Silage fermentation and ruminal degradation of cassava foliage prepared with microbial additive

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Abstract
To effectively utilize the tropical cassava (Manihot esculenta Crantz) foliage (CF) resources, the CF silages were prepared with microbial additives, including Chikuso-1 (CH1, Lactobacillus plantarum), Snow Lact L (SN, L. rhamnosus), Acremonium cellulase (CE), SN + CE and CH1 + CE. Silage fermentation, chemical composition and ruminal degradation were studied in Hainan, China. CF silages prepared with lactic acid bacteria (LAB) and CE were well preserved, with a higher (P < 0.05) lactic acid, a lower (P < 0.05) pH value, butyric acid content and NH3-N / total-N compared with the controls. The additive-treated silages showed increased crude protein (CP) content, but decreased (P < 0.05) NDF and ADF contents. Meanwhile, the additive treatment improved relative feed value and ruminal degradability of dry matter (DM), CP, neutral detergent fiber and acid detergent fiber. In addition, the combination of LAB and CE resulted in better fermentation quality and ruminal degradability compared with LAB or CE single treatment. The results demonstrated that the CF could be prepared as ruminant feed, and the combination of LAB and CE might exert beneficial synergistic effect on silage fermentation.

Keywords: Cassava foliage, Lactic acid bacteria, Cellulase, Silage fermentation, Ruminal degradation

Introduction
In order to meet the dramatically increased consumption of animal products, the lack of adequate and high-quality green roughage for animal feed has become increasingly prominent with the rapid development of ruminant livestock production based on grassland in China. As an Euphorbiaceae woody shrub and major food, bioenergy and feed crop, cassava, Manihot esculenta Crantz, is grown in tropics worldwide (Wang et al. 2014). Cassava foliage (CF) can be used as animal feed due to its high contents of protein, gross energy and mineral elements (Li et al. 2019a). Many studies have found that CF can positively affect the digestion, growth performance, carcass characteristics, digestive organ development and gut microbiome diversity of swine, ruminants and poultry (Borin et al. 2006; Oni et al. 2010; Fasae et al. 2011; Nguyen et al. 2012; Régnier et al. 2013; Li et al. 2017, 2019b). Cassava vigorously grows in the summer during rainy seasons, while it stops growing or dies in the cold seasons, leading to feed shortage. CF is normally ensiled after harvest at summer at vegetative stage to ensure continuous supply for ruminants in winter. However, the fermentation quality of CF silage remains low when no additive is applied (Man and Wiktorsson 2002; Napasirth et al. 2015; Li et al. 2019a).

CF is hard to convert to good-quality silage as it often contains low concentrations of water-soluble carbohydrates (WSC) (Napasirth et al. 2015). The quality of silage remains poor when CF is ensiled under natural conditions. Therefore, it is necessary to develop new technologies in order to prepare CF silage with good quality. The commercially available microbial additives, such as lactic acid bacteria (LAB) inoculants, have been developed and widely used for silage preparation (Cai et al. 1999; Napasirth et al. 2015; Guo et al. 2018; Ni et al. 2017; Li et al. 2017, 2019c; Wang et al. 2019; Yang et al. 2019). LAB depletes WSC and creates lactic acid in an anaerobic environment.
environment, thus leading to reduced pH and shortened time to reach pH stability. Cellulase enzyme (CE) promotes fiber degradation, elevating the WSC production for LAB to produce lactic acid (Yu et al. 2011; Li et al. 2014, 2017; He et al. 2018). Therefore, LAB and CE can determine the direction of silage fermentation. To the best of our knowledge, limited information is available on the CF silage processed by the commercial LAB inoculant or CE, and their true functions in silage production remain unknown under tropical conditions. In the present study, we aimed to investigate the effects of LAB, CE and their combination on the fermentation quality, chemical composition and ruminal degradation of CF silage.

