Heat-stress-induced damage to porcine small intestinal epithelium associated with downregulation of epithelial growth factor signaling

F. Liu,*† J. Yin,‡ M. Du,§ P. Yan,*‡ J. Xu,#‖ X. Zhu,# and J. Yu†

*College of Animal Science and Technology, Nanjing Agricultural University, Nanjing 210095, P. R. China; †Department of Animal Science and Technology, Beijing University of Agriculture, Beijing 102206, P. R. China; ‡College of Animal Science and Technology, China Agricultural University, Beijing 100193, P. R. China; §Department of Animal Science, University of Wyoming, Laramie 82071; #College of Veterinary Medicine, China Agricultural University, Beijing 100193, P. R. China; and ‖Key Laboratory of Development and Evaluation of the Chemical and Herbal Drugs for Animal Use, Ministry of Agriculture, Beijing 100193, P. R. China

ABSTRACT: Extreme heat during certain days of the summer renders pigs susceptible to severe heat stress, which negatively affects their growth performance. We hypothesized that such heat stress impaired the small intestinal mucosa, a site responsible for nutrient absorption. To simulate heat stress, Chinese experimental mini-pigs were treated with 5 h of continual 40°C temperature each day for 10 d in succession. Pigs were killed at 1, 3, 6 and 10 d after treatment, and small intestinal epithelia were sampled for histochemical examination and biochemical analyses. The duodenum and jejunum were seriously damaged within 3 d of initiation of treatment. Subsequent study of the process of jejunum recovery showed that the initiation of recovery started within 6 d following heat stress. Such damage was associated with the downregulation of epithelial growth factor signaling. In conclusion, heat stress induced short-term damage to the epithelium of porcine intestine. Because the intestinal epithelium is crucial for nutrient uptake, such damage should partially account for the impairment of growth performance of pigs under heat stress.

Key words: epithelial growth factor, gene expression, heat stress, intestinal mucosa, swine

INTRODUCTION

Heat stress is an important factor influencing domestic animal production during summer months (Collin et al., 2001; Khajavi et al., 2003; Spencer et al., 2005). The integrity of the small intestinal epithelium ensures its normal physiological function (Malago et al., 2002; Leon et al., 2005). Damage to the mucosal epithelium can directly affect its barrier function and the absorption of nutrients, impairing production performance of pigs (Boudry et al., 2004; Lallès et al., 2007). Existing mucosal epithelium are constantly and rapidly replaced by new cells, which is crucial for maintaining the normal functions of intestine (Deitch, 1993; Thomson et al., 2001). Such regeneration requires a huge amount of energy and is sensitive to stresses, which induce cellular necrosis and desquamation, especially at the tip of intestinal villi (Lambert et al., 2002). Enterocytes are also important target cells of various pathological factors (Boros et al., 1995; Soondrum and Hinds, 2006). Hence, their repair and regeneration needs to be more rapid than other cells.

Previous reports indicated that epithelial growth factor (EGF) and the EGF receptor (EGFR) were related to the damage and recovery of the small intestinal mucosa (Helmrath et al., 1998; Nair et al., 2008). This process has been frequently studied in rodents following a single injury or in vitro cultures of intestinal epithelium (Blikslager et al., 1997; Gookin et al., 2002). The damage to intestinal epithelium caused by high-temperature stress and the mechanisms of its regen-
eration have rarely been studied. In the present study, Chinese experimental mini-pigs were placed in an artificial climate chamber for 10 d, simulating the heat surge during summer in Beijing, to measure and assess the damage and the subsequent recovery of small intestinal mucosa caused by heat stress.

**MATERIALS AND METHODS**

The experimental protocol was approved by the Committee for Experimental Animals Care and Use at Beijing University of Agriculture.

**Animals**

Forty-eight male 2-mo-old Chinese mini experimental pigs (BW 7.10 ± 0.52 kg) were bought from Changping Experimental Pig Farm of China Agricultural University and randomly assigned to a control group and a heat treatment group (24 pigs per treatment) by balancing their BW and litter origin. All pigs were housed individually in 1.0 × 0.5 m² pens raised 30 cm above the floor. The floor of the pen was made of plastic and was fully slatted. Twelve cages were housed in one artificial climate chamber for 10 d, simulating the heat surge.

