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Effects Of γ-Aminobutyric Acid on Performance, Antioxidative Status and Biochemical Indices of Lactating Sows in Hot Weather

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Abstract

This study was carried out to determine the effects of γ-aminobutyric acid on the reproductive performance, antioxidative status and biochemical indices of lactating sows. Forty-two lactating sows (Landrace×Large White) were blocked by body weight, parity and backfat and randomly assigned to 6 treatments: 0 (control), 100, 200, 300, 400 and 500 mg γ-aminobutyric acid /kg diet. The average temperature and relative humidity were 30.5°C and 79.47% at 8:00 am while 38.5°C and 73.55% at 15:00 pm respectively during the 21 lactation period. Litter size was standardized to10 to12 piglets within 2 days after farrowing. Sow feed intake was measured daily. On days 1 and 21 of lactation, sow backfat and piglet weight were recorded, milk yield was measured by the weigh-suckle-weigh method, and milk and blood samples were collected for chemical analysis. The results showed that supplementation of 300 mg and 400 mg γ-aminobutyric acid/kg diet improved ($P<0.05$) sow feed consumption and milk output when compared with the control. Addition of 200 to 500 mg γ-aminobutyric acid/kg diet increased ($P<0.05$) litter weight gain. However, no significant differences ($P>0.05$) in sow backfat loss during lactation, weaning to estrus interval, piglet survival rate and diarrhea index among treatments were observed in this trial. Milk contents of lactose, butterfat, milk protein, total solids and non-fat solids were generally similar ($P>0.05$) among treatments. The results also indicated that γ-aminobutyric acid improved the antioxidative status of sows in lactation. Addition of 300 to 500 mg γ-aminobutyric acid/kg diet led to an increase in serum levels of superoxide dismutase (SOD) and glutathione peroxidase (GSHPx) and a decrease of malondialdehyde (MDA) content in serum ($P<0.05$) compared with the control. Moreover, 200 to 500 mg/kg γ-aminobutyric acid generally decreased ($P < 0.05$) the serum contents of alanine aminotransferase (ALT), aspartate aminotransferase (AST), phosphokinase (CK) and lactate dehydrogenase (LDH). In conclusion, our data indicated that γ-aminobutyric acid improved, in a dose-dependent manner, reproductive performance, antioxidative status and biochemical indices of multiparious lactating sows in hot weather.

Keywords: γ-Amino butyric acid; Lactating sows; Thermal environment; Serum biochemical indices; Antioxidant enzymatic system.

1. Introduction

Sows are sensitive to hot weather during the summer and high temperature often has significant negative influences on reproductive performance, antioxidative status and some biochemical indices such as alanine aminotransferase (ALT) aspartate aminotransferase (AST) phosphokinase (CK) and lactate dehydrogenase (LDH) of sows and subsequently longevity [1]. Sufficient feed intake of sows is probably one of the most critical aspect in the whole lactating period so that the optimal production performance can be obtained [2]. Adverse effects of high temperature on the highly productive sows during lactation have been described by several authors, including insufficient feed intake, decreased milk yield and litter weight gain [3-6]. Previous studies showed that feed intake of sows was reduced by 25% when ambient temperature increased to 30℃ [7] and that inadequate feed intake and therefore insufficient supply of nutrient of lactating sows resulted in lactation disorders and growth check of piglets and inferior growth performance during the growing-finishing period [8,9]. It was reported that the colostral nutrient content in the sows fed in tropical zones was less than that in the sows fed in temperate zones [10]. Moreover, increased metabolic burdens caused by hot weather on sows in lactation led to elevated systemic oxidative stress and it is related to decreased availability of antioxidants during this important period. Therefore, it may be necessary to increase the some antioxidants including vitamin E and A contents in the diet during the lactation period in order to compensate for the substantial loss of some nutrients [11,12].

In terms of animal feed intake regulation mechanisms and control techniques, some studies found that hypothalamic ventromedial nucleus (VMN) and lateral hypothalamic area (LHA) were the basic feeding regulatory centers and the food rich in γ-aminobutyric acid or γ-aminobutyric acid extract can be used to improve the health, anti-stress and immunity ability of sows [13,14]. The γ-aminobutyric acid is found in the mammalian brain and confirmed as one of inhibitory neurotransmitters in the central nervous system (CNS). It was proved that γ-aminobutyric acid was provided from glutamic acid as affected by glutamate dehydrogenase in alpha decarboxylation action [15]. As a major inhibitory neurotransmitter in the mammalian CNS, γ-aminobutyric acid plays a key role in modulating neuronal activity, which has several important physiological functions including neurotransmission, induction of hypotensive, diuretic effects, and tranquilizer effects [16]. Recently, some studies reported the γ-aminobutyric acid-ergic mechanisms in anxiolytic, anticonvulsant, sedative-hypnotic, antihypertensive and anti-stress actions [17,18].