Materials and methods

Silage preparation
The cassava was cultivated at the experimental base of Chinese Academy of Tropical Agricultural Sciences (CATAS), in Danzhou, P. R. China. The CF of approximately 1.5 m plant high was collected and cut into small segments (about 2–3 cm). The CF was wilted for 4 h in the shade. Following treatments were carried out in the present study: control (no additives), LAB inoculant Snow Lact L (SN, *L. Rhamnosus*; Snow Brand Seed Co., Ltd., Sapporo, Japan), Chikuso-1 (CH1, *L. plantarum*; Snow Brand Seed Co., Ltd., Sapporo, Japan), CE (*Acremonium cellulolyticus*, Meiji Seika Pharma Co., Ltd., Tokyo, Japan), SN + CE and CH1 + CE. Each treatment was performed with three replicates. Table 1 lists the production strain, main composition and carboxymethyl cellulase activity of CE used in this study. The application rate of LAB was $1.0 \times 10^5$ colony-forming units (cfu)/g of fresh matter (FM), and that of CE was 20 mg/kg of FM. Briefly, 200 g of CF was mixed with additives and kept in plastic bag (30 cm × 10 cm × 4 cm; Menghua Packing Co., Ltd., Guangzhou, China). Properly sealed bags (Jiaren Vacuum Sealer; Jiaren Home Electrical Appliance Co., Ltd., Wuhan, China) were maintained at room temperature (25 to 30 °C). After 30 days of ensiling, chemical composition and fermentation quality were analyzed.

Chemical analysis
Samples were dried at 65 °C for 48 h and milled through a 1.0-mm sieve for chemical analysis. Dry matter (DM), crude protein (CP), organic matter (OM) and ether extracts (EE) were determined based on previously established methods (AOAC 1990). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined by the methods of Van Soest et al. (1991). Heat-stable amylase and sodium sulfite were used during NDF procedure. Relative feed value (RFV) of the CF samples was calculated as previously described (Rohweder et al. 1978). Table 2 shows the chemical compositions of fresh CF. The RFV was calculated according to the equation:

$$RFV = \frac{[88.9 - (0.779 \times ADF)] \times (120 \div NDF)}{1.29}$$

The fermentation products of silages were analyzed using cold-water extracts. Briefly, 50 g wet silage was mixed with 200 mL distilled water and incubated at 4 °C overnight. The pH, organic acids (lactic acid, acetic acid, propionic acid and butyric acid) and NH$_3$-N were determined by the methods of Li et al. (2017).

Ruminal degradability analysis
The animal-related protocols were approved by the Animal Care and Use Committee of CATAS, P. R. China, and trials were carried out at CATAS in August 2017. Three healthy mature Hainan black goats were ruminally canulated to compare the in situ ruminal degradability of CF silages. The CF silages ruminal degradability of DM, CP, NDF and ADF were determined as previously described by Li et al. (2017).

Statistical analysis
A completely randomized design was applied to the data of silages, which were analyzed using the general linear models (GLM) of SAS (1996). Differences among various treatments were analyzed using probability of difference. Duncan’s multiple range tests were employed to compare

### Table 1 CMCase activity of CE used in this study

| Production strain       | *Acremonium cellulolyticus* |
|-------------------------|-----------------------------|
| Main composition        | Glucanase, pectinase        |
| CMCase activity         | 7350 U/g                    |

CMCase carboxymethyl-cellulase

### Table 2 Chemical composition of CF

|                  | DM (%) | OM (% DM) | EE (% DM) | CP (% DM) | WSC (% DM) | NDF (% DM) | ADF (% DM) | RFV  |
|------------------|--------|-----------|-----------|-----------|------------|------------|------------|------|
| Cassava foliage  | 24.80  | 92.00     | 5.73      | 22.67     | 8.21       | 41.19      | 33.88      | 141.17 |

DM dry matter, OM organic matter, EE ether extract, CP crude protein, WSC water-soluble carbohydrates, NDF neutral detergent fiber, ADF acid detergent fiber, RFV relative feed value
significant differences, and $P < 0.05$ was considered as statistically significant.

