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Supplementation of the sow diet with chitosan oligosaccharide during late gestation and lactation affects hepatic gluconeogenesis of suckling piglets

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ABSTRACT

Chitosan oligosaccharide (COS) has a blood glucose lowering effect in diabetic rats and is widely used as a dietary supplement. However, the effect of COS on the offspring of supplemented mothers is unknown. This experiment investigates the effect of supplementing sows during gestation and lactation on the levels of plasma glucose on suckling piglets. From day 85 of gestation to day 14 of lactation, 40 pregnant sows were divided into two treatment groups and fed either a control diet or a control diet containing 30 mg COS/kg. One 14 day old piglet per pen was selected to collect plasma and tissue (8 pens/diet). Performance, hepatic gluconeogenesis genes and proteins expression, amino acids contents in sow milk, hepatic glycogen and free fatty acid were determined. Results showed that supplementation of the maternal diet with COS improved daily gain and weaning weight ($P < 0.05$), and the concentration of amino acids in sow milk ($P < 0.05$). Meanwhile, maternal supplementation with COS increased ($P < 0.05$) mRNA expression levels and activities of PEPCK-C, PEPCK-M and G6Pase in the liver of piglets compared with piglets from control fed sows. Correspondingly, the level of plasma glucose was higher ($P < 0.001$) and hepatic glycogen was lower ($P < 0.05$) in piglets from COS fed sows when compared with that in the control group. In conclusion, dietary supplementation of the diet with COS during late gestation and lactation reduced piglet hypoglycemia by stimulating hepatic gluconeogenesis and improved the growth rate of suckling piglets.

1. Introduction

Feeding and the body condition of sows during the transition from gestation to lactation are important for neonatal piglet survival, lactation performance of sows, and piglet growth during the subsequent lactation (Hansen et al., 2012). Colostrum is being synthesized prepartum

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(Schneider, 1991). Milk production is being initiated with partitioned nutrients from the conceptus to the mammary tissue. Therefore, the transition period from late gestation to lactation is crucial for the sow and offspring (Theil et al., 2006). The perinatal period is associated with abrupt changes in energy supply. Neonatal piglets rely on body energy reserves to maintain glucose homeostasis until the intake of colostrum and milk can meet their energy demands. Thus, energy reserves at birth are crucial for ensuring piglet survival (Theil et al., 2011). Neonatal piglets require regular nursing and substantial gluconeogenesis activity to maintain normoglycemia. The available data show that, in the human newborn, gluconeogenesis appears soon after birth and accounts for 30–70% of the glucose produced. It has been speculated that the primary role of mitochondrial phosphoenolpyruvate carboxykinase (PEPCK-M) is lipogenesis for the high rate of lipogenesis and the absence of gluconeogenesis during the fetal period in rats (Kalhan and Parimi, 2000). Thus, nutritional strategies to improve energy transfer from the sow to the offspring should presumably increase piglet survival (Theil et al., 2014). A previous study demonstrated that supplementation with colostrum (and perhaps milk) stimulated gluconeogenesis in neonatal piglets. But the exact mechanism of this effect is still unclear (Lepine et al., 1991).

Chitosan oligosaccharides (COS), the hydrolyzed product of chitosan, is a mixture of oligomers of b-1,4-linked D-glucosamine residues (Xiao et al., 2013, 2014). It is abundant in the exoskeletons of crustaceans and the cell walls of fungi and insects (Pae et al., 2001). COS has the potential ability to improve food quality (Oliveira et al., 2008; Seyfarth et al., 2008; Wang et al., 2011) and human and animal health (Lee et al., 2003; Sun et al., 2009; Yin et al., 2008, 2010; Xia et al., 2011; Xiao et al., 2013; Kong et al., 2014; Xiong et al., 2015). Several studies showed that COS can be used as an antidiabetic agent for its effect on promotion of glucose tolerance and reduction of the plasma glucose in diabetic rats (Lee et al., 2003; Kim et al., 2009a,b, 2014). The ingestion of chitosan also decreased liver gluconeogenesis and increased glucose uptake in skeletal muscle to alleviate hyperglycemia in the diabetic rats (Liu et al., 2010, 2012a). Additionally, Kim et al. (2009a,b) clinically demonstrated the blood glucose lowering effect of low molecular weight COS in healthy human subjects.

