# Comparative Histology of the Swine Colon Raised under Intensive Management Farming and Backyard Farming Systems in Thailand

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## Abstract

Swine farming methods can influence gut health by altering intestinal morphology and immune function. This study aimed to compare the histological characteristics of the colon in swine raised under 2 different management systems - intensive management farming and backyard farming - to evaluate how these environments impact intestinal structure and health. Colon tissues (n = 10 per group) were collected and examined using Hematoxylin and Eosin staining. Histological analysis focused on the thickness of the mucosa, submucosa, and muscularis externa layers, the morphology of intestinal glands, and the presence of inflammatory cells and lymphatic nodules in the mucosa. The results showed that swine raised under intensive management farming had significantly thicker mucosal, submucosal, and muscularis externa layers than those raised under backyard conditions ($p < 0.001$). Backyard-farmed swine exhibited significantly shallower and narrower intestinal glands, as well as reduced numbers of inflammatory cells and lymphatic nodules ($p < 0.001$), suggesting a lower degree of immune activation. In conclusion, our findings suggest that intensive management enhances nutrient absorption and mucosal defense via a thicker colonic mucosa, whereas backyard farming may impair digestive efficiency and immune responsiveness. By linking husbandry conditions to intestinal histology, this study provides clinically relevant insights into how farming systems influence swine gut health which may ultimately impact overall productivity and product quality. These results underscore the importance of appropriate farm management in supporting gastrointestinal and immune function in livestock.

**Keywords:** Backyard farming system, Colon, Colon histology, Colon morphology, Intensive management farming system, Intestinal health, Swine

## Introduction

Swine farming practices play a pivotal role in determining the health and welfare of pigs, with significant implications for both the well-being and gastrointestinal health of these animals [1,2]. Among the various factors influencing swine gut health, environmental conditions, particularly housing systems, have garnered substantial attention [2,3].

Traditional indoor housing systems have long been employed in commercial swine production because they provide controlled environments and facilitate intensive management practices [4]. However, concerns over animal welfare and the desire for more sustainable farming methods have led to the development of alternative housing systems, such as backyard or free-range production [5]. These 2 farming systems differ in environmental control, feeding practices, and health management, all of which may influence intestinal development and function. Swine raised under intensive management farming and those raised under backyard farming differ in terms of breed, gender, feeding regimes, vaccination, and growth performance. In intensive management farming, commercial breeds such as Large White, Duroc, or their crossbreeds are commonly raised for their high productivity. In contrast, backyard farming typically involves a more diverse array of breeds, often indigenous or local, and crossbreeds well-adapted to the environment. Gender selection is more prevalent in intensive systems, with a preference for castrated males or females to optimize growth, while backyard farming is less selective, with both males and females being raised together and castration practiced less systematically. Feeding regimes also differ significantly in both systems. Intensive farming provides pigs with balanced, nutrient-rich commercial feeds tailored to promote rapid growth, with feeding adjusted according to age and growth stage. Conversely, backyard farming relies on locally available resources such as crop residues, kitchen waste, and natural foraging, resulting in a more varied diet and slower growth rates. Vaccination in intensive farming follows a strict, regular schedule managed by veterinarians, including vaccines for common swine diseases such as Classical Swine Fever, Porcine Reproductive, and Respiratory Syndrome. Backyard farming practices are less systematic, often dependent on the farmer's knowledge and resources, with a part of health management supplemented by traditional remedies. These differences contribute to varying growth performances for both systems. Intensive management farming results in high growth rates due to optimized nutrition, controlled environments, and comprehensive health management, allowing swine to reach market weight within 5 - 6 months. In contrast, pigs raised in backyard systems grow more slowly, typically taking 8 - 12 months or longer to reach market weight, with greater variability in growth rates because of less controlled feeding and health practices [6,7]. The comparison highlights the more systematic and controlled approach of intensive management farming compared to the more traditional, resource-dependent methods used in backyard farming, as summarized in **Table 1** [8].