**Results**

**Chemical composition of fresh CF and silages**

Table 3 lists the chemical compositions of CF silages. Compared with the control, the additive treatments increased ($P < 0.05$) DM contents of CF silage, while there were no great differences among additive-treated silages. The OM and EE contents were similar in all treatments. The CP contents of CH1 and CE-treated CF silages were higher compared with the control group, and in combination treatments (CH1 + CE or SN + CE) were higher ($P < 0.05$) than those of single treatment and control. In contrast, the CE and combination treatments decreased ($P < 0.05$) the ADF and NDF contents of CF silage compared with the control group. In addition, the ADF and NDF contents of CF silage treated with combination of LAB and CE were decreased ($P < 0.05$) compared with the CF silage treated with single additives. The additive treatments increased ($P < 0.05$) the RFV, and the RFV in the combination treatments (CH1 + CE or SN + CE) was higher ($P < 0.05$) than single additive treatments ($P < 0.05$). Compared with the CH1 and SN treatments, the CE treatment had a higher RFV ($P < 0.05$).

**Fermentation quality of CF silages**

Table 4 shows the fermentation quality of CF silages. Compared with the control group, the additive treatments decreased pH of CF silage ($P < 0.05$), and the pH of the combination treatments was lower ($P < 0.05$) than the single additive treatments. The LAB treatments increased ($P < 0.05$) the lactic acid content compared with the control group, and the lactic acid content in CE, CH1 + CE and SN + CE groups was higher ($P < 0.05$) compared the LAB treatment. The acetic acid content and NH$_3$-N / total-N in additive treatments were lower compared with the control group, and they were lower ($P < 0.05$) in

### Table 3 Chemical composition of CF silage

| Treatments | DM (%) | OM (% DM) | EE (% DM) | CP (% DM) | ADF (% DM) | NDF (% DM) | RFV |
|------------|--------|-----------|-----------|-----------|------------|------------|------|
| Control    | 32.52b | 91.39     | 6.88      | 21.55b    | 30.48a     | 41.39a     | 146.45c |
| SN         | 34.21a | 90.52     | 6.62      | 21.09b    | 30.49a     | 40.72a     | 148.84c |
| CE         | 34.36a | 89.77     | 6.57      | 22.26b    | 26.01b     | 38.83b     | 164.42b |
| CH1        | 34.51a | 89.62     | 6.83      | 21.85b    | 30.17a     | 40.56a     | 149.99c |
| SN + CE    | 34.75a | 90.14     | 6.77      | 24.84a    | 22.59c     | 33.96c     | 195.31a |
| CH1 + CE   | 34.60a | 92.10     | 6.92      | 24.20a    | 21.67c     | 35.26c     | 190.01a |
| SEM        | 0.45   | 0.39      | 0.06      | 0.62      | 1.66       | 1.27       | 8.89  |
| P-value    | 0.031  | 0.789     | 0.342     | 0.024     | 0.008      | 0.009      | 0.003 |

CH1: L. plantarum; SN: L. Rhamnosus; CE: cellulase enzyme; SN + CE: L. plantarum + cellulase enzyme; CH1 + CE: L. Rhamnosus + cellulase enzyme

DM dry matter, OM organic matter, EE ether extract, CP crude protein, NDF neutral detergent fiber, ADF acid detergent fiber, RFV relative feed value, SEM standard error of means

Means within the same column with different letters are significantly different ($P < 0.05$)

### Table 4 Fermentation quality of CF silage

| Treatments | pH     | Lactic acid (% DM) | Acetic acid (% DM) | Propionic acid (% DM) | Butyric acid (% DM) | NH$_3$-N / Total-N (% DM) |
|------------|--------|--------------------|--------------------|-----------------------|---------------------|--------------------------|
| Control    | 4.73a  | 0.22c              | 1.68a              | 0.79a                 | 0.23a               | 2.16a                    |
| SN         | 4.43b  | 1.08b              | 1.38b              | 0.64a                 | 0.17b               | 1.84b                    |
| CE         | 4.33b  | 3.01a              | 1.20c              | 0.63a                 | 0.21ab              | 1.25bc                   |
| CH1        | 4.38b  | 1.10b              | 1.41b              | 0.72a                 | 0.19b               | 1.48b                    |
| SN + CE    | 4.09c  | 3.26a              | 1.25c              | 0.71a                 | 0.09c               | 1.31bc                   |
| CH1 + CE   | 4.11c  | 3.46a              | 0.72d              | 0.69a                 | 0.07c               | 1.16c                    |
| SEM        | 0.09   | 0.564              | 0.13               | 0.02                  | 0.03                | 0.16                     |
| P-value    | 0.005  | 0.003              | 0.009              | 0.054                 | 0.023               | 0.018                    |

