Dietary chicory powder supplementation affects growth performance, carcass traits, and muscular profiles of amino acids and fatty acids in growing-finishing Xiangcun Black pigs

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ABSTRACT
This study was conducted to explore the effects of dietary supplementation with chicory powder on the growth performance, carcass traits, and meat quality of Xiangcun Black pigs. Forty-five pigs with an average initial body weight of 54.20 ± 8.70 kg were randomly assigned into one of three groups (15 pigs per group) according to their body weight and litter size. Pigs were fed either a basal diet with no supplement (control group), or a diet supplemented with 5% or 10% chicory powder. Results showed that compared with the control, 10% chicory powder decreased the feed:gain ratio in the first phase (P < 0.01), back fat thickness (P = 0.01), b* value (P = 0.01), and the concentrations of serum total cholesterol and low-density lipoprotein-cholesterol (P < 0.05), but increased the loin-eye area of the longissimus dorsi muscle (LDM, P < 0.05). Chicory also increased the concentrations of several free amino acids and the proportion of n-3 PUFA in the LDM (P < 0.05). In conclusion, these findings indicate that a dietary level of chicory powder up to 10% does not negatively affect performance, instead improving the growth performance, carcass traits, and meat quality of Xiangcun Black pigs.

Introduction
In recent years, swine production has focused much attention on dietary supplementation with herbs because of their anabolic effects on animal growth and health (Kong et al. 2007; Wang et al. 2017). Chicory (Cichorium intybus L.), a dicotyledonous herb, can play an important role in the regulation of normal intestinal microflora and immune response, maintenance of body weight, absorption of minerals, and improvement of bone health (Gibson et al. 1995; Abrams et al. 2005; Parnell and Reimer 2009; Vogt et al. 2015). More importantly, chicory is a deep-rooted plant that is drought resistant. It has a high content of minerals and uronic acid (Foster 1988; Dicksved et al. 2015) and a high-fibre digestibility, and is likely capable of maintaining high energy and nutritive value of the animal diet (Ivarsson et al. 2011). These characteristics have sparked substantial interest in the use of chicory as a potential feed additive or feedstuffs for livestock (Ivarsson et al. 2011; Dicksved et al. 2015).

A wealth of data has revealed the beneficial effects of chicory in animal feeding. For instance, a previous study found that 35-day-old piglets fed chicory diets displayed a high daily weight gain (Ivarsson et al. 2011). Upon further investigation, the same authors found that chicory forage could be included in pig diets at levels of up to 80 g/kg without any negative effects on short-term growth performance and digestibility. In addition, a combination of chicory forage and root synergistically affect the fecal microbiota (Ivarsson et al. 2012). Further evidence from other studies showed that chicory fed to lambs, calves, deer, and young rabbits improved growth performance (Jung et al. 1996; Rumball et al. 1997; Castellini et al. 2007).

Despite these interesting observations of the effects of chicory on animal production, few studies have investigated their effects on growth performance, carcass traits, meat quality, and the profiles of muscle amino acids (AAs) and fatty acids in growing-finishing pigs. Xiangcun Black pigs are a local lean-meat pig breed of China that possess strong adaptability, resistance, and fibre digestive ability and exert an increasingly significant role in the pork industry (Li et al. 2018). Thus, Xiangcun Black pigs were selected as an animal model in the current study to explore the growth effect of growing-finishing pigs fed chicory powder. We hypothesized that dietary supplementation with chicory powder might improve the growth performance, carcass traits, and meat quality of growing-finishing Xiangcun Black pigs in the present study.

Materials and methods
Chemical analysis of chicory powder
Chicory was bought from Hebei Weilefu Agricultural Technology Co., Ltd, Beijing, China. The leaves were air-dried, pro-
cessed, and analyzed as reported previously (Long et al. 2016). The basic nutritional composition of the dried chicory powder is shown in Table 1.

**Animals and diets**

The experiments were approved by the Animal Welfare Committee of the Institute of Subtropical Agriculture, Chinese Academy of Sciences (Li et al. 2016).