In addition to its CNS functions, the γ-aminobutyric acid-ergic system is also present in peripheral tissues, including the gastrointestinal tract, protecting liver and kidney and adjusting the hormone secretion [19]. In our previous study, we found that the γ-aminobutyric acid (Aalpha1) receptor subunit was abundantly expressed in the brain of sows [20], which suggested that γ-aminobutyric acid may play an important role in some physiological activities. Hence, the objective of this study was to evaluate the effects of γ-aminobutyric acid on reproductive performance, antioxidative status and the serum biochemical indices of lactating sows in a hot environment.

2. Material and Methods

2.1. Experimental design, diets and animal management

This experiment was conducted at the Guang'an Swine Research Farm in Yiyang District, Hunan province, China. This study was performed in accordance with Chinese Animal Welfare Act guidelines and approved by the Animal Care and Use Committee of the Institute of Subtropical Agriculture, the Chinese Academy of Science [21].

A total of forty-two of multiparous lactating sows were used in this experiment. The sows were evenly allocated by body weight (BW), backfat, expected farrowing date and parity into six dietary treatments, with seven replicates each. Litter size was standardized to 10 to12 piglets within 2 days after farrowing. The sows were housed individually in crate stalls from mating to day 35 of pregnancy. Then the sows were housed in group pens from day 35 to 110 of pregnancy. Five days before the expected date of confinement, all the sows were moved into the individual farrowing crates with a heated piglet nest on day 110 of pregnancy. Rooms were ventilated mechanically, and the ambient temperature and relative humidity were measured daily at 8:00 am and 15:00 pm. The average temperature and relative humidity were 30.5°C and 79.47% at 8:00am while 38.5°C and 73.55% at 15:00pm respectively during the 21 lactation period.

From day 110 of pregnancy the sows received a lactation diet (experimental diet, Table 1) with levels of nutrients and minerals based on NRC (1998) recommendation, which only differed in the dose of -aminobutyric acid: 0 (Group I), 100 (Group II), 200 (Group III), 300 (Group IV), 400 (V) or 500 (Group VI) mg γ-aminobutyric acid per kg diet. The dose of γ-aminobutyric acid was determined by previous studies from Liang (2009) [22]. On the day of farrowing sows didn't received any feed and the daily amount of feed was increased by 0.75 kg/day up to ad libitum during the first 4 days after farrowing, and thereafter the sows were fed twice daily, in the morning and evening, and had free access to water from nipple drinkers at all times. The lactation length was 21 days. The feed intake of sows was measured daily and the back fat was measured on day 1 and 21 of lactation. The sows' weaning to estrus interval

Table 1. Components and chemical composition of diet.

Components	[%]
Corn	60.00
Soybean Meal	20.03
Wheat Bran	12.63
NaCl	0.18
Dicalcium Phosphate	1.43
Limestone	1.06
Vegetable Oil	3.67
Premix	1.00
Total	100
Nutrients	**[%]**
Digestible Energy/ (MJ/ kg)	14.18
Crude protein	16.02
Calcium	0.75
Total Phosphous	0.63
Available-P	0.35
Lys	0.80
Leu	1.34

was recorded. The piglets were weighed at days 1 and 21 of lactation. No creep feed was provided. The number of healthy and dead piglets was recorded during the whole lactation to obtain the survival rate.

2.2. Sample collection and chemical analysis

On days 1 and 21 of lactation, milk yield was determined by the weigh-suckle-weigh method which measured the weight difference between the two sulking of piglets as described by Paulicks et al. (1998) [23]. One hour after the last milk output measurement, milk samples were drawn manually from every active teat of a sow after i.m. injection of 15 IU oxytocin. Concentrations of lactose, butterfat, protein, total solids and non-fat solids in milk were determined by infrared spectroscopy (Milko-scan B4A/B, A/SN Foss Electric, Hillerød, Denmark) with a spectroscope calibrated with sow milk.

