

## REVIEW ARTICLE

# Value of clay as a supplement to swine diets

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## Abstract

The use of practical management factors to maximize pig health improvement cannot guarantee freedom from diseases. Moreover, because of health safety concerns, the use of antibiotics has been restricted in livestock, including pigs. Therefore, the swine industry has been looking for various alternatives to antibiotics to improve pig's health and performance. Clay is a dietary factor generally accepted for improving pig health. It is a naturally occurring material and is primarily composed of fine-grained minerals. It has a specific structure with polar attraction. Because of this structure, clay has the ability to lose or gain water reversibly. In addition, clay has beneficial physiological activities. First, clay has anti-diarrheic and antibacterial effects by penetrating the cell wall of bacteria or inhibiting their metabolism. Second, it can protect the intestinal tract by absorbing toxins, bacteria, or even viruses. When added to the diet, clay has also been known to bind some mycotoxins, which are toxic secondary metabolites produced by fungi, namely in cereal grains. Those beneficial effects of clay can improve pigs' health and performance by reducing pathogenic bacteria, especially pathogenic *Escherichia coli*, in the intestinal tract. Therefore, it is suggested that clay has a remarkable potential as an antibiotics alternative.

**Keywords:** clay, diarrhea, swine

## Introduction

An important management point in the swine industry is to maximize pig health improvement to keep pigs free of various diseases. The most practical management factors are follows: all-in/all-out pig flow, age segregation, intense biosecurity practices, sanitation, new vaccinations, and depopulation/repopulation (Hardy, 2002; Adjiri-Awere and van Lunen, 2005). However, these techniques cannot guarantee freedom from diseases for pigs although they are common and widely used. Thus, it is necessary to apply other methods to support these limited technologies.

The use of antibiotics is one of the most effective ways to prevent diseases in any livestock, including pigs (Jang et al., 2016). However, it has been reported that the use of antibiotics in the



### OPEN ACCESS

**Citation:** Mun D, Lee J, Choe J, Kim B, Oh S, Song M. 2017. Value of clay as a supplement to swine diets. Korean Journal of Agricultural Science 44:181-187.

**DOI:** <https://doi.org/10.7744/kjoas.20170017>

**Editor:** Woo Kyun Kim, University of Georgia, USA

**Received:** March 24, 2017

**Revised:** May 23, 2017

**Accepted:** June 9, 2017

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swine industry has potential safety issues, such as the emergence of antibiotic-resistant enteric bacteria which cause a high risk to both animal and human health (Cromwell, 2002; Hardy, 2002). Due to these health safety issues, most countries have restricted antibiotics use, forcing the swine industry to find alternatives to antibiotics to improve pig health without safety issues.

Dietary factors (e.g., feed ingredients, feed additives, or feeding methods) have been increasingly considered for the improvement of pigs' health and performance (Pluske et al., 2002; Stein and Kil, 2006; Park et al., 2016). Moreover, it is generally accepted that some dietary factors, such as clay, spray-dried plasma, and enzymes, are important nutrient sources and can improve pig health. Some literature reported that these factors provide physiological activities such as the modulation of the intestinal environment and absorption properties which affect pathogenic microbes directly or indirectly (Song et al., 2012, Jang et al., 2016). This implies that dietary factors can be an effective component of swine health management programs along with existing practical management practices. This article reviews the value of dietary factors with a focus on the value of clay supplement.

## Character of Clay and Utilization in Swine Diets

### Definition and Structure of Clay

“The term ‘clay’ refers to a naturally occurring materials, found in geological deposits, which is composed primarily of fine-grained minerals (< 2.0  $\mu\text{m}$  in diameter) such as, phyllosilicate and other minerals. These impart plasticity to clay as variable amounts of water are trapped in the mineral structure by polar attraction. Clay will harden when dried or fired” (Guggenheim and Martin, 1995; Williams et al., 2009).

Natural clay deposits are rarely pure and most of them contain mixtures of a variety of minerals from various clay mineral groups such as kaolinite, montmorillonite-smectite, illite, and chlorite (Williams et al., 2009). Three different structures exist: 1) 1 : 1 layer structure formed between a single octahedral sheet ((Al, Mg, Fe) $\text{O}_6$ ) and a single tetrahedral sheet ((Al, Si) $\text{O}_4$ ), 2) 2 : 1 layer structure formed from sandwiching a single octahedral sheet ((Al, Mg, Fe) $\text{O}_6$ ) between two tetrahedral sheets ((Al, Si) $\text{O}_4$ ), and 3) framework structure that is a three dimensional frameworks of  $\text{SiO}_4^{4-}$  and  $\text{AlO}_4^{5-}$  tetrahedra linked through shared oxygen atoms (Papaioannou et al., 2005; Williams and Haydel, 2010).