Forty-five growing-finishing Xiangcun Black barrows with similar initial body weight (54.20 ± 8.70 kg) were randomly assigned to one of three groups in a completely randomized design according to the body weight. Each treatment group had 15 pigs (replicates). Pigs were fed either a basal diet (control group) or a basal diet plus 5% or 10% chicory powder. Notably, in the first phase (from day 1 to day 30), the basal diet for pigs was growing feed, and in the second phase (from day 31 to day 90), the basal diets for pigs were finishing feed. All diets were formulated and met the nutritional recommendations of the 2012 National Research Council for 30–90 kg pigs (NRC 2012) (Table 2). All pigs consumed the diets for 90 days.

All pigs in each group were housed in a cage (3.5 × 5.0 m) equipped with feed intake recording equipment (Henan Heshun Automation Equipment Co., Zhengzhou, China) as previously described (Hu, Jiang, Zhang, Yin, Li, Deng, et al. 2017b). Pigs had 24 h access to feed and water since they were labelled with an individual electronic ear marker and the space provided by the equipment allowed one pig at a time to have ad libitum access to the feed. The housing condition environment (temperature 23–28°C, humidity 68–85%) was controlled by an air-conditioning system.

**Growth performance**

Feed intake recording equipment was used to record daily feed intake as previously described (Hu, Jiang, Zhang, Yin, Li, Duan, et al. 2017a). Body weights (BW) were measured at the beginning of the trial, at the end of the first phase, and at the end of the second phase, respectively. Based on these data, the average daily gain (ADG), average daily feed intake (ADFI), and the feed:gain (F:G) ratio were calculated for the period of days 1–30 and days 31–90, according to the method of (Kong et al. 2007). Briefly, ADG = (Final BW − Initial BW)/feeding trial time, ADFI = Total feed intake/feeding trial time, F:G = ADFI / ADG.

**Sample collection**

At the end of the experiment, eight pigs from each group were fasted overnight (12 h), and then slaughtered by electrical stunning (250 V, 0.5 A, for 5–6 s) and exsanguination. Before slaughter, for the determination of serum biochemical parameters and free AA profile, blood samples were collected into 10 mL tubes via the jugular vein puncture. Serum was separated and stored as previously described (Duan, Duan, et al. 2016a). After slaughter, the hot carcass weight was immediately recorded. The carcass was split before cooling at 4°C for 24 h. The left side of the carcass was cut between the 10th and 11th ribs to measure the *longissimus dorsi* muscle (LDM) area and back fat thickness. LDM tissues from the right side of the carcass were collected and rapidly stored at −20°C for the analysis of free AA profiles, intramuscular fat (IMF) content, and fatty acid composition.

**Muscle quality measurements**

Muscle pH was determined at three locations on the 10th rib interface using a hand-held pH metre (model 2000, VWR Scientific Products Co., South Plainfield, NJ, USA). After chilling the samples at 4°C for 24 h, the CIELAB L* (lightness), a* (redness), and b* (yellowness) colour of the 10th rib were determined from three orientations (middle, medial, and lateral) using a colorimeter with 8 mm aperture and 0° viewing angle (CR410 chromameter, Minolta, Tokyo, Japan).

**Biochemical parameter analyses**

Serum activity of alkaline phosphatase (ALP) and plasma concentrations of albumin (ALB), total protein (TP), urea, urea acid (UA), creatinine (CREA), total cholesterol (TC), high density lipoprotein-cholesterol (HDL-C), low-density lipoprotein-cholesterol (LDL-C), and immunoglobulin G (IgG) were analyzed using a CX-4 Automatic Biochemical Analyzer (Beckman Inc., USA) and commercial kits (Leadman Biochemistry Technology Company, Beijing, China), according to the manufacturers’ instructions.

**Table 1. Basic nutritional composition in dried chicory powder.**

| Ingredient       | Growing feed | Finishing feed |
|------------------|--------------|---------------|
| Glucose          | 1.00         | 1.00          |
| Wheat bran       | 5.00         | 5.00          |
| Soybean meal     | 22.50        | 17.00         |
| Gold protein     | 0.50         | 0.50          |
| Cereal           | 22.50        | 17.00         |
| Premix 1         | 4.00         | 4.00          |
| Total            | 100.00       | 100.00        |

Muscle pH was determined at three locations on the 10th rib interface using a hand-held pH metre (model 2000, VWR Scientific Products Co., South Plainfield, NJ, USA). After chilling the samples at 4°C for 24 h, the CIELAB L* (lightness), a* (redness), and b* (yellowness) colour of the 10th rib were determined from three orientations (middle, medial, and lateral) using a colorimeter with 8 mm aperture and 0° viewing angle (CR410 chromameter, Minolta, Tokyo, Japan).

