Macleaya cordata Extract Decreased Diarrhea Score and Enhanced Intestinal Barrier Function in Growing Piglets

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Macleaya cordata extract is of great scientific and practical interest to researchers, due to its antimicrobial and anti-inflammatory responses within experimental animals. This study was designed to determine the diarrhea score and innate immunity of growing piglets after they had received Macleaya cordata extract supplements. A total of 240 growing pigs were randomly assigned to one of three dietary treatments, with 8 replicates per treatment and 10 piglets per replicate. All pigs received a basal diet containing similar amounts of nutrients. The three treatments were a control (no additive), an antibiotic (200 mg/kg colistin), and the Macleaya cordata extract supplement group (40 mg/kg Macleaya cordata extract). The diarrhea score was calculated after D 28. The jejunal samples were obtained from five piglets selected randomly from each treatment on D 28. In comparison with the control group, the dietary Macleaya cordata extract and colistin group demonstrated a substantially decreased diarrhea score. The introduction of Macleaya cordata extract supplements to the diet significantly increased volumes of ZO-1 and claudin-1, particularly in comparison with the pigs in the control group (P < 0.05). The findings indicate that Macleaya cordata extract does enhance intestinal barrier function in growing piglets and that it could be used as a viable substitute for antibiotics.

1. Introduction

In recent years, there has been an increased focus on reducing or eliminating the use subtherapeutic antibiotics within livestock diets. For this reason, there has been a concerted effort to identify alternative effective therapies that could serve as a substitute for antibiotics in pig diets. The aim is to maintain acceptable performance levels and ensure food safety for consumers [1]. The medicinal plant extracts used as an alternative for antibiotics in swine diets are effective when it comes to increasing BW, intestinal health, nutrient digestibility, and antioxidative potential, and immunity. They also decrease the incidence and vulnerability to diarrhea [1, 2].

Macleaya cordata extract is believed to be an effective natural appetiser in swine, bovine, poultry, and even fish...
nutrition [3]. *Macleaya cordata* extract is blended from intact aerial parts and a fraction of quaternary benzo[c]phenanthidine alkaloids (QBAs), primarily sanguinarine (SG) and chelerythrine (CH), and standardised to 1.5% w/w SG [4].

Sanguinarine (SA), a quaternary benzo[c]phenanthidine alkaloid, is synthesised from dihydrosanguinarine, via the activities of dihydrobenzophenanthidine oxidase [5]. It has been shown to have beneficial effects. It is antimicrobial [6,7], antifungal, adrenolytic, sympatholytic, immunomodulatory [5], and anti-inflammatory [8,9].

Chelerythrine can be found within the greater celandine plant and a number of additional poppy *Fumaria* varieties. It is a quaternary benzo[c]phenanthidine alkaloid. According to studies, it mostly exhibits tumour resistant, microbe resistant, and inflammation resistant qualities. Plus, the substance is a powerful disruptor when it comes to PKC (or protein kinase C). As such, the prospective utilisation of CHE, as a form of inflammation resistance, has been the topic of much debate. Its qualities are linked to its capacity to engage with DNA and proteins [10]. This is an enzyme that plays an important part in the control of signal transduction, cell propagation, and cell variation [11].

For this study, we hypothesised that dietary supplementation with *Macleaya cordata* extracts might stimulate the immune system and, as a consequence, decrease the incidence of diarrhea in growing piglets. Thus, the objective of the study was to evaluate the impact of *Macleaya cordata* extract, as a dietary supplement, on diarrhea scores and the expression of tight junction proteins.

### 2. Materials and Methods

#### 2.1. Experimental Design, Animals, and Housing

All of the procedures used in this study have been approved by the Institute of Subtropical Agriculture, the Chinese Academy of Sciences Animal Care and Use Committees. A total of 240 (Yorkshire × Landrace) × Duroc (56 d old; BW 15.82 ± 1.13 kg) pigs were obtained from a commercial swine herd in Guangdong, China. 240 piglets were assigned, in completely random design (but based on their BW), to 24 pens. The pens each contained a total of ten piglets. The process was carried out according to the experimental animal allotment program created by Kim et al. [12]. All pens were equipped with a feeder, a nipple-type drinker (with modification; more details later), and plastic-covered expanding metal floors. The room temperature was set at 28.0°C and slowly increased by 0.5°C/wk.