### General Effects and Proposed Mechanisms of Clay

Clays have several potential effects when they are administered orally or topically (Carretero, 2002; Gomes and Silva, 2007; Tateo and Summa, 2007). For oral applications, first, clays are used as gastrointestinal protectors, especially palygorskites or kaolinites. The gastric and intestinal mucous membranes can be protected as clays adhere to them and absorb toxins, bacteria, or even viruses, but they also eliminate enzymes or other nutritive elements. Second, clays, especially sodium smectites, are used as osmotic laxatives to encourage defecation. This is not a function of the clay itself but of the interlayered  $\text{Na}^+$  as it spreads and produces the osmotic pressure in the intestines. Third, clays are used as antidiarrheics, especially clays with absorbent minerals such as kaolinites, palygorskites, or calcium smectites, which have a high capacity for water absorption. They work by reducing the quantity of liquid and the speed of passage through the intestines as clays absorb excess water as well as gases in the digestive tract. Fourth, clays have potential antibacterial (bacteriostatic or bactericidal) effects by penetrating the cell wall of bacteria or inhibiting their metabolisms.

There are two types of proposed mechanisms, physical and chemical means (Papaioannou et al., 2005; Williams et

al., 2009). As an example of physical means, clays are hydrophilic or organophilic. Organophilic smectites (modified clays), made by inserting alkylammonium compounds into the clay interlayer, can attract the bacterial cell to the surface of the clay with enough physical force that the cell membrane is torn (adsorption property), causing bacterial cell death (Papaioannou et al., 2005; Williams et al., 2009). Natural clays also have this same effect of bacterial cell lysis by physical force. This adsorption property combined with the physical force of clays may be beneficial for killing bacteria. However, clays may harm host tissues because they can also adhere to gastrointestinal walls and modify or reinforce the mucus lining of intestines (Tateo and Summa, 2007).

As an example of chemical means, French green clays used for treating Buruli ulcer caused by *Mycobacterium ulcerans* are dominated by illite and Fe-smectite mineralogically, which are hydrophilic (Papaioannou et al., 2005; Williams et al., 2008). These natural clays may have potential effects that kill bacteria with chemical exchanges in aqueous media by providing a toxin to bacteria, depriving bacteria of essential nutrients for their metabolism, or changing pH and oxidation state in the intestines. There are also other clay effects such as dermatological protection, excipients for drug, pelotherapy, etc., but only oral application cases are considered in this review.

## Physiological Effects of Clays

### Clays as a Mycotoxin Binder

Mycotoxins (aflatoxin, ergot alkaloids, fumonisin, orchartoxin, vomitoxin, or zearalenone) are the toxic secondary metabolites produced by fungi (*Aspergillus*, *Fusarium*, *Penicillium*, and *Claviceps* species) in cereal grains during storage, growth, harvest, transportation, or processing (Lindemann et al., 1993). These mycotoxins are detrimental to animal growth, production, and health when animals consume diets contaminated with them. A practical approach has been the addition of adsorbents to contaminated feed to bind the mycotoxins and to reduce the detrimental effects by mycotoxins. One solution may be the addition of clays in livestock diets. A hydrated sodium calcium aluminosilicate (HSCAS, clay) has been known to bind some of these mycotoxins when added to the livestock diets (Phillips et al., 1988; Papaioannou et al., 2005). *In vitro* studies showed the adsorption of mycotoxins by clays (Lemke et al., 1998; Lemke et al., 2001). *In vivo* studies showed that the addition of clays in the pig diets reduce the adverse effects of aflatoxin in the diets on growth rate and serum indicators of protein synthetic capabilities and of liver damage of pigs (Lindemann et al. 1993; Schell et al., 1993a; Schell et al., 1993b).

### Effects of Clay on Pig Performance

Field observations suggest that clays in pig diets also have anti-toxic or -diarrheic effects. Without challenge, clays may improve (Pond et al., 1988; Papaioannou et al., 2004; Alexopoulos et al., 2007; Table 1) or may not improve (Ward et al., 1991; Poulsen and Oksbjerg, 1995; Parisini et al., 1999) the growth rate of pigs. This may be because the ion exchange, adsorption, and catalytic properties of clays may reduce the passage rate through intestinal tract, reduce the enzymatic hydrolysis of diets, and reduce absorption of nutrients (Shurson et al., 1984; Pond et al., 1988). Clays may not affect serum minerals (Papaioannou et al., 2002; Alexopoulos et al., 2007), or may affect them, because of ion exchange properties of clays or interference of mineral ions (e.g., Al) from degradation of clays in the acidic environment (Shurson et al., 1984; Ward et al., 1991). Clays may reduce serum urea nitrogen (Shurson et al., 1984; Poulsen and Oksbjerg, 1995; Alexopoulos et al., 2007) or toxic compounds (Shurson et al., 1984; Ramu et al., 1997) because of the high affinity of clays for ammonium ions, resulting from the deamination of proteins, and for toxic