**Table 2. Composition and nutrient levels of basal diets (as-fed basis).**

| Ingredient       | Growing feed | Finishing feed |
|------------------|--------------|---------------|
| Corn             | 65.00        | 61.00         |
| Soybean meal     | 22.50        | 17.00         |
| Wheat bran       | 5.00         | 8.00          |
| Glucose          | 1.00         | –             |
| Total            | 100.00       | 100.00        |

**Table 2. Composition and nutrient levels of basal diets (as-fed basis).**
Serum and muscle free AA profile determination

As previously described, an ion exchange AA analyze (L8800, Hitachi, Tokyo, Japan) was used to analyzed serum free AA concentration (Hu et al., 2019) and muscle hydrolyzed AA concentration (Liu et al., 2015).

Intramuscular fat and fatty acid composition determination

IMF in LDM was analyzed in duplicate using the Soxhlet extraction method, as previously described (Li et al. 2015). The fatty acid composition of the LDM was measured using gas–liquid chromatographic analysis of methyl esters using an Agilent 7890A GC, as previously described (Li et al. 2015; Liu et al. 2015). The fatty acid composition was expressed as a percentage of the total fatty acids. The following parameters were also calculated based on the fatty acid composition: the sum of saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), the ratio of PUFAs to SFAs, and the ratio of n-6 to n-3 PUFA.

Statistical analysis

Data were analyzed using one-way analysis of variance (ANOVA) using the SAS version 8.2 (SAS Institute Inc., Cary, NC, USA) software followed by Duncan’s multiple comparison test. Results are presented as means ± standard errors. Differences between significant means were considered statistically different at P < 0.05. Probability values between 0.05 and 0.10 were considered trends.

Results

Growth performance

As shown in Table 3, no significant difference was observed in the ADG and ADFI across all groups, throughout the study period (P > 0.05). However, in phase 1, the F:G ratio was the lowest and highest in the 10% and control groups (P < 0.05), respectively. In phase 2, the F:G ratio in the 10% group was of similar value to the control group, and was lower than the 5% group (P < 0.05).

Carcass traits and meat quality

No significant effects were observed on carcass weight, pH45 min, and pH24h among these groups (P > 0.05, Table 4). The average back fat thickness was lower in the pigs fed chicory powder diets than in pigs fed the control diet. The muscle area of the LDM was significantly increased in the 10% group compared with that in the control group, and an intermediate value was observed in the 5% group (P < 0.05). The b* value was lowest in the 10% group compared with that in the other two groups (P < 0.05), and there was no significance difference in the values of L* and a* among these groups (P > 0.05).

Serum biochemical parameters

As presented in Table 5, the serum concentrations of LDL-C and TC were lower in the pigs fed diets supplemented with chicory powder than in those fed the control diet (P < 0.05). There was no significant difference in the serum concentrations of ALB, ALP, TP, urea, UA, HDL-C, CREA, and IgG among these groups (P > 0.05).

Serum free AA profile

As summarized in Table 6, the serum concentrations of most AAs were significantly affected by the diets supplemented.
with chicory powder. In particular, compared with the control diet, the chicory powder-supplemented diets decreased levels of lysine, threonine, valine, leucine, phenylalanine, aspartic acid, glutamic acid, serine, tyrosine, total essential AA (EAA), and total non-essential AA (NEAA) (P < 0.05). The concentrations of n-3 PUFAs such as C18:3 and C22:6 were highest in the 10% group, intermediate in the 5% and 10% groups compared with that in the control group (P < 0.05). The concentrations of n-6/n-3 PUFA in the LDM were highest in the 5% group, and lowest in the control group (P < 0.05). Conversely, the ratio of n-6/n-3 PUFA in the LDM was highest in the 10% group, and lowest in the control group (P < 0.05). Non-essential AA in the 5% group (versely, the ratio of n-6/n-3 PUFA in the LDM was highest in the 5% group, and lowest in the control group (P < 0.05). The IMF content of the LDM increased with chicory powder. In particular, compared with the control diet, the chicory powder-supplemented diets decreased levels of lysine, threonine, valine, leucine, phenylalanine, aspartic acid, glutamic acid, serine, tyrosine, total essential AA (EAA), and total non-essential AA (NEAA) (P < 0.05). There was no difference among these groups in the concentrations of other AAs (P > 0.05).