Blood samples (10 mL) were taken from ear veins into vacuum blood collection tubes on days 1 and 21 of lactation. The blood samples were allowed to clot at room temperature for 30 min, and then centrifuged at 3000 rpm for 15 min with the resulting serum stored at - 20℃ until analysis [24]. The activities of serum glutamic-pyruvic transaminase (ALT), glutamic-oxaloacetic transaminase (AST), creatine kinase (CK) and lactate dehydrogenase (LDH) were determined by Automatic Biochemistry Analyzer (Mindray BS-200, Shenzhen, China) using commercial kits according to the manufacturer's instructions. All the kits were purchased from Beijing Chemlin Biotech Co., Ltd. (Beijing, China).The activities of superoxide dismutase (SOD), glutathione peroxidase (GSH-Px) and malondialdehyde (MDA) were determined by kits (Nanjing Jiancheng Technology LTD., China). These antioxidant indices in serum were analyzed with the corresponding assay kits according to the manufacturer's instructions.

2.3. Data analysis

All data were analyzed by ANOVA using the GLM procedures of SPSS11.0. The statistical model consisted of the effect of diet. Pen was used as the experimental unit for the piglet's performance data, whereas individual sow was used as the experimental unit for reproductive performance and blood analysis. Multiple comparisons were carried out by the Tukey method. Differences were considered significant when P<0.05. The results are reported as the means and standard errors (means±SE).

3. Results

3.1. Performance of lactating sows

The results showed that the γ-aminobutyric acid had beneficial effects on the reproductive performance of sows during the lactation in hot weather in a dose-dependent manner. Average daily feed intake of the sows increased with increasing contents of γ-aminobutyric acid in the diet and reached the maximum with 300mg/kg diet (Figure 1). The feed intake in the 300 mg/kg and 400 mg/kg γ-aminobutyric acid groups exceeded about 9.38% and 6.82% (P<0.05) while the milk production also increased by 28.53% and 22.25% respectively (P<0.05) compared with the control. A quadratic trend was observed for feed consumption and milk

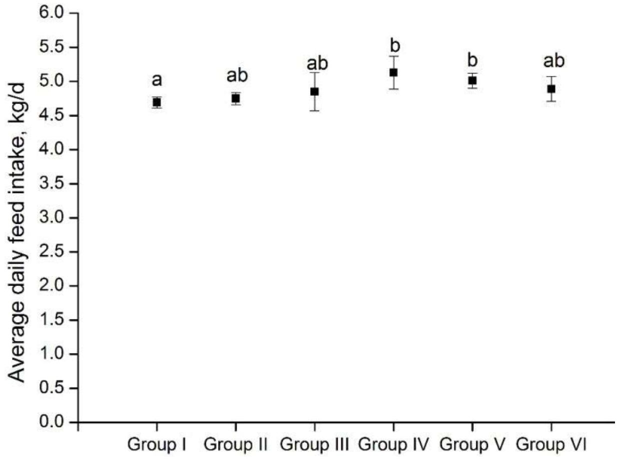


Figure 1. Effects of dietary supplementation of different levels of GABA on average daily feed intake in lactating sows. Values are means ± SE, n=6. Means without common lower-case letters differ (P<0.05).

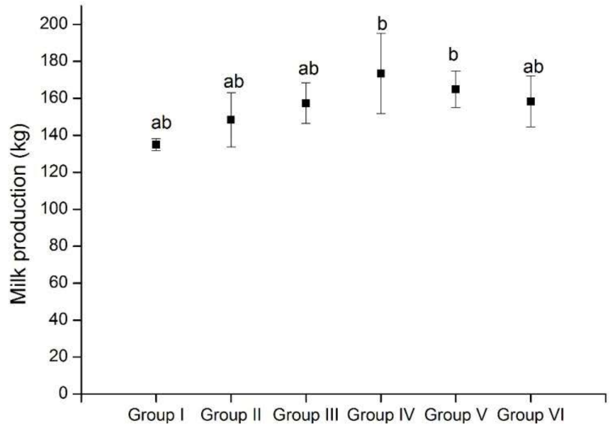


Figure 2. Effect of dietary supplementation of different levels of GABA in on milk production of lactating sows. Values are means ± SE, n=6. Means without common lower-case letters differ (P<0.05).

production with increasing levels of γ-aminobutyric acid (Figures 1,2). As for the body reserve change as indicated by the back fat loss and weaning to estrus interval, there was no significant difference in this trial (P>0.05). During lactation the growth of piglets was improved and showed a dose-effect with increasing the level of γ-aminobutyric acid (Table 2) as indicated by the litter weight gain for Groups III (P<0.01), IV

Table 2. Effects of dietary supplementation of different levels of γ-aminobutyric acid on growth performance of piglets during lactation.