CH1, L. plantarum; SN, L. Rhamnosus; CE, cellulase enzyme; SN + CE, L. plantarum + cellulase enzyme; CH1 + CE, L. Rhamnosus + cellulase enzyme

DM dry matter, SEM standard error of means

Means within the same column with different letters are significantly different ($P < 0.05$)
CH1 + CE and SN + CE groups than compared with the LAB treatment. The propionic acid content remained relatively stable in all treatments. The butyric acid content in additive treatments was lower (P < 0.05) compared with the control group, and such acid content in CH1 + CE and SN + CE groups was lower (P < 0.05) compared with the other treatments.

**Ruminal degradability of CF silages**

Table 5 shows the ruminal degradability of CF silage. The DM, CP, ADF and NDF degradability of CF silage treated with LAB and CE were higher compared with the control group, and these values were higher (P < 0.05) in CH1 + CE and SN + CE groups compared with the LAB or CE treatment.

**Discussion**

**Chemical composition**

Generally speaking, CF has relatively low WSC content and less epiphytic LAB, leading to poor fermentation quality of silages without additives (Napasirth et al. 2015; Li et al. 2019a). It is necessary to use microbial inoculants to control silage fermentation during ensiling (Cai et al. 1999; Li et al. 2017; Wang et al. 2019). Moisture of material is also an important factor affecting silage fermentation. In the present study, additive treatments increased the DM of CF silage, which is consistent with previous studies on other silages (Kung and Ranjit 2001; Li et al. 2014, 2017; Wang et al. 2019). This could be attributed to that the additives treatment promoted the growth and propagation of LAB, which could inhibit the growth of aerobic and anaerobic bacteria by the lower pH, then reduce nutrient consumption of these microbial keep more nutrient substance and result in higher DM. Such elevation in CP content could be attributed to the concentration effect due to the loss of organic carbon during fermentation or the combination of proteolysis inhibition and concentration effect (He et al. 2018). However, the mechanism underlying such finding remains largely unexplored. We found that the CF silage treated with LAB or CE had higher RFV and lower NDF and ADF contents compared with the control treatment. Consistently, few studies have reported that CE can decrease the fiber fractions (NDF and ADF) of silages (Liu et al. 2012; Li et al. 2014, 2017; Chen et al. 2016; Ni et al. 2017). These results could be explained by that CE increased the availability of WSC derived from fiber by enzymolysis and acid solubilization, leading to increased availability of fermentation substrates for LAB. Moreover, CE promote fermentation and fiber degradation. Taken together, LAB and CE treatments resulted in less degradation of protein and more degradation of fiber during ensiling, by which more nutrients were preserved in CF silage.

**Fermentation quality**

The fermentation quality of silage is the result of the combined effects of pH, lactic acid, volatile acid composition and NH$_3$-Ntotal-N as well as other factors. LAB should be dominant in the fermentation process of the good silage, which can accelerate the fermentation process and improve the fermentation quality (Cai et al. 1999). In this study, the LAB or CE treatment reduced the pH and NH$_3$-N content, elevated the content of lactic acid, and ameliorated the fermentation quality of silage compared with the control treatment. Similar effects on other silage fermentation have been achieved by applying LAB and CE (Colombatto et al. 2003; Kung et al. 2003; Napasirth et al. 2015; Chen et al. 2016; Ni et al. 2017; Li et al. 2017, 2019c). We also found that the CE treatment led to a higher production of lactic acid and a lower concentration of acetic acid. This finding suggested that the LAB used in this study was driven toward homo-fermentation type of lactic acid, resulting in promoted silage fermentation. Furthermore, the combination of LAB and CE was more effective compared with LAB or CE single treatment, indicating that there was a synergistic effect on silage. Perhaps the cellulase hydrolysis of fiber fractions increased the availability of WSC acting as a fermentation substrate of LAB and produced more lactic acid, leading to reduced pH and improved fermentation quality (Ni et al. 2017; Li et al. 2017, 2019c).