Collectively, COS or chitosan has a clear potential function in regulating glucose metabolism. However, few studies have reported about the effect of dietary chitosan oligosaccharide on the hepatic gluconeogenesis in offspring. Thus, the present study examined the effect of dietary COS in sows during late gestation and lactation on growth performance and hepatic gluconeogenesis capacity of suckling piglets.

2. Materials and methods

This study was conducted according to the guidelines for the treatment of animal subjects as approved by the Animal Care Committee of the Institute of Subtropical Agriculture, Chinese Academy of Science (Wu et al., 2013a,b).

Table 1
Composition of gestation and lactation diets (as-fed basis).

Ingredient (%)	Control	COS
Corn	70.30	70.30
Soybean meal	12.00	12.00
Wheat middling	4.00	4.00
Rice bran meal	3.00	3.00
Puffed soybean	3.00	3.00
Salt	0.35	0.35
Potassium chloride	0.75	0.75
Vitamin-mineral Premix[a]	3.00	3.00
Dicalcium phosphate	2.20	2.20
Limestone	0.50	0.50
Soy oil	0.50	0.50
Mold-inhibiter	0.09	0.09
L-Lys HCl	0.20	0.20
DL-Met	0.06	0.06
L-Thr	0.05	0.05
Chitosan oligosaccharide	0.00	0.003
Nutrient composition		
DM, %	88.2	88.2
ME, MJ/kg	13.5	13.5
CP, %	14.7	14.7
Lys, %	0.78	0.78
Met + Cys, %	0.69	0.69
Ca, %	0.92	0.92
Total *P*, %	0.67	0.67

[a] Premix provided the following per kg of diet: Fe ($FeSO_4 \cdot H_2O$), 80 mg; Mn ($MnSO_4 \cdot 5H_2O$), 45 mg; Zn (ZnO), 100 mg; Cu ($CuSO_4 \cdot 5H_2O$), 20 mg; I (KI), 0.70 mg; Se ($Na_2SeO_3 \cdot H_2O$), 0.25 mg; vitamin A, 10,000 IU; vitamin D_3, 2500 IU; vitamin E, 100 IU; vitamin K, 10 IU; vitamin B_2, 10 mg; vitamin B_6, 1 mg; vitamin B_{12} 50 μg; biotin, 80 μg; folic acid, 5 mg; nicotinic acid, 15 mg; choline chloride 1500 mg.

2.1. Animals and experimental treatment

Forty pregnant sows (Large White × Landrace) with the same parturition history were fed one of two experimental diets from day 85 of gestation to day 14 of lactation (20 sows/diet). COS (the degree of polymerization was 2–7) was provided by Beijing Zhong Tai He Technology (ZTH Tech. Co., Beijing, China).

The dietary treatments consisted as following: (a) basal corn/soybean control diet (no COS; Control) (Table 1); (b) basal diet with supplement of COS (30 mg chitosan oligosaccharide per kg basal diet; COS). Content of COS was determined by preliminary experiment (Tang et al., 2005a). All sows were housed individually in gestation crates (2.0 m × 0.6 m, concrete floor) and transferred to individual farrowing crates (2.2 m × 1.5 m) on d 107 of gestation. From the fourth day prior to the expected date of confinement, daily intake was gradually reduced by 0.5 kg/day for each sow until the day of delivery. The same keeper was responsible for feeding management from the preliminary experiment before delivery to the restricted feeding method in the whole process. Sows were fed approximately 3.0 kg diets in 5–10 days before delivery, and then increased gradually until the maximum feed intake of sows 5 days after delivery. The gestation and lactation diet were formulated to meet or exceed all the requirements for gestating and lactating sows as referred in our previous study (Liu et al., 2012b). Sows and piglets had free access to water at all times (Tan et al., 2009).