All piglets were fed the same basal diet, with a similar amount of nutrients (Table 1). This diet was formulated to meet or exceed the NRC (2012) nutrient specifications for pigs weighing 10 to 30 kg. In total, there were 3 experimental treatments and study groups: the negative control (NC; no in-feed or in-water additive), the antibiotic group (AB; in feed, 0.2 g/kg colistin), and the *Macleaya cordata* extract group (MC; in-feed, 40 mg/kg *Macleaya cordata* extract). The *Macleaya cordata* extract was kindly provided by Phytobiotics Futterzusatzstoffe GmbH, Eltville, in Germany and Micolta Bioresource Inc., in Changsha, China. The pigs had unlimited access to feed and water throughout the entirety of the study.

#### 2.2. Sample Collection and Analytical Procedure

On days 7, 21, and 28 of treatment, 10 mL of blood was collected in plastic uncoated tubes between 8:00 and 10:00 a.m. After collection, these blood samples were centrifuged at 8000×g for 10 min at 4°C, with sera collected and frozen at −20°C until further analyses.

#### 2.3. Faecal Score and Sampling

To evaluate diarrhea incidence, faecal consistency scores (0, normal; 1, soft faeces; 2, mild diarrhea; and 3, severe diarrhea) were determined for each pen. These scores were collected by a trained individual, but who had no prior knowledge of the dietary treatments provided. The incidence of diarrhea was calculated by dividing the total number of pigs with diarrhea by the total number of all experimental pigs. The rate ratios were then calculated. On day 28 of the experiment, a number of the pigs (1 pig/pen) were killed. 1 sample of jejunal mucosa was collected in a sterile sample bag and stored at −20°C until analysis.

#### 2.4. Concentration of IgG, IgM, D-Lactate, DAO, and TNF-α

The serum volumes of IgM and IgG were calculated according to readings from the 125I Radio Immunoassay Analysing tool (Beijing North Institute of Biological Technology, Beijing, China). A γ-calculating instrument GC-300 (Zhongjia Co.,
The proportion of tumour necrosis factor-α (TNF-α) within serum was calculated via the use of a Porcine TNF-α Colorimetric ELISA tool (Nanjing Jiancheng Bioengineering Institute, Nanjing, Jiangsu, China). Recommendations from the maker were followed at all times. All changes to or within the serum diamine oxidase were calculated with assay equipment.

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Identification parameter for TNF-α (in accordance with SPSS 22.00 Statistical Software) was utilised to calculate dissimilarities across mean values.

3. Results

Figure 1 demonstrates that the diarrhea score for pigs in the MC group was lower than that of the NC group and the AB group. The score for the AB group was still lower than that of the NC group.

Table 2 demonstrates the impact of dietary supplementation with Macleaya cordata extract on the serum biochemical parameters and volume of antibodies in the growing pigs on days 7, 14, and 28 after the start of the study.

On day 7, the concentration of IgG was higher (\( P < 0.05 \)) in pigs from the MC group, when compared with the other 2 groups. The serum concentrations of D-lactate, DAO, IgM, and TNF-α did not exhibit any substantial or notable differences (\( P > 0.05 \)) across the treatments, on day 7 after the launch of the study.

On day 14, the serum concentration of D-lactate was the only parameter that showed a significant difference (\( P < 0.05 \)) across the treatments. There was a lower concentration in pigs from the AB group. The other serum parameters for the pigs remained the same (\( P > 0.05 \)), due to the impact of dietary supplementation with Macleaya cordata extract (Table 2). On day 28, the serum concentration of IgM decreased in the pigs from the MC group, in comparison with those from the AB group (\( P < 0.05 \)). The other parameters exhibited no notable changes (\( P < 0.05 \)), as a consequence of the experimental treatments.

Figure 2 demonstrates the protein expression levels of occludin, ZO-1, and claudin-1 within the jejunal mucosa. The occludin levels did not notably differ across any of the groups. The protein expression levels of ZO-1 within the jejunal mucosa increased substantially (\( P < 0.05 \)), in comparison with those in the NC and AB groups. Also, ZO-1 protein increased significantly (\( P < 0.05 \)), in comparison with that of the NC group. Thus, the dietary supplementation of Macleaya cordata extract and antibiotics substantially increased the expression of Claudin-1 (\( P < 0.05 \)), particularly when compared with that of the NC group.
Table 2: Effect of dietary supplementation with Macleaya cordata extract on D-lactate, IgG, IgM, and TNF-α in growing pigs.