**Ruminal degradability**

Digestibility of forage is one of the most important evaluation indexes of feeding value, which affects feed intake and greatly relies on its chemical compositions, especially...
the fiber fraction and structure (Chabot et al. 2008). Previous studies have reported that LAB or CE additives have either positive effect (Cai et al. 2003; Cao et al. 2010; Li et al. 2014; Moselhy et al. 2015; Bureenok et al. 2016; Chen et al. 2016; Li et al. 2017; He et al. 2018) or no effect (Jaakkola et al. 1991; Zahiroddini et al. 2004; Moharrery et al. 2009; Fang et al. 2012; Ellis et al. 2016) on degradability improvement. In our study, LAB or CE treatment enhanced the ruminal degradability of CF silage. The possibility mechanism could be that the addition of LAB and enzymes destroyed the structure of plant cell wall, effectively released the intracellular contents, supplied more fermentation substrate for rumen microorganisms, and then improved the ruminal degradability (Yu et al. 2011; Li et al. 2014; Chen et al. 2016; Li et al. 2017). The ruminal degradability of different forages could be differently impaired by LAB or CE. However, such discrepancy may be attributed to characteristic differences in forage materials, especially their chemical compositions. Furthermore, the higher degradability of the CF silages can be attributed to their high CP content and low fiber, which provide more fermentation substrate for rumen microorganisms, then promoted rumen digestion. Besides, the appropriate carbon–nitrogen ratio or the protein structure of CF silage is easily digestible. Low ruminal degradability has been reported in both typical tropical forages, King grass with low CP and high fiber and Stylo with moderate CP and high fiber, in neither of which the carbon–nitrogen ratio is appropriate (Li et al. 2014, 2017). Therefore, a reasonable combination of CF and other tropical forages could maximize the use of local feed resources, promote the balance of animal diets and improve animal performance.

The fermentation quality, chemical composition and ruminal degradability of CF silage prepared with commercial LAB inoculant and CE in tropics were studied. The LAB and CE could effectively improve the fermentation quality, chemical composition and ruminal degradability compared with the control group, and the combination of LAB and CE displayed more effective results. The results confirmed that the CF could be prepared into good-quality silage, and the combination of LAB and CE had a beneficial synergistic effect on silage fermentation.

Abbreviations
CF: cassava foliage; CE: cellulase enzyme; LAB: lactic acid bacteria; CP: crude protein; DM: dry matter;WSC: water-soluble carbohydrates; CATAS: Chinese Academy of Tropical Agricultural Sciences; FM: fresh matter; OM: organic matter; EE: ether extracts; NDF: neutral detergent fiber; ADF: acid detergent fiber; RFV: relative feed value; GLM: general linear models.

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Authors’ contributions
ML, XZ, HZ and YC designed the experiments. ML, XZ, JT and RL performed the experiments. ML, XZ and YC analyzed the data. ML and XZ wrote the main manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
Not applicable.

Ethics approval and consent to participate
The animal-related protocols were approved by the Animal Care and Use Committee of CATAS, P. R. China, and trials were carried out at CATAS in August 2017.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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References
Association of Official Analytical Chemists (AOAC) (1990) Official methods of analysis of the association of official analytical chemists, 15th edn. Association of Official Analytical Chemists (AOAC), Arlington, pp 1–1298
Borin K, Lindberg JE, Ogle RB (2006) Digestibility and digestive organ development in indigenous and improved chickens and ducks fed diets with increasing inclusion levels of cassava leaf meal. J Anim Physiol A Anim Nutr 90:230–237
Bureenok S, Sisaath K, Yuaniklang C, Vasupen K, Schonewille JTH (2016) Ensiling characteristics of silages of Stylo legume (Stylosanthes guianensis), Guinea grass (Panicum maximum) and their mixture, treated with fermented juice of lactic bacteria, and feed intake and digestibility in goats of rations based on these silages. Small Rumin Res 134:84–89
Cai Y, Benno Y, Ogawa M, Kumai S (1999) Effect of applying lactic acid bacteria isolated from forage crops on fermentation characteristics and aerobic deterioration of silage. J Dairy Sci 82:520–526
Cai Y, Fujita Y, Murai M, Ogawa M, Yoshihda N, Kitamura A, Miura T (2003) Application of lactic acid bacteria (Lactobacillus plantarum Chikuso-1) for silage preparation or forage paddie rice. J Jpn Soc Grassl Sci 49:77–85
Cao Y, Takahashi T, Horiguchi K, Yoshida N (2010) Effect of adding lactic acid bacteria and molasses on fermentation quality and in vitro ruminal digestion of total mixed ration silage prepared with whole crop rice. Grassl Sci 56:19–25
Chabot DA, Chabot CD, Conway LK, Soto-Navarro SA (2008) Effect of fat supplementation and wheat pasture maturity on forage intake and digestion characteristics of steers grazing wheat pasture. J Anim Sci 86:1263–1270
Chen L, Guo G, Yuan X, Zhang J, Li J, Shao T (2016) Effects of applying molasses, lactic acid bacteria and propionic acid on fermentation quality, aerobic stability and in vitro gas production of total mixed ration silage.
prepared with oat–common vetch intercrop on the Tibetan Plateau. J Sci Food Agr 96:1678–1685