**Table 1** Comparative approaches to swine rearing: Intensive management farming system vs. Backyard farming system [8].

| Aspect | Intensive management farming swine | Backyard farming swine |
|---|---|---|
| Breed | Typically, commercial breeds such as large white, landrace, duroc, or their crossbreeds are used for high productivity. | More diverse, often indigenous or local breeds, and crossbreeds suited for resilience and adaptability are used. |
| Gender | Gender selection is common, often focusing on castrated males or females for optimal growth and meat quality. | Gender is less selective in this approach, with both males and females reared together. Castration might be practiced but less systematically. |
| Feeding regimes | Balanced, nutrient-dense commercial feeds designed to promote rapid growth and efficient feed conversion are used. Feeding is carefully controlled and adjusted according to age and growth stage. | A diverse feeding regime, often based on locally available resources such as crop residues, kitchen waste, or foraging is used. Less emphasis is placed on specialized feeds, leading to slower growth rates. |
| Vaccination | Regular vaccination schedules are maintained with strict adherence to prevent diseases; | Vaccination is less systematic and depends on farmers' knowledge and resources. Swine may |

| Aspect | Intensive management farming swine | Backyard farming swine |
|---|---|---|
| | managed under the guidance of veterinarians. Common vaccines include those for classical swine fever, porcine reproductive and respiratory syndrome, and foot-and-mouth disease. | receive basic vaccinations but often with fewer types and less regularity. Traditional remedies may supplement health management. |
| Growth rate | High growth rates observed are due to optimized nutrition, controlled environment, and routine health management. | Slower growth rates are due to variable feeding, environmental exposure, and inconsistent health practices. |
| Time to reach market weight | Typically reach market weight within 5 - 6 months. | Typically require 8 - 12 months or more to reach market weight. |
| Growth rate variability | Low variability in growth performance across individuals. | Greater variability in growth performance due to uncontrolled environmental and management factors. |

The transition from intensive management to backyard housing represents a significant shift in the living conditions experienced by swine, potentially impacting various aspects of their physiology and biology [9]. To date, studies comparing gastrointestinal histology between swine housing systems remain limited. While previous work has demonstrated that different living conditions can alter stomach histology [9], comparative data on colonic histology under varying farming practices are scarce. We previously revealed that different living conditions lead to different stomach histological morphology in the stomach of swine [10]. However, 1 crucial aspect that remains relatively underexplored in this context in the literature is the histological characteristics of the swine's colon under different housing conditions. The colon, a part of the large intestine, plays a vital role in nutrient absorption, water balance, and fecal storage. Its histological organization - comprising the mucosa, submucosa, muscularis externa, and serosa - is critical for maintaining these functions [11]. Alterations in colonic morphology can be indicative of physiological adaptation or stress and may affect nutrient absorption and immune responses. It consists of distinct layers, including the mucosa, submucosa, muscularis externa, and serosa, each contributing to its overall function and integrity [11]. Histological analyses of the colon provide valuable insights into its microscopic structure, cellular composition, and tissue organization, which are closely linked to its physiological functions. The mucosa contains specialized epithelial cells and glands responsible for nutrient absorption and mucus secretion, while the muscularis externa comprises smooth muscle fibers essential for peristalsis, the rhythmic contractions that propel food and waste material through the digestive tract [12]. Besides performing vital functions, the swine's colon is susceptible to various diseases and pathologies. Conditions such as colitis, colonic ulcers, and inflammatory bowel disease can significantly impact swine health and productivity [13]. Understanding the histopathological changes associated with these conditions is crucial for accurate diagnosis and effective management of colon diseases in swine [14]. This study aimed to investigate and compare the histological characteristics of the swine colon under intensive management and backyard farming systems. We hypothesized that controlled diets, hygienic environments, and regulated health protocols in intensive farming may promote mucosal thickening and enhance immune activity, whereas backyard systems may result in reduced mucosal development due to varied and less regulated conditions. Understanding these histological differences may offer insights into gut health under different farming systems and inform practices aimed at improving animal welfare and productivity.

## Materials and methods
### Ethical considerations

This study adhered to the Laboratory Animal Use Convention guidelines established by the National Institutes of Health. Before any experimental procedures involving animals were conducted,

approval was obtained from the animal ethics committee at the Center for Animal Research, Naresuan University (Approval no. NU-AEE620505).

