released from the adrenal cortex. It is well known that cortisol is increased by external stimulation such as heat stress and social stress (Valros *et al*., 2013). Many studies have reported that the cortisol level rises with increased stocking density (Oh *et al*., 2010; Hemsworth *et al*., 2013; Zhang *et al*., 2013). In the current study, although the serum cortisol level was not affected by high stocking density, throughout each growth stage, pigs housed at high density showed the highest level of serum cortisol, especially in FP, which was approximately double that in T1 compared with T3.

Conclusion

In conclusion, the authors observed the effects of space allowance on the growth performance, carcass grade and immunity in pigs housed in sawdust fermentative pigsties. Overall, the results of this study indicate that high density in all growth stages has detrimental effects on growth performance and the immune system. They suggest that the space allowance for maximizing growth performance and stabilizing the immune response of pigs in sawdust fermentative pigsties is 0.55, 0.70 and 1.00 m^2/pig at a bodyweight of 15 - 40 kg, 40 - 75 kg and 75 - 110 kg, respectively. This information can be utilized to optimize the pig production system and enhance the growth performance of pigs reared in sawdust fermentative pigsties.

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Authors' Contributions

K.H. Kim and Y.H. Kim conceived and designed the experiments. E.S. Cho, K.S. Kim and J.E. Kim conducted the field trial. K.H. Seol, S.J. Sa and Y.M. Kim collected and analyzed the samples. K.H. Kim wrote the paper. Y.H. Kim discussed and reviewed the paper.

Conflict of Interest Declaration

The authors declare that they have no conflict of interest.

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