| Parameter                              | No additive | Dietary supplementation | SEM± | P value |
|----------------------------------------|-------------|-------------------------|------|---------|
|                                        |             | Macleaya cordata extract |      |         |
|                                        |             | Colistin                |      |         |
| D 7 after initiation of treatment      |             |                         |      |         |
| D-Lactate, mg/L                        | 7.95        | 9.12                    | 7.06 | 1.197   | 0.477  |
| DAO, units/mL                          | 2.53        | 2.46                    | 2.42 | 0.216   | 0.536  |
| IgG, mg/mL                             | 138.41b     | 174.45a                 | 143.44b | 10.801 | <0.05  |
| IgM, mg/mL                             | 43.20       | 39.60                   | 38.40 | 6.635   | 0.869  |
| TNF-α, pg/mL                           | 62.34       | 58.98                   | 59.36 | 7.510   | 0.478  |
|                                        |             |                         |      |         |
| D 14 after initiation of treatment     |             |                         |      |         |
| D-Lactate, mg/L                        | 10.26a      | 8.21ab                  | 7.45b | 0.813   | <0.05  |
| DAO                                    | 2.42        | 2.39                    | 2.30 | 0.166   | 0.632  |
| IgG, mg/mL                             | 183.89      | 176.17                  | 184.58 | 20.04   | 0.947  |
| IgM, mg/mL                             | 50.00       | 49.40                   | 51.00 | 7.799   | 0.989  |
| TNF-α                                  | 64.13       | 59.42                   | 61.37 | 6.590   | 0.589  |
|                                        |             |                         |      |         |
| D 28 after initiation of treatment     |             |                         |      |         |
| D-Lactate, mg/L                        | 9.10        | 9.36                    | 7.60 | 1.169   | 0.535  |
| DAO                                    | 2.25        | 2.30                    | 2.18 | 0.157   | 0.453  |
| IgG, mg/mL                             | 196.38      | 219.60                  | 201.72 | 16.768  | 0.604  |
| IgM, mg/mL                             | 63.20ab     | 49.60b                  | 70.00a | 6.224   | <0.05  |
| TNF-α                                  | 60.73       | 58.98                   | 60.22 | 7.586   | 0.673  |

ab, Means within the same row with different superscript differ significantly (P < 0.05).
The experiment lasted 28 d; n = 6.

4. Discussion

Diarrheal syndrome occurs primarily because of an increase in Escherichia coli and others pathogenic bacteria inside the gut after weaning. This leads to a loss of water and electrolytes, via the semiliquid faeces [1]. According to Kommera et al. [13] and Kong et al. [1], the supplementation of medicinal plant extracts decreases diarrhea incidence in pigs, mainly because the extract has antimicrobial properties and it aids in the regulation of organic functions, intestinal pH, and peristalsis.

As Newton et al. [7] explain, the antimicrobial properties of sanguinarine have been clearly demonstrated. If it is added to swine diets, as a supplement, it has the potential to support the intestinal colonisation of beneficial bacteria and increase competitive exclusion in GIT. It also reduces water secretion from the intestinal epithelial cells and/or improves the absorption of water and nutrients from the intestinal lumen [1]. These results are primarily caused by an increase in the metabolism of biomolecules and by antioxidant activities within the small-intestinal mucosa.

There is a relationship between intestinal pH, microflora population, and diarrhea incidence in pigs [1]. This is clear because both stabilization of the intestinal pH value at a reasonably low level and the maintenance of an optimal balance of intestinal microbiota play a major role in the reduction of diarrhea incidence [5,14]. It is noteworthy then that although these key results relating to the anti-diarrheal effect of medicinal plant extracts have been seen in piglets, we also found a similar response in growing pigs.

Crucially, Macleaya cordata extract also has other important characteristics, such as its anti-inflammatory effect and immunomodulatory properties [5, 8, 9], which improve intestinal immune function. This reduces inflammation within the small-intestinal mucosa that usually develops as a result of stress. Although the precise mechanisms are not clear, our results demonstrate that Macleaya cordata extract, provided as a natural supplement to growing pigs, could be a viable substitute for feed antibiotics.
Serum antibody volume is another useful indicator of humoral immunity. Actually, IgG and IgM are key components and signifiers of humoral immunity in all mammals because they are the major serum immunoglobulins. They protect the extravascular compartment against pathogenic bacteria and microorganisms [15]. Furthermore, IgG also has antibacterial and antitoxin effects [16]. These findings suggest that a higher concentration (P < 0.05) of IgG in pigs of MC group (Table 2) leads to an increase in the production of antibodies by B lymphocytes. This is beneficial for immune status and, consequently, animal response [15, 17].