**Sample collection and histological analysis**

Ten colons were obtained from 4-month-old swine (*Sus domesticus*) weighing between 100 and 120 kg, with matched age and weight between the 2 groups, raised under intensive management and backyard farming systems on farm enterprises in Thailand. All animals had been raised under their respective farming systems from weaning to slaughter (approximately 12 weeks). Both groups of swine were slaughtered using a process designed to be as quick and humane as possible, per regulations prioritizing animal welfare. The standard procedure involved stunning the swine using high concentrations of carbon dioxide to render them unconscious, followed by exsanguination through the cutting of major blood vessels. After the slaughter, the tissues were immediately chilled at 0 - 4 °C to slow down bacterial growth and enzymatic activity. In each swine, 10 tissue samples were collected from the entire colon, each measuring approximately $1.5 \times 1.0$ cm$^2$. These tissue samples were then fixed in 10% neutral buffered formalin for 7 days. Following the fixation, the tissue specimens were processed and embedded in paraffin wax. Protocols for tissue processing and histological analysis followed recent standard practices for intestinal tissue preservation and processing, and for paraffin embedding and H&E staining procedures [15]. Then, these specimens, still embedded in paraffin blocks, were sectioned using a rotary microtome to a thickness of 3 microns in superficial, middle, and deep parts. Hematoxylin and eosin staining was conducted on all 300 tissue slides, followed by mounting. Subsequently, each slide was scanned and captured in 3 fields of view using the Aperio ImageScope Program version 10.0.35.1798. The histological characteristics of all colon tissue slides were examined in 3 specific fields under the microscope. Morphological and quantitative evaluations were performed to measure the thickness of the colon wall layers, including the mucosa, submucosa, and muscularis externa, using a magnification of 2.5×. The depth and width of the intestinal glands in the mucosa were measured at a magnification of 10×. The quantification of inflammatory cell numbers and lymphoid tissues in the mucosa was conducted at a magnification of 40×. Additionally, the characteristics of the crypts of Lieberkühn in the mucosa layer were examined using a magnification of 10×. All quantitative results were analyzed using the ImageJ program.

**Statistical analysis**

The data, calculated as the mean ± standard error of the mean using SPSS program version 23, underwent statistical analysis. An independent samples t-test was employed to discern any significant differences, with a $p$-value of $\leq 0.05$ considered statistically significant.

**Results and discussion**

**Thickness of the colon wall in the 2 groups of swine**

In our study of the histology of the colon of swine raised under intensive management and backyard farming systems, we focused on examining the thickness of the mucosa, submucosa, and muscularis externa layers. **Figure 1** depicts the morphology reflecting the thickness of these 3 layers of the colon. We observed the 3 layers of colon structures among the 2 groups of swine (**Figure 2**). The calculated Cohen's d for this comparison was 0.81, indicating a large effect size. The mucosa layer of swine raised under backyard farming was also significantly thinner than that of swine raised under intensive management farming (0.34 ± 0.08 and 0.39 ± 0.01, respectively, $p < 0.001$, **Figure 2(A)**). The thickness of the submucosa layer of swine raised under backyard farming was significantly thinner than that of swine raised under intensive management farming (0.53 ± 0.02 and 0.69 ± 0.28, respectively, $p < 0.05$, **Figure 2(B)**). Cohen's d was 0.72 for submucosa thickness. The muscularis externa layer of swine under backyard farming was significantly thinner than that of the other group (0.33 ± 0.01 and 0.38 ± 0.01, respectively, $p < 0.001$, **Figure 2(C)**), with an effect size (Cohen's d) of 1.05. Our findings revealed notable differences in the thickness of these layers between the 2 groups. The mucosa layer of swine raised under backyard farming was significantly thinner than that of the other group, suggesting potential differences in nutrient absorption and gastrointestinal transport between the 2 groups [16]. These findings align with