Colombatto D, Mould FL, Bhut MK, Morgavi DP, Beauchemin KA, Owen E (2003) Influence of fibrolytic enzymes on the hydrolysis and fermentation of pure cellulase and xylan by mixed ruminal microorganisms in vitro. J Anim Sci 81:1040–1050

Ellis J, Bannink A, Hindrichsen IK, Kinley RD, Pelliwaan WF, Milora N, Dijkstra J (2016) The effect of lactic acid bacteria included as a probiotic or silage inoculant on in vitro rumen digestibility, total gas and methane production. Anim Feed Sci Technol 211:61–74

Fang JC, Matsuzaki M, Suzuki H, Cai YM, Horiguchi K, Takahashi T (2012) Effects of lactic acid bacteria and urea treatment on fermentation quality, digestibility and ruminal fermentation of roll bale rice straw silage in wethers. Grasal Sci 58:73–78

Fasea OA, Adu IF, Aina ABJ, Dipeolu MA (2011) Growth performance, carcass characteristics and meat sensory evaluation of West African dwarf sheep fed varying levels of maize and cassava hay. Trop Anim Health Prod 43:503–510

Guo XS, Ke WC, Ding WR, Xu DM, Wang WW, Zhang P, Yang FY (2018) Profiling of metabolome and bacterial community dynamics in ensiled Medicago sativa inoculated without or with Lactobacillus plantarum or Lactobacillus buchneri. Sci Rep 8:357

He L, Zhou W, Wang Y, Wang C, Chen X, Zhang Q (2018) Effect of applying lactic acid bacteria and cellulase on the fermentation quality, nutritive value, tannins profile and in vitro digestibility of Neolamarckia cadamba leaves silage. J Anim Physiol Anim Nutr 102:1429–1436

Jaakkola S, Huhtanen P, Hissa K (1991) The effect of cell wall degrading enzymes or formic acid on fermentation quality and on digestion of grass silage by cattle. Grass Forage Sci 46:75–87

Kung L Jr, Ranjit NK (2001) The effect of Lactobacillus buchneri and other additives on the fermentation and aerobic stability of barley silage. J Dairy Sci 84(5):1149–1155

Kung L, Stokes MR, Lin CJ (2003) Silage additives. In: Buxton DR, Muck RE, Harrison JH (eds) Silage science and technology. American Society of Agronomy, Madison, WI, pp 305–360

Li M, Zi X, Zhou H, Hou G, Cai Y (2014) Effects of sucrose, glucose, molasses and cellulase on fermentation quality and in vitro gas production of king grass silage. Anim Feed Sci Technol 197:206–212

Li M, Zhou H, Pan X, Xu T, Zhang Z, Xi X, Jiang Y (2017) Cassava foliage affects the microbial diversity of Chinese indigenous geese caecum using 16S rRNA sequencing. Sci Rep 7:45697

Li M, Zhou H, Xu T, Zi X (2019a) Effect of cassava foliage on the performance, carcass characteristics and gastrointestinal tract development of geese. Poul Sci 98:2133–2138