**Treatment**

The experiment was performed in 2 phases. In the first phase, pigs from both the control group and the heat treatment group were housed for 5 d at 23°C. In the second phase, the temperature for the heat treatment group was increased back to 26°C at a constant speed for about 15 min. The rectal temperature was measured at 0800 h. The pigs were electrically stunned using a head-only electric stun tong apparatus (Xingye Butchery Machinery Co. Ltd., Changde, Hunan Province, China) and subsequently exsanguinated. The proximate 2 cm of the intestinal samples, including the duodenum beginning 5 cm distal to the pyloric junction, the jejunum (the middle part of the whole jejunum), and the ileum (5 cm proximal to the ileocecal junction) were rapidly collected and washed with physiological saline. Each sample was cut into 3 pieces: 1) a 1-cm length section was fixed in 10% neutral formalin for paraffin embedding; 2) a 1-mm² sample of jejunum was fixed in 4% glutaraldehyde for electron microscopic examination; and 3) the rest (3-cm length section) was minced and placed into 3 sample tubes, snap frozen in liquid N, and stored at −80°C.

**Exp. 1. Morphological Study**

Paraffin sections (5 µm thick) were prepared from the formalin-fixed samples of duodenum, jejunum, and ileum, and were stained with hematoxylin and cosin (Driscoll and Ryan, 1978). The mucosal structure was observed by BH2 Olympus microscope (Olympus, Tokyo, Japan) and analyzed using an Image Analysis System (Olympus 6.0). Using 40× magnification, villus height and crypt depth of at least 5 well-oriented villi were measured. Further, the intestinal epithelial cell was examined by electron microscopy. Small pieces of intestine were fixed for 1 h at 4% glutaraldehyde in 0.1 M cacodylate buffer (pH 7.4). Preparations were washed in the same buffer and postfixed for 1 h in cold 1% osmium tetroxide in cacodylate buffer. After dehydration in graded ethanol solutions, the preparations were embedded in Araldite (EPON 812, Emicon, Shanghai, China). Ultra-thin sections were stained with saturated uranyl acetate in 50% ethanol and lead citrate, and examined by transmission electron microscopy (JEM, 1230, JEOL Company, Tokyo, Japan).

**Exp. 2. Damage and Repair of Jejunum**

**DNA Content of Jejunal Mucosa.** Total DNA was isolated from the jejunal mucosa of pigs using phenol-chloroform-isoamyl alcohol extraction (Cler et al., 2006). The concentration of total DNA was calculated based on absorbance at 260 nm using a ND-1000 spectrophotometer (Nano-Drop Technologies, Rockland, DE).

**Protein and Messenger RNA Expression of EGF and EGFR.** The protein expression level of EGF and EGFR was determined by microplate reader (Bio-Rad Laboratories, Hercules, CA) using a commercially available porcine ELISA Kit (Rapidbio Systems, Columbia, CA) according to the manufacturer’s
instructions. The whole protein was isolated from 100 mg of jejunal epithelium using Keygene Whole Protein Extraction Kit (Keygen, Nanjing, China) according to the manufacturer’s specifications. Contents of EGF and EGFR were expressed as picograms per milligram of total protein.

**Total RNA Isolation and Reverse Transcription.** Total RNA was isolated from the jejunum using phenol and guanidine isothiocyanate based Trizol reagent (Invitrogen, Carlsbad, CA) according to the manufacturer’s instructions. The RNA integrity was verified electrophoretically with 1.2% agarose gel containing formaldehyde stained with 1 µg/mL of ethidium bromide. The RNA purity was determined by OD260/OD280 ratio using a ND-1000 spectrophotometer. The RNA integrit was verified electrophoretically with 1.2% agarose gel containing formaldehyde stained with 1 µg/mL of ethidium bromide. The RNA purity was determined by OD260/OD280 ratio using a ND-1000 spectrophotometer.