previous studies that have highlighted the importance of swine as a model for studying gastrointestinal physiology [17]. Moreover, our study also observed that the submucosa layer of swine raised under backyard farming was significantly thinner than that of swine raised under intensive management, suggesting potential differences in the structural integrity of the colon wall between the 2 groups. It is worth noting the higher variability in submucosa thickness among the intensively managed group (SD = 0.28), which may indicate individual variability in response to the intensive system. The observed differences in the thickness of the colon wall layers between the 2 groups of swine might reflect how swine adapt to environmental conditions and dietary factors [18]. The significant thinner mucosa, submucosa, and muscularis externa layers in swine raised under backyard farming, compared to those under intensive management, might indicate that swine undergo morphological adjustments to different living environments [19]. Swine raised under intensive management farming exhibited significantly thicker mucosa, submucosa, and muscularis externa layers compared to those raised under backyard farming. Functionally, a thicker mucosa may enhance the absorptive surface area and increase the colon's capacity to transport and absorb nutrients, electrolytes, and water [20,21]. Conversely, a thinner mucosa - as seen in backyard-farmed swine - may reduce nutrient absorption efficiency due to decreased epithelial and goblet cell populations, which can impair barrier function and mucosal immunity. This structural alteration may compromise the colon's ability to protect against pathogens, absorb water and electrolytes efficiently, and maintain homeostasis. While thinner mucosa has been associated with increased susceptibility to inflammation and impaired nutrient absorption, it may also reflect adaptations to lower-energy diets or higher fiber content typical of backyard environments [19,20]. Our findings support the idea that structural adaptations of the gastrointestinal tract may reflect nutritional strategies or resource availability under different husbandry systems [21].
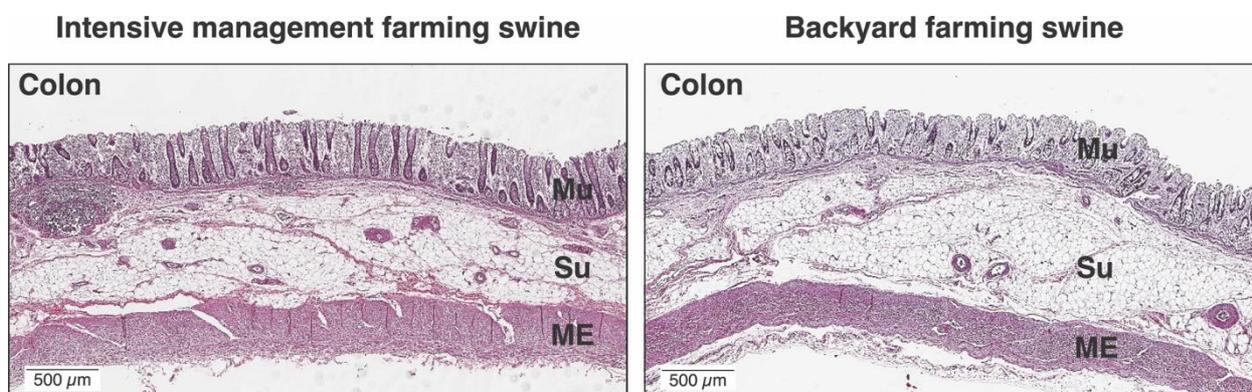


**Figure 1** Histological overview of the 3 layers of the colonic wall. Representative images of the colonic wall highlighting the mucosa (Mu), submucosa (Su), and muscularis externa (ME) in swine raised under intensive management and backyard farming systems, observed using a 4× microscope objective.
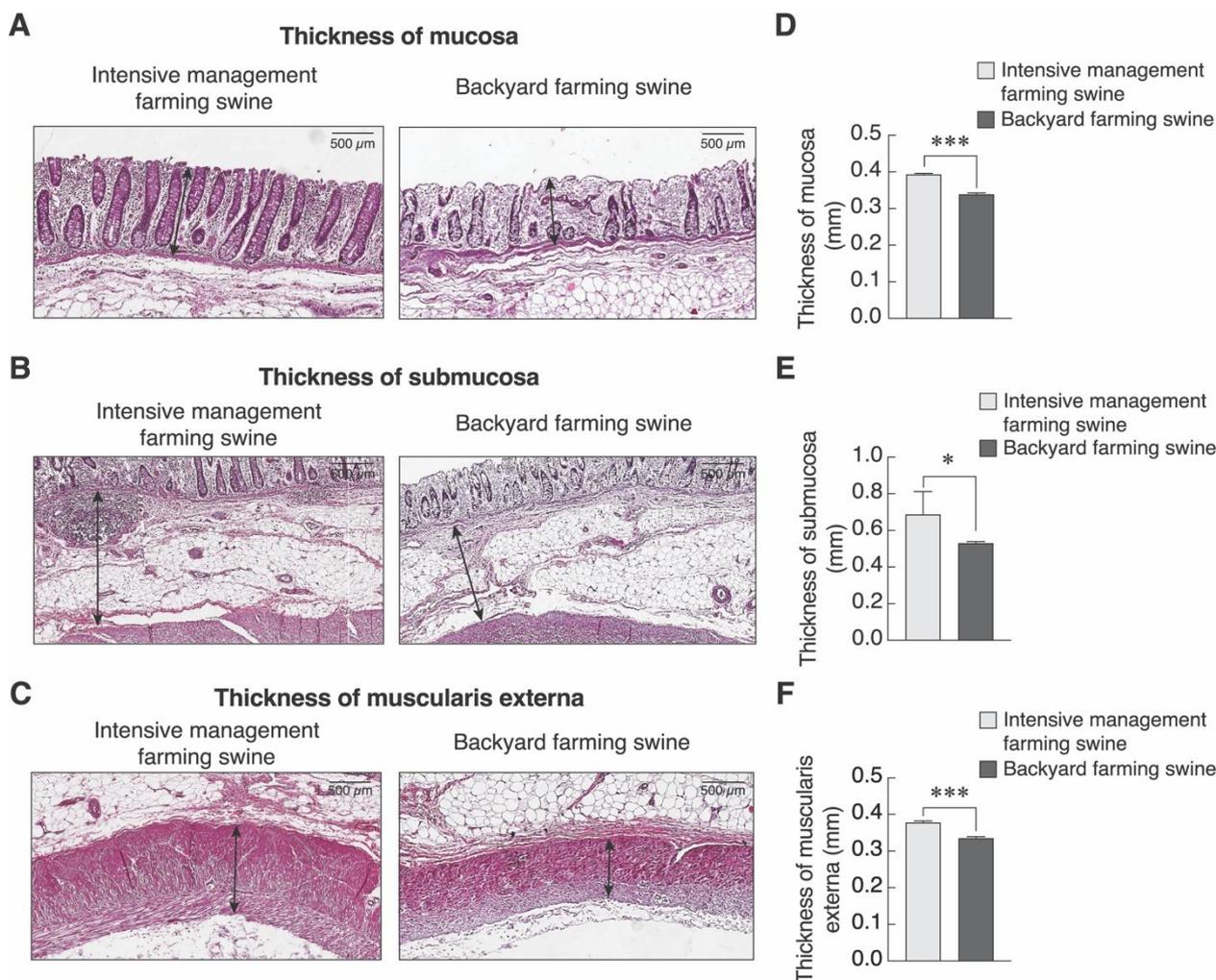
**Figure 2** Thickness of the mucosal, submucosal, and muscularis externa layers of the colonic wall in swine raised under intensive management and backyard farming systems. Histological thickness of the mucosa (A), submucosa (B), and muscularis externa (C) in swine raised under intensive management and backyard farming systems. Quantitative comparison of the thickness of the mucosa (D), submucosa (E), and muscularis externa (F) between the 2 groups. Observations were made using a 10× microscope objective. Data are presented as mean ± S.E.M. *$p < 0.05$, ***$p < 0.001$, indicating significant differences between the 2 groups.