Items	Group I	Group II	Group III	Group IV	Group V	Group VI
Average individual weight (kg)						
0d	1.43 ± 0.54	1.39 ± 0.38	1.41 ± 0.45	1.42 ± 0.57	1.45 ± 0.41	1.41 ± 0.48
21d	5.47 ± 0.62Aa	5.63 ± 0.73 AaBb	5.73 ± 0.57ABb	6.13 ± 0.64Bb	5.82 ± 0.52ABb	5.73 ± 0.61ABb
Average individual daily weight gain (g/d)						
	201.57 ± 6.37Aa	211.59 ± 18.34AaBb	215.24 ± 21.67AaBb	223.18 ± 19.68Bb	219.25 ± 20.67ABb	216.93 ± 23.47ABb
Litter weight (kg)						
0d	13.23 ± 2.32	14.06 ± 3.19	13.58 ± 2.86	14.36 ± 2.84	14.21 ± 2.51	14.24 ± 3.27
21d	42.51 ± 4.68Aa	48.29 ± 5.29AaBb	48.83 ± 4.56AaBb	54.67 ± 6.94Bb	49.35 ± 3.67AaBb	49.61 ± 5.03ABb
21 daily litter weight gain (kg)						
	29.30 ± 2.92Aa	34.26 ± 3.90AaBb	35.19 ± 3.66ABb	40.34 ± 4.67Bb	35.17 ± 3.27ABb	35.37 ± 4.57ABb
Diarrhea rate (%)						
	6.24 ± 0.08	5.37 ± 0.04	6.53 ± 0.03	5.59 ± 0.03	6.17 ± 0.05	5.71 ± 0.03
Survival rate (%)						
	85.21 ± 9.13	85.26 ± 9.14	87.17 ± 8.16	89.07 ± 9.67	87.73 ± 7.29	86.56 ± 7.91

Values are means ± SE, n=6. Means within a row without common lower-case letters differ (P<0.05)

(P<0.05), V (P<0.05) and VI (P<0.05). However, neither the survival rate nor the diarrhea of piglets was affected by the dietary treatment (P>0.05). Similarly, no significant differences in the contents of lactose, butterfat, milk protein, total solids and non-fat solids in colostrum and milk were observed among the treatments (P>0.05), except that the level of milk lactose in Group IV was higher (P<0.05) than the control (Table 3).

Table 3. Effects of dietary supplementation of different levels of γ-aminobutyric acid on milk nutrients composition of lactating sows on days 0 and 21 of lactation.

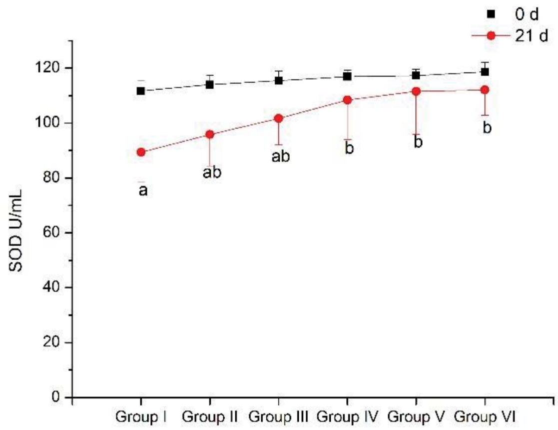
Items	Group I	Group II	Group III	Group IV	Group V	Group VI
Total solids (%)						
0d	18.25 ± 2.01	17.97 ± 4.21	20.54 ± 5.12	19.71 ± 2.28	19.65 ± 1.83	19.61 ± 3.59
21d	18.02 ± 0.85	18.68 ± 1.06	18.73 ± 1.69	18.79 ± 1.05	18.43 ± 0.75	18.17 ± 1.67
Solids of non-fat (%)						
0d	13.35 ± 2.32	13.43 ± 3.86	13.24 ± 3.57	13.36 ± 0.48	13.51 ± 2.65	14.03 ± 3.15
21d	11.48 ± 0.99	11.59 ± 0.31	11.97 ± 0.54	12.13 ± 56	12.22 ± 0.18	12.41 ± 0.99
Fat (%)						
0d	6.49 ± 0.73	6.37 ± 0.43	6.54 ± 1.27	6.55 ± 0.95	6.56 ± 1.29	6.51 ± 0.95
21d	6.52 ± 1.16	6.72 ± 0.83	6.63 ± 1.31	7.07 ± 0.97	7.08 ± 0.71	6.31 ± 1.04
Protein (%)						
0d	6.88 ± 2.49	7.11 ± 3.51	7.31 ± 4.12	6.93 ± 1.58	7.06 ± 2.76	7.13 ± 3.43
21d	5.44 ± 0.16	5.41 ± 0.49	5.67 ± 0.31	5.49 ± 0.81	5.37 ± 0.45	5.41 ± 0.48
Lactose (%)						
0d	4.03 ± 0.26	3.96 ± 0.65	4.09 ± 1.26	4.14 ± 0.27	4.12 ± 0.74	4.08 ± 1.22
21d	5.51 ± 0.86a	5.27 ± 0.61ab	5.97 ± 0.28ab	6.47 ± 0.26b	5.49 ± 0.21ab	5.29 ± 0.59ab