**Muscle free AA profile**

As shown in Table 7, several AA concentrations in the LDM were significantly affected by the dietary chicory powder (P < 0.05). Specifically, compared with the control diet, the chicory powder-supplemented diets increased the muscular concentrations of threonine, phenylalanine, histidine, aspartic acid, glutamic acid, and alanine (P < 0.05). However, other AAs, total EAA, and total NEAA were unaffected by the dietary treatments (P > 0.05).

**Muscle fat content and fatty acid composition**

As presented in Table 8, the IMF content of the LDM increased in the 5% and 10% groups compared with that in the control group (P < 0.05). The concentrations of n-3 PUFAs such as C18:3 and 22:6 were highest in the 10% group, intermediate in the 5% group, and lowest in the control group (P < 0.05). Conversely, the ratio of n-6/n-3 PUFA in the LDM was highest in the control group and lowest in the 10% group, with an intermediate value in the 5% group (P < 0.05). Other fatty acids were not affected by the dietary treatments (P > 0.05).

**Discussion**

To the best of our knowledge, the present study is the first report on the use of chicory forage in Chinese Xiangcun Black pigs and was conducted with the aim to determine its impact on growth performance, carcass traits, and meat quality. Chicory forage is a relatively novel feedstuff for growing-finishing pigs but has been previously used as feed for weaned piglets, without any negative effect on growth performance (Ivarsson et al. 2011).

In this study, we found that, although ADG and ADFI were not significantly affected by dietary treatments containing...
chicory, the F:G ratio markedly decreased throughout the experiment when the dietary chicory level was increased up to 10%, thus, improving the growth performance of the Xiangcun Black pigs. Our results were not consistent with the findings of previous studies, which showed no differences in the values of ADG, ADFI, and F:G ratio between piglets fed control and chicory diets at all inclusion levels (Ivarsson et al. 2011). This discrepancy was probably due to the differences in growth phases (growing-finishing period versus post-weaning period) and the breeds of pigs studied (Xiangcun Black pigs versus Swedish Landrace × Yorkshire pigs) since Xiangcun Black pigs have strong fibre digestion ability (Li et al. 2018). Another interesting finding was that contrary to the control group and 10% group, the F:G ratio in 5% group was phase 1 < phase 2. Similar results were obtained in broilers, in which the F:G reduced at 1% chicory root powder in the first phase (0–10 days) and, at 3% in the second phase (11–24 days) and total periods (0–24 days) (Izadi et al. 2013). The varied response of F:G ratio to dietary treatments remained elusive, and there is little information available. However, it has been reported that chicory typically contains lots of bioactive components, including esculin, coumarins, and flavonoids in dry matter (Kim and Shin 1996; van Loo 2007), which could enhance nutrition absorption through improvement of intestinal structure and function. Therefore, we speculate that this inconsistency may be due to the higher amount of chicory powder and the higher content of bioactive components, which facilitated the digestion of the feed nutrient and subsequently increased the feed efficiency. Taken together, dietary chicory supplementation in the rapid growing period might not be as effective as in the late finishing period, because the fibre digestibility of the late finishing period is much higher than that of the growing period.

An interesting finding in the present study was that dietary supplementation with 10% chicory powder significantly elevated the muscle area of the LDM. Chicory supplementation is suspected to increase the absolute rates of protein synthesis in skeletal muscles. All AAs are required for protein synthesis, and elevation of the availability of free AA has been reported to be positively related to alterations in muscle protein synthesis (Hundal and Taylor 2009; Drummond et al. 2010). Consistent with this observation, our results showed that pigs fed chicory diets exhibited increased concentrations of several free AAs (especially threonine, phenylalanine, histidine, aspartic acid, glycine, and alanine) in the LDM.