### Crypts of Lieberkühn and depth and width of intestinal glands in the colon of the 2 groups of swine

We conducted a detailed histological examination of the Crypts of Lieberkühn, or intestinal glands, in both groups of swine. Variations in the characteristics of intestinal gland histology within the mucosa layer were observed and compared between the groups. Within the mucosa layer, a simple columnar epithelium lining composed of enterocytes and goblet cells was identified. Moreover, Paneth cells and enteroendocrine cells were discerned within the intestinal glands under light microscopy. The epithelial inner surface displayed invaginations known as colonic crypts, which are tube-shaped structures with a central lumen extending along their length. Connective tissues and a thin layer of smooth muscle cells were also noted as the lamina propria and muscularis mucosae layers, respectively. Furthermore, we evaluated the depth and width of the intestinal glands within the mucosa (**Figure 3(A)**). Cohen's d was calculated at 1.04, indicating a strong effect. Our findings revealed that the depth of the intestinal glands in the mucosa layer of swine raised under backyard farming was significantly lower than that of swine raised under intensive management farming (0.25 ± 0.02 and 0.38 ± 0.01, respectively, $p < 0.001$, **Figure 3(B)**). The width data showed relatively high variability in the backyard group (SD = 0.04), which might reflect environmental heterogeneity.

Similarly, the width of the intestinal glands in the mucosa layer of swine raised under backyard farming was significantly lower compared to that of the other group ($0.12 \pm 0.04$ and $0.15 \pm 0.02$, respectively, $p < 0.05$, **Figure 3(B)**). We observed differences in the morphology of the Crypts of Lieberkühn and the depth and width of intestinal glands between the 2 groups of swine, which could be indicative of variations in gastrointestinal function and adaptation [22]. The evaluation of the depth and width of the intestinal glands within the mucosa layer unveiled significant differences between the 2 groups. Specifically, swine raised under backyard farming exhibited a notably lower depth and width of intestinal glands compared to those under intensive management. These findings suggest potential implications of environmental factors, such as housing conditions, on the morphological characteristics of the intestinal glands [23]. The reduced depth and width of intestinal glands observed in swine raised under backyard farming may suggest a more efficient absorption and processing of nutrients, indicating adaptations to outdoor rearing systems, potentially influenced by factors such as dietary composition, physical activity, and exposure to natural stimuli [24]. The Crypts of Lieberkühn, or intestinal glands, play a crucial role in the functioning of the colon in swine [25]. These glands are responsible for producing important substances such as mucus, enzymes, and hormones that aid in digestion and absorption of nutrients [25]. Therefore, our detailed histological examination of the Crypts of Lieberkühn in the colons of swine raised under intensive management and backyard farming systems provides valuable insights into the differences in histological characteristics between the 2 groups. Further investigation into the mechanisms underlying these differences could elucidate the adaptive responses of the intestinal epithelium to environmental variations.
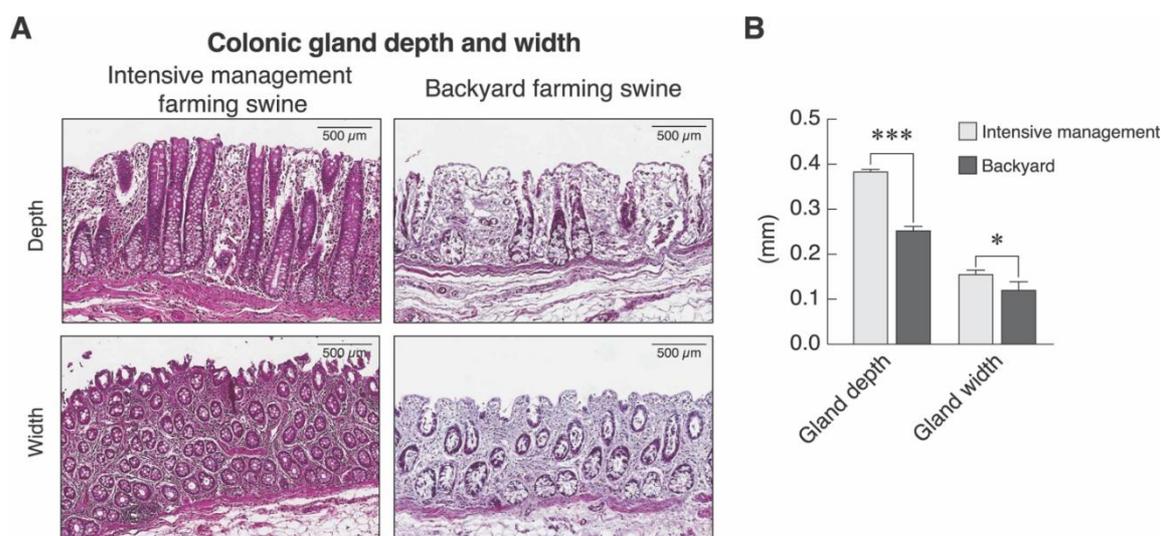


**Figure 3** Depth and width of intestinal glands (Crypts of Lieberkühn) in the mucosa of the colon in swine raised under intensive management and backyard farming systems. (A) Histological examination of the intestinal glands observed using a 10× microscope objective. (B) Quantitative comparison of intestinal gland depth and width between swine raised under intensive management and backyard farming systems, with data presented as mean $\pm$ S.E.M. * $p < 0.05$ and *** $p < 0.001$, compared between 2 groups.

**Number of inflammatory cells and lymphatic nodules in the colon of the 2 groups of swine**

To provide quantitative insights into inflammatory cells, we assessed the number of inflammatory cells present in the mucosa and number of lymphatic nodules in both the mucosa and submucosa layers of the colons of the swine in both groups. We conducted further investigation into the inflammatory cells, characterized by their large, condensed nuclei, within the mucosal layer. Additionally, we observed and identified irregularly scattered solitary lymphatic nodules throughout the mucous membrane and lamina propria. Subsequently, we quantified the number of inflammatory cells present in the mucosa and the