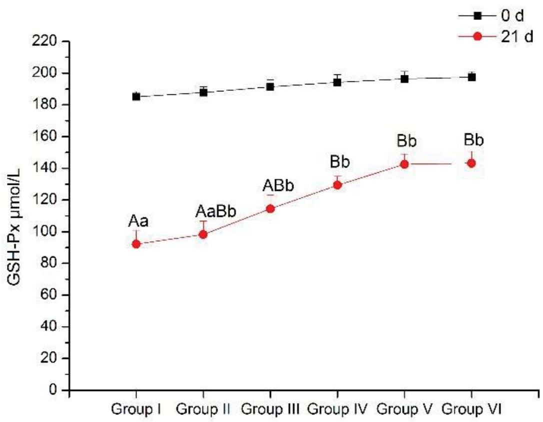
Values are means ± SE, n=6. Means within a row without common lower-case letters differ (P<0.05).

3.2. Serum biochemical indices of lactating sows

The results indicated that the antioxidative status of sows in lactation showed obvious changes and differences between the diets (Figure 3). The concentrations of SOD (P<0.05) and GSHPx (P<0.01) in serum on day 21 of lactation were increased to a greater or lesser extent compared with the control. A decline (P<0.05) of 28.52% and 27.76% in serum MAD level was observed in Groups V and VI on day 21 of lactation, respectively, relative to the control.

The effects of dietary γ-aminobutyric acid on the levels of ALT, AST, CK and LDH in serum on day 21 of lactation are presented in Table 4. The contents of ALT, AST, CK and LDH were significantly decreased (P<0.05) to a great or lesser extent with increasing level of dietary γ-aminobutyric acid. The content of ALT in serum declined (P<0.05) from 34.86 IU/l (Group I, control) to 28.56 IU/l (Group III), 27.56IU/l (Group V) and 27.34IU/l (Group VI). The serum AST concentration showed a similar tendency with a





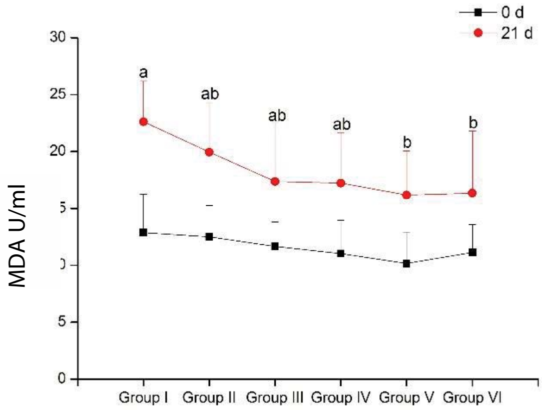


Figure 3. Effects of dietary supplementation of different levels of GABA on serum MDA level of lactating sows. Means within same day of lactation without common lower- (P<0.05) or upper- (P<0.01) case letters differ.