### Table 1. The primer sequences for real-time quantitative PCR of gene target

<table>
<thead>
<tr>
<th>Gene target</th>
<th>Primer sequence</th>
<th>Product, bp</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGF</td>
<td>Forward: 5′-CAGTAACCTGGGAATGTGGC-3′</td>
<td>231</td>
</tr>
<tr>
<td></td>
<td>Reverse: 5′-GGGCTGTATGGGCAAATGAT-3′</td>
<td></td>
</tr>
<tr>
<td>EGFR</td>
<td>Forward: 5′-GCCCTAGCGTCTTATCCAA-3′</td>
<td>299</td>
</tr>
<tr>
<td></td>
<td>Reverse: 5′-TGGGCACAGATGACTTTGAT-3′</td>
<td></td>
</tr>
<tr>
<td>β-Actin</td>
<td>Forward: 5′-AGAAGCATTGCGGTGGAC-3′</td>
<td>218</td>
</tr>
</tbody>
</table>

1EGF = epithelial growth factor; EGFR = EGF receptor.

**Results**

**Statistical Analysis**

Statistical analysis was performed by independent-samples t-test using SPSS 12.0 (SPSS Inc., Chicago, IL). The individual pig was the experimental unit for the analysis of all the data. Differences were considered significant at P < 0.05.

**RESULTS**

Body temperatures in control pigs averaged 39.0 ± 0.33°C and were elevated to 40.22 ± 0.25°C (P = 0.001, n = 6) in the heat treatment group. Average daily feed intake changed from 675 ± 29.6 g to 542.5 ± 31.4 g (P = 0.001, n = 6) in the heat treatment group at d 3. During the entire experimental period, the body temperature in control pigs averaged 38.9 ± 0.05°C and was elevated to 39.86 ± 0.30°C (P = 0.01, n = 4) in the heat treatment group; ADFI changed from 678.4 ± 26 g to 550.8 ± 22.64 g (P = 0.001, n = 4) with high-temperature treatment. These results confirmed that the heat-treatment model was successful.

**Exp. 1. Morphological Study**

**Morphological Alterations of Porcine Small Intestine.** The heat treatment resulted in morphological alterations of the porcine small intestine. Desquamation was found at the tips of the intestinal villus (Figure 1); the desquamation of mucosal epithelium extended to the lamina propria, and such damage was more serious for jejunum. The change in ileal villus height (Table 2), especially in the duodenum (P = 0.002) and jejunum (P = 0.001). The change in ileal villus height was more marked after the first 3 d than the other days (P = 0.01). Between d 6 and 10, no difference in villus height was observed.
Depth of Porcine Small Intestinal Crypts. The depth of small intestine crypts of duodenum and jejunum was shallower (Table 2) than controls after the first 3 d of continuous high-temperature treatment ($P = 0.002$; $P = 0.007$), especially in jejunum. The ileal crypt depth was not different from controls. On d 6 and 10 of high-temperature treatment, the depth of the intestinal crypt remained shallower than that of the control pigs.

Ratio of Villus Height to Crypt Depth. When the ratio of villus height to crypt depth was calculated, a slight increase was seen after high-temperature treatment (Table 2). The ratio for the duodenum was greater than controls after the first 3 d ($P = 0.004$), but was not different by d 6 ($P = 0.55$). The ratio for the jejunum was greater than control on d 1 ($P = 0.050$), and the ileum did not differ.

Ultrastructure Morphological Alterations of Porcine Jejunal Epithelium. Microvillus height of jejunal epithelium of heat-stressed pigs was shorter than controls, but no difference was observed on nucleolus structure (Figure 2, panel D, ×10,000). The jejunal epithelium showed increased numbers of the mitochondria with shortened internal cristae; the organelle debris within the lysosomes was clearly seen with different electron density; and the enterocyte tight junction was observed (Figure 2, panels C and F, ×50,000).

Exp. 2. Damage and Repair in Jejunum

DNA Content of Jejunal Intestinal Epithelium Following High-Temperature Treatment. The DNA content of jejunal intestinal epithelium decreased ($P = 0.012$, Figure 3) during the initial 3 d following high-temperature treatment. The DNA content partly recovered by d 6.

Protein Expression of EGF and EGFR in Jejunum. Following high-temperature treatment, the protein expression of EGF and EGFR was decreased ($P = 0.005$, Figure 4, panel A; $P = 0.001$, Figure 4, panel