There is compelling evidence that free AA composition is positively correlated with protein synthesis (Li et al. 2011; Duan et al. 2015; Duan, Guo, et al. 2016b). For instance, glycine could serve as a signaling molecule to promote skeletal muscle protein anabolism through modulation of intracellular cell signaling pathways such as the mammalian target of rapamycin complex 1 pathway (Liu et al. 2016; Sun et al. 2016). Interestingly, threonine is associated with the synthesis of glycine (Wu 2009). Therefore, our findings indicated that dietary supplementation with 10% chicory powder increased the available free AAs for the LDM, suggesting a growth-promoting action in the muscles.

The back fat thickness, a key index to evaluate the fat content in pigs (Hu, Jiang, Zhang, Yin, Li, Su, Wu and Kong 2017b), was consistently affected by the 10% chicory supplementation. Consequently, we suspected that it may affect carcass traits and our data support this notion. Improvements were observed for the b* value of the LDM as evidenced by the reduction. It should be noted that although these effects of chicory on carcass traits in the current study are promising, and further investigation is warranted. Moreover, it has been shown that low pH can reduce the effect of myoglobin in selectively absorbing green light, leading to less red and more yellow in meat (Castellini et al. 2002). In this study, pH values were not significantly influenced by dietary treatments. These data indicate a possible strategy for improving meat colour in pork.

Alterations in the serum TC concentration can reflect dynamic lipid absorption and nutritional status in animals. It has been reported that the serum TC concentration is positively correlated to body fat deposition and the incidence of coronary heart disease (CHD) in humans (Sink et al. 1973; Liu et al. 2019). The risk for CHD is increased by 2%–3% in response to a 1% elevation in either TC or LDL-C (Anderson and Konz 2001). In the present study, pigs fed chicory diets exhibited decreased serum concentrations of TC and LDL-C at all supplementation levels, and these values varied significantly from the corresponding values observed in the pigs fed the control diet. These data were in accord with the backfat thickness results and suggest, to some extent, that inclusion of up to 10% of chicory does not negatively affect pig performance and health.

To further investigate whether dietary chicory supplementation improved meat quality, we measured the fat content and fatty acid composition in the LDM. IMF content is one of the key indices of meat quality and influences the juiciness and tenderness of cooked meat. In particular, when IMF content is decreased below 2.0%–2.5%, the sensory properties of pork are negatively affected (Wood et al. 2008). The fatty acid composition of the IMF also significantly affects meat quality by determining the oxidative stability and nutritional value of muscle. On the one hand, the level of fatty acid saturation can affect the degree of fat firmness, consequently influencing the quality and acceptability of meat products (Perry et al. 1998). Therefore, appropriate levels of SFA and PUFA should be maintained to ensure superior meat quality. In general, the ratio of PUFA to SFA in meat is 0.40 or above (Wood et al. 2008). On the other hand, the proportion of n-3 PUFA could affect the nutritional value of muscle. More specifically, a decrease in the ratio of n-6 to n-3 PUFA protects against degenerative diseases and, therefore, provides health benefits (Simopoulos 2006; Russo 2009; Duan et al. 2014). In the present study, we found that pigs fed chicory diets exhibited a higher IMF value (above 2.50%) at all supplementation levels. Moreover, in the LDM of pigs fed 5% chicory diets, the ratio of PUFA to SFA achieved the recommended target of 0.40 and did not differ significantly from the corresponding values observed in pigs fed with the other diets. Consistent with this observation, the n-3 PUFA concentrations and the ratio of n-6 to n-3 PUFA were greatly improved in the pigs fed diets with 10% chicory powder. Based on these data, we suggested that the synthetic capacity of n-3 PUFA in the LDM was increased and the pig meat quality was improved in response to dietary supplementation with chicory.
Conclusion

In conclusion, the current study provides evidence that dietary supplementation with up to 10% chicory powder did not impair pig growth performance, but instead contributed to improving the growth performance, carcass traits, and meat quality of Xiangcun Black pigs. Thus, chicory forage is an attractive option for fibre-rich feed stuff for growing-finishing Xiangcun Black pigs and may contribute to maintaining the nutritious value of meat.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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