Table 4. Effects of γ-aminobutyric acid on the biochemical indexes in serum of lactating sows on day 21 of lactation.

item	Group I	Group II	Group III	Group IV	GroupV	Group VI
ALT IU/L	34.86 ± 3.48a	32.52 ± 4.72ab	28.79 ± 3.64b	28.56 ± 4.21b	27.84 ± 3.37b	27.34 ± 4.69b
AST IU/L	30.57 ± 4.71a	28.71 ± 7.32a	27.14 ± 5.26a	27.05 ± 4.79a	24.78 ± 4.87b	24.43 ± 5.98b
CK IU/L	1637.71 ± 328.65Aa	1433.42 ± 255.03AaBb	1241.34 ± 337.99ABb	1213.57 ± 294.37ABb	1025.78 ± 327.55Bb	1104.48 ± 297.51Bb
LDH IU/L	374.42 ± 83.50Aac	347.85 ± 73.19Aac	296.29 ± 60.93AaBbc	254.28 ± 62.29Bb	248.57 ± 107.22Bb	262.71 ± 79.03Bb

Note: Values are means ± SE, n=6. Means within a row without common lower- (P<0.05) or upper- (P<0.01) case letters differ

significant decline of 18.94% (Group IV) and 20.09% (Group V) compared with the control (P<0.05).

Similar to ALT and AST, the content of CK in serum was significantly lower in Group IV (1213.57 IU/l, P < 0.05), Group V (1025.78 IU/l, P<0.01) and Group VI (1104.48 IU/l, P<0.01) than in the Group I (1637.71IU/l, control). The serum concentration of LDH measured on day 21 of lactation decreased significantly and an obvious decline of 10.91%, 11.53% and 7.59% in Groups IV, V and VI, respectively, was observed compared with the control (P<0.01).

4. Discussions

The high temperature has significant negative influences on reproductive performance of lactating sows which often leads to huge economic losses [1]. Sows are sensitive to hot weather because it can cause heavy metabolic burden, which often leads to feed intake reduction, body reserve loss, abnormal antioxidative status, or changes of some biochemical indexes related to the stress of sows [5]. Previous studies showed that feed intake of lactating sows were declined by 25% when the ambient temperature rose to 30℃ [7]. In the Spencer's study hot temperature reduced the feed intake of sows by approximately 38% [25] Sows lactating for 19 days consumed more feed per day than those weaned at day 14, and sows lactating for 19 days in the hot environment lost more BW compared with the sows in the normal environment during lactation [25]. Maximizing feed intake of lactating sows is the main nutritional strategy to promote the production performance, such as increase of milk production, litter weight gain, and sow body reserve [26].

In the present study, average daily feed intake of lactating sows fed diets containing γ-aminobutyric acid increased. High feed intake during lactating of sows resulted in the better weight gain and high survival rate as well as the reduction of the risk in delaying weaning [26]. γ-Aminobutyric acid can improve not only weight gain and feed intake, but also promote the recovery of nutrient for livestock [27]. Supplementation of γ-aminobutyric acid improved the performance including average daily gain, feed intake and feed conversion rate of growing pigs when they were fed the basal diet added with 100mg/kg γ-aminobutyric acid [28]. Previous results indicated that γ-aminobutyric acid reduced serum leptin level and promoted feed intake through activating neuropeptide Y neurons [29]. Li et al. (2015) [30] showed that plasma growth hormone and neuropeptide Y concentration were significantly increased in weaned pigs by the γ-aminobutyric acid supplementation.

The milk output during the lactation is one important index to measure the livestock reproductive performance. The results from the present study demonstrated that γ-aminobutyric acid had beneficial effects on milk yield. However, γ-aminobutyric acid had no obvious influences on the nutrient composition of milk except some change of lactose in this trial. Similarly, [31] reported that dry matter intake and milk production increased in cows fed diets containing γ-aminobutyric acid, but contents of milk protein and fat did not differ across the treatments. No significant changes of the survival rate and diarrhea of piglets as well as back fat loss and weaning to estrus interval of lactating sows were observed, which indicated that the huge body reserve loss of sows in γ-aminobutyric acid groups didn't happen in lactation. Some studies showed that litter weight gain was not affected by feed intake since sows that are more feed restricted mobilized more body reserves to compensate for the lower feed intake [32]. Improvement of sow feed intake and milk yield by γ-aminobutyric acid may demonstrate partly its anti-heat stress effect.