Table 2. Effect of chronic heat stress on small intestinal morphometry of pigs

<table>
<thead>
<tr>
<th>Intestinal section</th>
<th>Day</th>
<th>Control</th>
<th>Heat treatment</th>
<th>Control</th>
<th>Heat treatment</th>
<th>Control</th>
<th>Heat treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duodenum</td>
<td>1</td>
<td>317.0 ± 11.9</td>
<td>278.3 ± 19.9**</td>
<td>208.8 ± 6.2</td>
<td>183.0 ± 26.7</td>
<td>1.5 ± 0.1</td>
<td>1.6 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>320.3 ± 16.7</td>
<td>282.3 ± 14.9**</td>
<td>212.0 ± 26.3</td>
<td>162.8 ± 17.5**</td>
<td>1.5 ± 0.1</td>
<td>1.7 ± 0.1**</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>318.7 ± 8.8</td>
<td>298.0 ± 7.7*</td>
<td>206.2 ± 16.7</td>
<td>183.2 ± 15.6</td>
<td>1.6 ± 0.1</td>
<td>1.5 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>315.0 ± 11.1</td>
<td>306.5 ± 15.8</td>
<td>209.7 ± 18.2</td>
<td>196.8 ± 17.6</td>
<td>1.5 ± 0.1</td>
<td>1.6 ± 0.1</td>
</tr>
<tr>
<td>Jejunum</td>
<td>1</td>
<td>332.0 ± 13.4</td>
<td>262.7 ± 16.5**</td>
<td>206.8 ± 11.0</td>
<td>170.8 ± 11.4**</td>
<td>1.6 ± 0.0</td>
<td>1.5 ± 0.1*</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>335.0 ± 12.4</td>
<td>271.8 ± 11.0***</td>
<td>208.2 ± 19.6</td>
<td>161.7 ± 23.7**</td>
<td>1.6 ± 0.0</td>
<td>1.7 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>329.0 ± 14.1</td>
<td>296.3 ± 14.30**</td>
<td>210.7 ± 19.1</td>
<td>183.0 ± 16.0</td>
<td>1.6 ± 0.1</td>
<td>1.7 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>333.1 ± 26.2</td>
<td>316.3 ± 18.8</td>
<td>212.5 ± 15.9</td>
<td>192.3 ± 19.3</td>
<td>1.6 ± 0.0</td>
<td>1.6 ± 0.1</td>
</tr>
<tr>
<td>Ileum</td>
<td>1</td>
<td>302.8 ± 20.9</td>
<td>269.0 ± 22.8*</td>
<td>198.3 ± 16.6</td>
<td>172.2 ± 21.1</td>
<td>1.5 ± 0.1</td>
<td>1.6 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>305.3 ± 14.3</td>
<td>275.7 ± 15.8**</td>
<td>194.7 ± 12.3</td>
<td>175.7 ± 16.9</td>
<td>1.5 ± 0.0</td>
<td>1.6 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>304.7 ± 14.2</td>
<td>291.2 ± 18.9</td>
<td>202.3 ± 25.5</td>
<td>183.8 ± 23.1</td>
<td>1.5 ± 0.1</td>
<td>1.5 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>307.0 ± 23.4</td>
<td>293.0 ± 16.2</td>
<td>198.0 ± 22.2</td>
<td>192.0 ± 21.4</td>
<td>1.5 ± 0.1</td>
<td>1.5 ± 0.1</td>
</tr>
</tbody>
</table>

1Different from controls: *$P < 0.05$, **$P < 0.01$, and ***$P < 0.001$. Values are means ± SE, n = 6.
B) on d 1 compared with control pigs. No difference was seen on d 6 (Figure 4).

**The mRNA Expression of EGF and EGFR.** The trend of mRNA expression is consistent with protein expression. A decreased value was observed on d 1 in heat-stressed pigs compared with control pigs ($P = 0.005$), but was not different by d 6 (Figure 5).

**DISCUSSION**

The Lesions of the Intestinal Villus Epithelium

Heat stress is an important stressor of pigs (Nyachoti et al., 2004; Patience et al., 2005; Song et al., 2009).