number of lymphatic nodules in the submucosa layers in the colons of swine raised under intensive management and backyard farming systems (**Figures 4(A) and 5(A)**, respectively). Our findings revealed significant differences between the 2 groups. Specifically, the number of inflammatory cells in the mucosa layer of swine raised under backyard farming was notably lower than that of the other group (26.43 ± 0.22 and 42.86 ± 0.58, respectively, $p < 0.001$, **Figure 4(B)**) Cohen's d was 1.94, suggesting a very large effect size. Similarly, the number of lymphatic nodules in swine raised under backyard farming was significantly lower than that of swine raised under intensive management farming (1.11 ± 0.34 and 3.93 ± 0.52, respectively, $p < 0.001$, **Figure 5(B)**). There was moderate variability in lymphatic nodules within the backyard group, indicating biological diversity possibly related to antigen exposure. Our results unveiled significant disparities between the 2 groups. Specifically, swine raised under backyard farming exhibited a notably lower number of inflammatory cells within the mucosal layer compared to those under intensive management. The lower number of inflammatory cells and lymphatic nodules in the mucosa of swine raised under backyard farming compared to those under intensive management may indicate differences in immune response and mucosal defense mechanisms between the 2 groups [26]. Swine raised under backyard farming, being exposed to a wider range of environmental antigens, may have developed a more regulated and less reactive immune system in response to constant antigen exposure [27]. This could result in a lower baseline level of inflammation and a reduced need for lymphatic nodules in the mucosa [28]. The lower number of lymphatic nodules and inflammatory cells in backyard swine may indicate a less reactive baseline mucosal immune status, potentially due to increased microbial diversity in the environment promoting immune tolerance [27,28]. This supports earlier studies suggesting that natural microbial exposures may regulate mucosal immunity and reduce chronic inflammation [29]. The reduced presence of inflammatory cells and lymphatic nodules in swine raised under backyard farming suggests potential benefits associated with outdoor rearing systems, potentially attributed to increased exposure to natural stimuli or reduced stressors [30]. A previous study also showed inflammatory cells within the mucosal layer