It should be noted that this serum antibody (IgG) did not increase (P < 0.05 = on subsequent days (d 14 and 28)), perhaps because of a higher immunological stability in the pigs. However, other studies on medicinal plant additives have shown a variably in the serum concentration of IgG in pigs [15, 17]. Interestingly, the serum concentration of IgM did decrease (P < 0.05 = in pigs from MC group). IgM is the first to be synthesised, as a response to infection [17]. Despite variations in the serum concentration of immunoglobulins, after supplementation with *Macleaya cordata* extract, we observed a healthy response in growing pigs (Table 2). According to the work of Tewari et al. [18], the underlying mechanisms that regulate immunological function are likely to be multifactorial. As such, they recommended that future studies use molecular biology and proteomics technologies.

When it comes to sustaining and protecting the translocation of bacteria in the intestines, an undamaged intestinal barrier is very important. It stops allergenic and toxic substances from making their way inside the gut and becoming a danger [19, 20]. D-Lactate and diamine oxidase can usually be found in modest amounts, within the circulation [21]. Yet, if the protective capacity of the intestine is decreased, mucosal permeability begins to rise. This enables a larger volume of D-lactate and DAO to get inside the peripheral circulation. For this reason, D-lactic acid and plasma DAO can potentially be used as indicators of damage to the intestinal barrier system [22, 23]. This paper has discussed, in depth, the relationship between MC extracts and this degree of protection within the intestine. For example, there is much evidence to support the idea that if baby pigs are taken from their mothers and weaned too early, it leads to diminished intestinal barrier capacities [24, 25]. On the other hand, according to the data collected, MC extract supplements actually boost jejunal mucosa DAO. However, it lowers the volume of plasma DAO and D-lactate. This suggests that intestinal mucosal development and barrier strength can be enhanced by introducing MC supplements.

The intestinal barrier is tightly controlled by a carefully arranged piece of the epithelial junctional complex. It is usually called “the tight junction” [26]. The porousness and protective capacities of the intestine have, for a long time, been treated as signifiers of intestinal epithelial barrier strength. It consists of various distinct proteins, like the transmembrane protein occludin [27], some members of the claudin family [28], junctional adhesion molecule [29], various linker proteins such as ZO-1, and more. The most valuable and essential are occludin, ZO-1, and claudin-1 because they are linked to the functional and operational management of the tight junctions [30]. ZO-1 is a valuable linker protein for the tight junction because it joins the C-terminal selections of β-actin and occludin [30]. It also functions as a connection between cytoskeleton proteins and the plasma membrane. Claudin-1 seems to be mostly linked to the display of ZO-1 inside the small intestine. Finally, for the epithelial tight junction, occludin is a vital membrane protein. It plays a big part when it comes to sustaining the strength and barrier quality of the tight junction [27]. For this study, we calculated fluctuations within the display of occludin, ZO-1, and claudin-1 at the mRNA level. This allowed us to more accurately judge the molecular catalyst for the decrease in intestinal strength within growing pigs after they had been given artificially increased levels of Zn. The outcomes show that adding *Macleaya cordata* to the diet, as an additional supplement, boosts volumes of ZO-1 and Claudin-1 proteins.

The experiment shows that introducing *Macleaya cordata* extracts to the diet, as an additional supplement, can increase resistance to intestinal damage, to some degree. This is achieved, throughout the growing stage, via increases in the volume and generation of claudin-1 and ZO-1. A number of earlier studies, on animals, had already made it clear that intestinal strength is closely linked to claudin-1 and ZO-1 volumes [31]. According to Kansagra et al. [32], fluctuations within intestinal strength, throughout the weaning stage, can be explained by the deterioration of tight junction reliability and quality. These studies discussed the fact that baby pigs in the weaning phase suffer various pressures (e.g., swapping from a liquid diet to a solid one). This makes them vulnerable to infections created by enterotoxigenic *E. coli* [33]. It happens because tight junction proteins have become disarrayed or their volumes have been lowered [21]. For all of these reasons, epithelial strength is compromised. In turn, this unusually high degree of intestinal porousness leads to increased antigenic vulnerability, a weaker immune system, and persistent inflammation. This greatly decreases barrier strength [34] and, eventually, leads to dangerous levels of after-weaning sickness.

To summarise, boosting the diet with *Macleaya cordata* extract supplements caused a reduction in faecal dysfunction. This result was underscored by larger volumes of claudin-1 and ZO-1. Consequently, the fortifying impact of *Macleaya cordata* supplements may be, to some degree, linked with the enhancement of intestinal barrier strength, particularly when it comes to treating conditions like diarrhea.

**Competing Interests**

The authors declare that there is no conflict of interests regarding the publication of this paper.

**Authors’ Contributions**

Gang Liu and Guiping Guan contributed equally to this paper.
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