**Figure 2.** Ultrastructure morphological alterations of porcine jejunal epithelium with high-temperature treatment on the third day. Panels A, B, C: jejunum control; panels D, E, F: jejunum heat treatment. The arrow in section (panel A, ×10,000) indicates the normal microvillus height; the arrow in the section (panel D, ×10,000) on the left indicates the microvillus height of the heat treatment group; it is shorter than the control group; and the arrow in the central section (panel D, ×10,000) indicates an increase in the numbers of mitochondria and secondary lysosomes; the arrow of section (panel B, ×50,000) indicates mitochondria of the control group. The arrow on the right (panel E, ×50,000) indicates the internal cristae of mitochondria became swollen and shorter in the heat treatment (panel E, ×50,000). The arrow in the center pointing toward the dark ball (panel E, ×50,000) indicates the difference in electron density of the organelle debris within the lysosome (panel E, ×50,000). The arrow in section C indicates the tight junction of epithelium (panel C, ×50,000). The arrow in section F indicates that there was no change in the tight junction between the unexfoliated epithelium (panel F, ×50,000).
The normal body temperature of pigs ranges between 38.0 to 39.5°C, and porcine sweat glands are poorly developed (Straw et al., 2008). Under high temperature, systemic blood flow is redistributed to support the heart, brain, and other vital organs, as well as to dissipate heat via the peripheral circulation. Gastrointestinal ischemia inevitably affects the microcirculation, damaging sensitive epithelium of the intestinal villus (Hinnebusch et al., 2002).

Similar to the results of Leon et al. (2005), body temperatures were elevated in the present study; ADFI also changed during the initial 3 d of high-temperature treatment in this experiment. At the same time, the morphological trauma in small intestine resulting from heat treatment with 40°C for 10 d (5 h/d) included epithelium shedding at the tips of the intestinal villi; the intestinal mucosa lamina propria were exposed, and such damage was more serious in the jejunum. At the same time, the villus height was shorter and depth of crypt was shallower for duodenum and jejunum at 3 d and recovered over 6 d compared with the control group.

One of the characteristics of the intestinal villus epithelium is a short proliferation cycle and rapid growth (Sigdestad and Lesher, 1970; Cheng and Leblond, 1974). The regenerative cycle is about 48 h, and the intestinal villus epithelium has a good self-repair capacity (Morini et al., 2000; Wang et al., 2002). The small intestinal villus has a profuse blood capillary network, which enables the countercurrent exchange of nutrient substances between the ascending and descending blood vessels in the intestinal villus, maintaining high absorptive functions (Yao, 2001). The microcirculation of small intestinal villus is like a hairpin, with the tip located at the top of the villus with reduced blood supply. In addition, the capillaries branch at a right angle from the mother branches, easily resulting in the disjunction of the red blood cells; the jejunal villus is morphologically like slender lobes, which are susceptible to form epithelium lesions following a decrease in blood oxygen supply (Guo and Su, 2005).

Previous studies have shown that under the severe heat stress, such as trauma or shock, the systemic blood flow was redistributed (Secchi et al., 2000; Ooue et al., 2007; Leon, 2008). To dissipate heat, the primary physiological autonomic responses increase blood flow to the body surface (Abraham et al., 1994; Horowitz, 2003), which resulted in the earliest gastrointestinal ischemia and hypoxia (Hinnebusch et al., 2002). Furthermore, heat stress often causes the changes of inflammatory factor, hypoxia and ischemia, heat-shock proteins, ion balance and channel, and permeability. Therefore, these

---

**Figure 3.** The DNA content of porcine jejunal mucosa with high-temperature treatment. Values are means ± SE, n = 6. *P < 0.05 (the high-temperature treatment vs. the control). The DNA content of jejunal mucosal tissues decreased during the initial 3 d (*P < 0.05) with high-temperature treatment and recovered partly by d 6.

**Figure 4.** Protein expression of epithelial growth factor (EGF) and EGF receptor (EGFR) of porcine jejunum with high-temperature treatment. Values are means ± SE, n = 6. *P < 0.05 (the high-temperature treatment vs. the control). Panel A: protein expression of EGF of jejunum (pg/mL); panel B: protein expression of EGFR of jejunum (pg/mL). Horizontal axis is present as a protein content of EGF or EGFR. Protein expression of EGF and EGFR in the jejunum was decreased on d 1 compared, respectively, with their controls (*P < 0.05). No differences were seen on d 6.
damages and changes occurred the earliest and recovered the latest (Gaffin and Hubbard, 1996; Malago et al., 2002; Leon, 2008).

Indeed, in this study, we observed that heat stress induced damage to the epithelium. We speculated that such damage is similar to the lesions due to ischemic reperfusion caused by burns, surgery, or inflammatory factors (Thomson et al., 2001; Malago et al., 2002). In summary, these data clearly showed that the small intestinal villus of pigs reacted to heat stress and also proved that the gastrointestinal tract was first affected when organ dysfunction happened under the stress (Tateishi et al., 1997; Tong, 2007).