Li M, Zi X, Tang J, Zhou H, Cai Y (2019b) Silage fermentation, chemical composition and ruminal degradation of king grass, cassava foliage and their mixture. Grassl Sci. 65:210–215

Li P, Zhang Y, Gou W, Cheng Q, Bai S, Cai Y (2019c) Silage fermentation and bacterial community of bur clover, annual ryegrass and their mixtures prepared with microbial inoculant and chemical additive. Anim Feed Sci Technol 247:285–293

Liu Q, Chen M, Zhang J, Shi S, Cai Y (2012) Characteristics of isolated lactic acid bacteria and their effectiveness to improve stylo (Stylosanthes guianensis Sw) silage quality at various temperatures. Anim Sci J 83:128–135

Man NC, Viktorsson H (2002) Effect of molasses on nutritional quality of cassava and Gliricidia tops silage. Asian Aust J Anim Sci 15:1294–1299

Moharrerly A, Hvelplund T, Weisbjerg MR (2009) Effect of forage type, harvesting time and oxgenous enzyme application on degradation characteristics measured using in vitro technique. Anim Feed Sci Technol 153:178–192

Moselhy MA, Borba JP, Borba AES (2015) Improving the nutritive value, in vitro digestibility and aerobic stability of Hedychium gardnerianum silage through application of additives at ensiling time. Anim Feed Sci Technol 2068–18

Napasirith V, Napasirith P, Sulitihone T, Phommachankh K, Cai Y (2015) Microbial population, chemical composition and silage fermentation of cassava residues. Anim Sci J 86:279–280

Nguyen TH, Ngoan LD, Bosch G, Verstegen MWA, Hendriks WH (2012) Ileal and total tract apparent crude protein and amino acid digestibility of ensiled and dried cassava leaves and sweet potato vines in growing pigs. Anim Feed Sci Technol 172:171–179

Ni K, Wang F, Zhu B, Yang J, Zhou G, Pan Y, Tao Y, Zhong J (2017) Effects of lactic acid bacteria and molasses additives on the microbial community and fermentation quality of soybean silage. Bioreسور Technol 238:706–715

Oni AO, Arigbede OM, Oni OQ, Onwuka C (2010) Effects of feeding different levels of dried cassava leaves (Manihot esculentum, Crantz) based concentrates with Panicum maximum basal on the performance of growing West African Dwarf goats. Livest Sci 129:24–30

Régnier C, Bocage B, Archméde H (2013) Digestive utilization of tropical foliage of cassava, sweet potatoes, wild cocoyam and erythrina in Creole growing pigs. Anim Feed Sci Technol 180:44–54

Rohweder DA, Barnes RF, Jorgensen N (1978) Proposed hay grading standards based on laboratory analyses for evaluating quality. J Anim Sci 47:747–759

SAS (1996) User’s guide: statistics, version 6.12. SAS Institute, Inc., Cary

Van Soest PJ, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J Dairy Sci 74:3583–3597

Wang W, Feng B, Xiao J, Xia Z, Zhou X, Li P, Zhang W, Wang Y, Møller BL, Zhang P (2014) Cassava genome from a wild ancestor to cultivated varieties. Nat Commun 10:5110

Wang Y, He L, Xing Y, Zhou W, Pan R, Yang F, Chen X, Zhang Q (2019) Bacterial diversity and fermentation quality of Moringa oleifera leaves silage prepared with lactic acid bacteria inoculants and stored at different temperatures. Bioreسور Technol 284:349–358

Yang L, Yuan X, Li J, Dong Z, Shao T (2019) Dynamics of microbial community and fermentation quality during ensiling of nonsterile and nonsterile alfalfa with or without Lactobacillus plantarum inoculant. Bioreسور Technol 275:280–287

Yu Z, Naoki N, Guo XS (2011) Chemical changes during ensilage and in sacco degradation of two tropical grasses: rhododendron and guineagrass treated with cell wall-degrading enzymes. Asian Aust J Anim Sci 24:214–221

Zahrioddini H, Baah J, Absalom W, McAllister TA (2004) Effect of an inoculant strains with cell wall-degrading activities based on laboratory analyses for evaluating quality. J Anim Sci 153:178–192

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