with distinctive characteristics, notably their large condensed nuclei in the intestinal tract [31]. Concurrently, irregularly scattered solitary lymphatic nodules were observed and identified throughout the mucous membrane and lamina propria in colonic carcinoma specimens [32]. Our findings align with histological studies in other species, such as broilers, where well-developed ileal thickness is associated with reduced luminal microbiota diversity, increased beneficial bacteria, and enhanced epithelial absorption and immune function through active community anabolism [33]. In rodents, environmental enrichment or outdoor access - such as the provision of nylon gnaw sticks - has been shown to influence gut microbiota and the expression of immune-related cytokines [34]. Similarly, studies in European pigs show that pasture-raised animals exhibit distinct gut morphology compared to those reared indoors [35]. Comparable patterns have also been observed in tropical and low-resource swine systems, where thinner mucosal layers and reduced lymphoid tissue likely result from dietary variability, limited nutrients, and environmental stressors [36,37]. These parallels underscore the need for adaptive husbandry strategies - especially in backyard settings - to support mucosal development and immune function. While our findings offer meaningful insights, several limitations should be noted. The relatively small sample size may affect generalizability, and the cross-sectional design precludes assessment of longitudinal changes. Future studies should incorporate larger cohorts and repeated sampling to better understand developmental dynamics in colonic morphology. For example, longitudinal studies tracking the same individuals across different growth stages or under changing environmental or dietary conditions could reveal how mucosal architecture and inflammatory responses evolve over time, providing stronger causal inferences. Additionally, assessing histological characteristics in swine at different ages - from weaning to market weight - would offer valuable insights into age-related morphological adaptations and their implications for gut health and function.
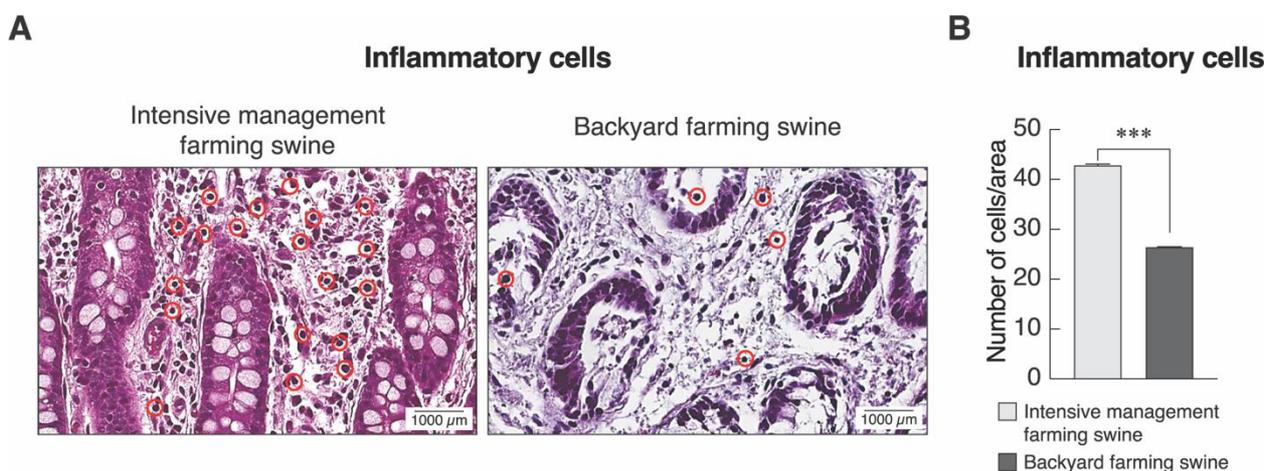
**Figure 4** Number of inflammatory cells in the colonic mucosa of swine raised under intensive management and backyard farming systems. (A) Histological morphology of inflammatory cells (indicated by circles) observed using a 40× microscope objective. (B) Quantitative comparison of the number of inflammatory cells between swine raised under intensive management and backyard farming systems. Data are presented as mean ± S.E.M. *$p < 0.001$, indicating significant differences between the 2 groups.
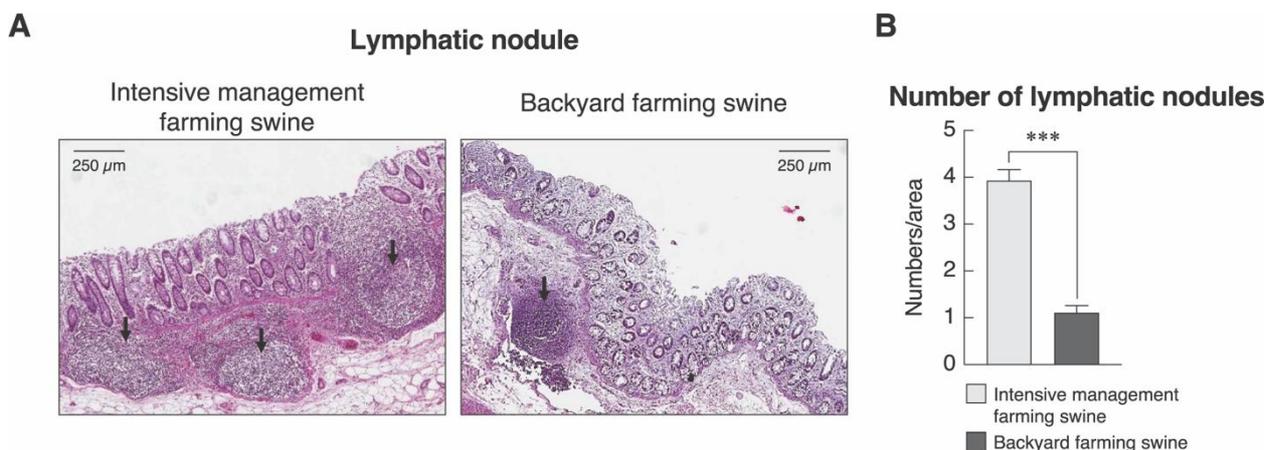