The ultrastructure of the jejunal epithelium showed increased numbers of mitochondria with shortened internal raphé; the organelle debris within the lysosomes was clearly seen with different electron density. Lysosomes are involved in intracellular digestive functions closely associated with autocyto lysis and cytophylaxis. Mitochondria are cell metabolism organs; lysosomes involve in intracellular digestive functions closely associated with autocytyolysis and cytophylaxis. We speculate that the increase in numbers of mitochondria and secondary lysosomes was related to lesions caused by the high-temperature treatment.

Unlike previous studies, the intestinal mucosal morphological injuries in pigs caused by repeated heat stress were more serious and lasted much longer than that by a single stress (Wagner et al., 1979; Varedi et al., 2001). It can be speculated that the accumulated injuries need a longer period to recover.

With the gradual increase in average temperatures, the loss caused by heat stress to animal production has become greater in the north of China (Zhang et al., 2010).

Figure 5. The messenger RNA (mRNA) expression of epithelial growth factor (EGF) and EGF receptor (EGFR) of porcine jejunum with high-temperature treatment. Values are means ± SE, n = 6. *P < 0.05 (the high-temperature treatment vs. the control). The unit of vertical axis is a target gene threshold cycle (Ct) corrected for β-actin. Panel A: relative quantity chart of EGF on d 1; panel B: relative quantity chart of EGFR on d 1; panel C: relative quantity chart of EGF [fluorescence values (dRn)] on d 6; panel D: relative quantity chart of EGFR on d 6. The mRNA expression of EGF and EGFR in the jejunum were decreased on d 1, respectively, compared with their controls (*P < 0.05). No differences were seen on d 6.
2006). Animal performance, feed intake, and feed conversion rates decrease under high temperature (Nienaber et al., 1996; Patience et al., 2005; Garriga et al., 2006). In the present study, morphological change observed in the small intestine illustrated one possible mechanism for the loss of animal production induced by heat stress in summer. Because of the characteristics of the jejunum in histological structure and the important role in digestive and absorptive functions, we chose the jejunum as the object of further research to investigate the repair of intestinal epithelium.

Repair of Jejunal Mucosa

Generally, cellular DNA, RNA, and heat shock protein concentrations are correlated with cell proliferation (Fu and Wang, 1989; Yeo et al., 2007). Both EGF and EGFR are widely distributed on the surface of the intestinal mucosa and are crucial for stimulating enterocyte proliferation and regeneration of mucusal epithelium (Ryan et al., 1997; Engler et al., 1999; Thomson et al., 2001). Under high ambient temperature treatment of 40°C for 10 d (5 h per day), cellular DNA concentration, level of protein, and mRNA expression of EGF and EGFR were decreased initially.

Many researchers consider that EGF may have no effect on the normal intestinal mucosal epithelium, but it can promote cell proliferation, repair, and migration during regeneration following damage (Helmrath et al., 1998; Nair et al., 2008). The signal transmission mediated by EGFR is characterized by pleiotropy including cell proliferation, repair and migration, and internal environment stabilization (Helmrath et al., 1998). Previous studies showed that EGF/EGFR promotes cell proliferation through inducing the expression of the fos and jun genes. The expression products of fos and jun combine to form heterodimers, called activator protein-1. Binding of activator protein-1 to its receptor in the control region affects multiple gene expression. Therefore, the content of DNA in intestinal mucosa and the expression of EGF/EGFR and their mRNA should be correlated with the damage and recovery of the small intestinal mucosa.

Damage and structural abnormality of epithelium of intestinal villus definitely affects nutrient digestion and absorption, and feed conversion. Over 6 d of repair time of the small intestine morphological structure was very important for the animals to adapt to high temperature and recover performance. Injury mechanism of intestinal epithelium under high temperature needs to be studied further to reduce heat stress on the injury of the small intestine villi and promote the repair of such injury, which has the great guiding significance in actively adopting countermeasures to alleviate heat stress.

In summary, we studied the process of damage and the subsequent recovery of the small intestinal mucosa after heat stress. The duodenum and jejenum were seriously damaged. These findings indicated that the worst damage occurred within 3 d and gradually repaired over the subsequent 6 d. Such damage was associated with downregulation of EGF signaling.

LITERATURE CITED