Previous result showed that longer feed consumption time and lower biting incidences were observed in weaned pigs fed γ-aminobutyric acid [30] which postulated that dietary addition of γ-aminobutyric acid might, via the central nerve system, shorten the time spent in moving, prolong the sow sleeping time, and hence reduce metabolic burden. Animal metabolism undergoes dramatic changes as influenced by environmental temperature. The increased metabolic burden caused by hot weather on sows during lactation causes the elevated systemic oxidative stress and decreases availability of antioxidants such as SOD, GSH-Px and metallothionein. It may be necessary to increase the antioxidant contents in the diet during the lactation period in order to compensate for the substantial loss of these compounds. Antioxidant enzymatic activities are also related to tissue injury [33,34]. It is generally believed that heat stress impacts the SOD, GSH-Px, and MDA. MDA, a very toxic compound, is one of the most frequently used indicators of lipid peroxidation. SOD and GSH concentration is also used as a parameter to show antioxidative status. The production of free radicals and glutathione increased rapidly when animals suffer from stress [35]. It has been showed that pregnancy and lactation were an oxidative stress status, which is characterized by the production of reactive oxygen species including superoxide and hydrogen peroxide [36] Some previous studies indicated that oxidative stress and a disrupted antioxidant system were related to the pregnancy complications such as fetal growth restriction, preeclampsia and miscarriage [37] There existed an increased systemic oxidative stress during late gestation and lactation, which are not fully recovered until the weaning [38], which suggested that the oxidative stress had an influence on the pathophysiology of infertility [39]. Therefore, it may be necessary to increase the activities of GSH-Px and SOD while decrease the level of MDA in the serum during the gestation and lactation period in order to compensate for the substantial loss of these nutrients.

The GSH-Px and SOD plays an important role in antioxidant defense mechanism in animals. An increase of MDA content is considered to be an indicator of oxidative stress [40]. It was reported that serum SOD and GSH-Px concentration increased linearly whereas MDA was reduced for variables related to antioxidative status [31]. In our study, the decreased MDA and increased GSH-Px and SOD indicated an enhanced antioxidative status in the sows fed γ-aminobutyric acid. From the result of the present study, when γ-aminobutyric acid dose was increased to 300 mg/kg, 400 mg/kg, and 500 mg/kg, the magnitude of increase in serum GSH-Px and SOD decreased gradually. It was found that dietary supplementation of γ-aminobutyric acid was of great benefits to improve ability of oxidation resistance of the lactating sows in the present research.

The changes of biochemical indexes in the blood are the important indicators of animal metabolism during the period of heat stress. In general, ALT and AST are sensitive indexes mainly indicating the liver damage, while CK, mainly existing in cardiac and skeletal muscle, can be released into the circulation due to the increase of cytomembrane permeability in response to long-term muscle malnutrition, such as inadequate nutrient intake under chronic heat stress. LDH catalyzes the reversible conversion of pyruvate to lactate accompanied by the interconversion of NADH and NAD+. Lactate elevation in blood is commonly observed in heat-stressed animals [41].The increased reliance on lactate for energy in tissues with the capacity of oxidizing lactate has been proposed as a glucose-sparing mechanism by which obligate glucose users can be provided with adequate glucose under heat stress [41]. Enzymes AST, ALT, CK and LDH responded sensitively to supplementation of γ-aminobutyric acid under the heat stress in the present study. In our study, these enzyme activities decreased gradually with increasing addition of γ-aminobutyric acid and leveled off when the γ-aminobutyric acid supplementation level reached 400 mg/kg and 500 mg/kg.

5. Conclusion

The γ-aminobutyric acid had a significant and direct effect on the sow reproductive performance including average daily feed intake, milk output and litter weight gain of piglets during the whole lactation period. Feed intake regulation might be a very important mechanism. Moreover, γ-aminobutyric acid played a role in regulating the antioxidant system and anti-stress capacity of sows by influencing activities of some antioxidant enzymes and stress sensitive enzymes, thus enhancing the ability of sows to resisting heat stress. The optimal supplementation level of γ-aminobutyric acid is 300 mg/kg diet based on the dose-effect relationship between γ-aminobutyric acid and reproductive performance, antioxidative status and biochemical indices for lactating sows. It is concluded that γ-aminobutyric acid had a positive effect on the reproductive performance and health status of sows during lactation in thermal environment.

Conflict of interest statements

The authors declare that they do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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