**Figure 5** Number of lymphatic nodules in the submucosa of the colon in swine raised under intensive management and backyard farming systems. (A) Histological morphology of the lymphatic nodules (indicated by arrows) observed using a 4× microscope objective. (B) Quantitative comparison of the number of lymphatic nodules between swine raised under intensive management and backyard farming systems, with data presented as mean ± S.E.M. ***$p < 0.001$, compared between the 2 groups.

## Conclusions

Our findings reveal distinct histological differences in the colonic mucosa of swine raised under intensive and backyard farming systems, underscoring the influence of environmental conditions on intestinal structure and gut health. These insights suggest practical opportunities for intervention, such as enhancing backyard diets with fiber-rich or microbiota-supportive components to promote mucosal integrity. Future longitudinal studies - including histological assessments across developmental stages, from weaning to market weight - are warranted to elucidate how these structural features evolve over time. Such research will be instrumental in advancing more resilient and welfare-oriented swine production systems.

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**Declaration of Generative AI in Scientific Writing**

The authors used ChatGPT to refine and correct grammar during manuscript preparation and revision.

**CRediT author statement**

**Jarinthorn Teerapornpuntakit**: Conceptualization; Methodology; Formal analysis; Writing - Review & Editing; Visualization. **Saimai Chatree**: Data curation; Writing - Original Draft; Visualization. **Kittipong Limpatchayopas**: Software; Validation. **Jenjira Chamta**: Software; Investigation. **Arnaud Monteil**: Conceptualization; Supervision. **Charkriya Promsuban**: Conceptualization; Methodology; Formal analysis; Writing - Original Draft; Writing - Review & Editing; Project administration.

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