**Table 1.** Effects of clay on pig performance (adapted from Song et al., 2012).

Item	Control	Clay
ADG (g)	382.5	383.5
ADFI (g)	859.5	748.5
G : F	0.450	0.535

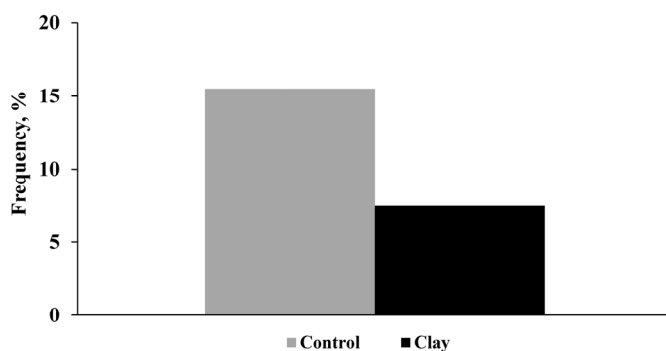
compounds, resulting from microbial degradation. Clays may affect or may not affect (Alexopoulos et al., 2007) hematological parameters such as hematocrit, white blood cell count, and hemoglobin concentrations because of intestinal irritation or inflammation by clays.

### Effects of Clay on Pigs' Health

Clays reduce piglets' diarrhea (Stojic et al., 1998; Papaioannou et al., 2004; Fig. 1) after weaning, maybe because of antibacterial effects by clays' adsorption properties. Trckova et al. (2009) reported, in pigs, that, with a pathogenic *E. coli* challenge, the clay treatment improves body weight gain (but not growth efficiency), reduces the colonization and shedding of pathogenic *E. coli*, and does not change hematological parameters of serum or histopathological features of mucosa in small and large intestines compared with pigs fed the control diet.

In addition, some *in vitro* studies and human research support the antibacterial and mycotoxin binding effects of clays. Ramu et al. (1997) showed that clays adsorb and inactivate the heat-labile (LT) enterotoxins of *E. coli* and the cholera enterotoxins (CT) of *Vibrio cholerae*. Some reports showed clays eliminate or inhibit growth of pathogenic *E. coli* (Tong et al., 2005; Hu and Xia, 2006; Haydel et al., 2008), *Salmonella choleraesuis* (Tong et al., 2005), and other antibiotic-susceptible and antibiotic-resistant bacteria (Haydel et al., 2008) by damaging bacterial cell wall causing leakage of bacterial enzymes, by inhibiting bacterial respiratory metabolism, or by changing chemical conditions such as pH and oxidation state. Also, *in vivo* studies of human health showed evidences of those benefits. Some reports showed that clays attenuate overall disorder of diarrhea-predominant irritable bowel syndrome and abdominal pain, discomfort intensity (Chang et al., 2007), and severity of acute diarrhea of children (Madkour et al., 1993; Dupont et al., 2009). In addition, clay may reduce exposure and adverse effects of mycotoxin-contaminated food for humans (Wang et al., 2005).

*In vitro* studies have shown antiviral effects of clays. Some reports showed clays adsorb rotavirus and coronavirus (Clark et al., 1998), which generally cause gastroenteritis (acute diarrheal disease), and reovirus (Lipson and Stotzky,

**Fig. 1.** Effect of clay on frequency of diarrhea of pigs (adapted from Song et al., 2012).

1983), which causes gastrointestinal and respiratory problems, with high affinity by physical forces such as van der Waals forces and hydrogen bonding and by formation of a cation bridge between clays and viruses, although the clay-virus complex retained infectivity.

## Conclusion

Clay is a naturally occurring material and is composed primarily of fine-grained minerals (phyllosilicate minerals). It has a specific structure which has the ability to lose or gain water reversibly to adsorb molecules and to exchange ions. Based on these properties, we conclude that there are several beneficial physiological activities such as protection of the intestinal tract, anti-diarrheic and antibacterial effects, etc. Those beneficial effects can contribute to improvement of pig performance and health by reducing pathogenic bacteria in the intestinal digestive tract (modulation of microbiota), especially pathogenic *E. coli* that cause piglets' diarrhea after weaning.

## Acknowledgements

This work was financially supported by the research fund of Chungnam National University in 2015.

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