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In situ rumen digestibility of ester-linked ferulic and *p*-coumaric acids in crop stover or straws in comparison with alfalfa and Chinese wild ryegrass hays

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ABSTRACT

Phenolic acids are widely distributed in graminaceous plant cell walls. Five Charolais × Nanyang crossbred steers, fitted with rumen fistulas, were used as experimental animals. Nylon bags containing corn stover, wheat straw, rice straw, alfalfa hay and Chinese wild ryegrass, commonly used forages on dairy farms in China, were incubated in the rumen for 6, 12, 24, 36, 48 and 72 h. Unlike the observations for alfalfa hay, ruminal disappearance of ester-linked ferulic (FAest) and *p*-coumaric (PCAest) acids in Chinese wild ryegrass and crop stover and/or straw was dependent on the incubation time ($P < 0.001$), and the disappearance of FAest was much greater than that of PCAest. The rapidly degradable fractions (*a*) of FAest and PCAest were all lower than the insoluble but potentially degradable fractions (*b*) in all forages except alfalfa hay. The degradation rate (c) of fraction *b* for both phenolic acid types was highest in alfalfa hay, followed by Chinese wild ryegrass hay, crop straw and/or stover ($P < 0.001$). Consequently, effective degradability (ED) ranked as: alfalfa hay > Chinese wild ryegrass > corn stover > rice straw > wheat straw ($P < 0.001$). Contents of lignin (sa), ether-linked ferulic acid (FAeth) and ether-linked *p*-coumaric acid (PCAeth) in the forages were negatively correlated with *a*, *b*, c and ED values of forage FAest and PCAest degradation ($P < 0.05$). In contrast with alfalfa hay, soluble FAest and PCAest fractions were lower in crop straw and/or stover and Chinese wild ryegrass, and the insoluble phenolic acid fraction can be potentially degraded in the rumen. The degradation of FAest and PCAest in the rumen was dependent on forage FAeth and PCAeth contents, as well as lignin (a) content, in the forages.

1. Introduction

Phenolic acids, especially ferulic acid and *p*-coumaric acid, are receiving increasing attention because of their association with plant cell wall lignification (Wang et al., 2013). These acids are ubiquitous residues in plant cell wall, and account for 2–20 g/kg of the cell wall of forages (Fahey and Jung, 1989). As shown in Fig. 1, most ferulic acids in the primary cell wall

Abbreviations: *a*, rapidly soluble fraction; ADFom, acid detergent fiber corrected with residual ash content; *b*, insoluble but potentially degradable fraction; *c*, degradation rate for fraction *b*; ED, Effective degradability; FAest, ester-linked ferulic acid; FAeth, ether-linked ferulic acid; Lignin (sa), lignin determined by solubilization of cellulose with 72% sulfuric acid; NDFom, neutral detergent fiber corrected with residual ash content; PCAest, ester-linked *p*-coumaric acid; PCAeth, ether-linked *p*-coumaric acid.

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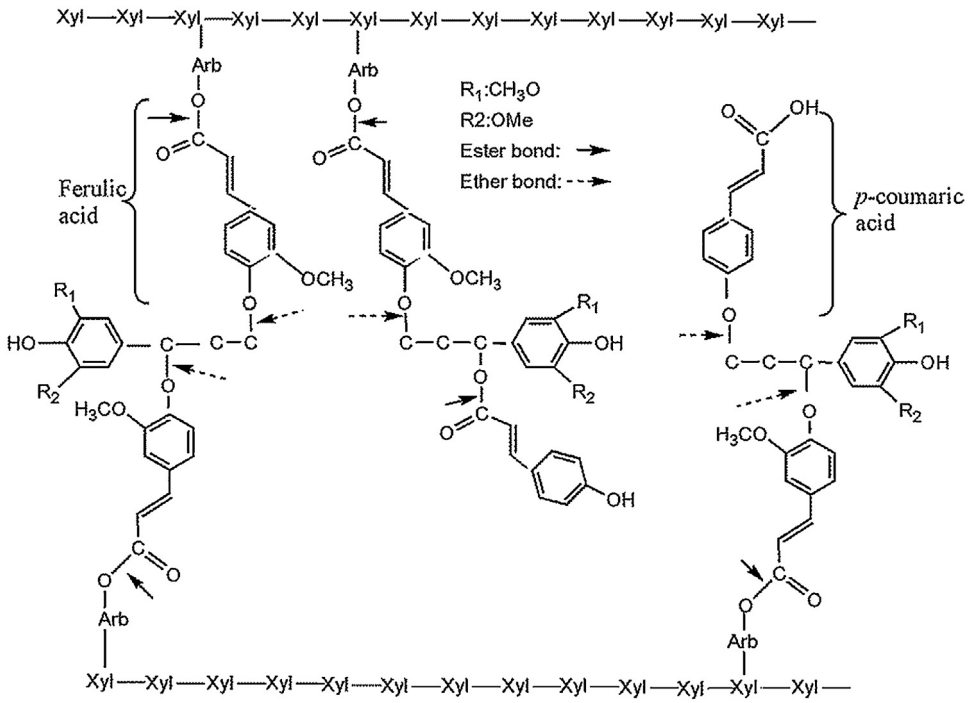

Fig. 1. Ferulic and *p*-coumaric acids linkages in the plant cell wall through ester and ether bonds.

are linked with araboxylan by ester bonds, while some ferulic acids are linked with lignin by ether bonds during cell wall maturation to form cross linking structures (Iiyama et al., 1990; Argillier et al., 1996b; Jung and Lamb, 2003). Other well-accepted indicators of lignification are *p*-coumaric acid which form ester bond linkages with syringyl monolignol units of lignin in secondary cell walls (Argillier et al., 1996a). The ester bonds in the plant cell wall, along with other cell components, can be disrupted by esterase activity of rumen microorganisms to release the free form of ferulic acids and *p*-coumaric acids into the rumen contents.

Lignin is considered a key factor affecting the potential extent and rate of cell wall digestion (Casler and Jung, 1999; Jung and Lamb, 2003). Lignin has been reported to accounts for 0.4–0.6 of the variation in cell wall digestion in ruminants (Jung et al., 2011). Non-lignified cell wall tissues can be digested quickly and completely, whereas the degradation of lignified tissues are limited (Engels and Jung, 2005). The presence of ether-linked ferulic acids (FAeth), as a measurement of cross linking between lignin and arabinoxylans, negatively affected cell wall digestibility (Rodrigues et al., 2007; Jung et al., 2011). Rumen microorganisms can degrade FAest and PCAest deposited in the cell wall; however, little research has focused on the effects of lignin and cross linking structures on the degradation of ester-linked phenolic acids.

Crop residues (*e.g.* crop stover or straws) are often used as forage ingredients for ruminants in China, despite their low digestibility due to high lignin content and cross-linking between lignin polymers and polysaccharides in the cell wall. Wang et al. (2013) reported that the lignin content was negatively and positively correlated with ferulic and *p*-coumaric acid contents, respectively. However, knowledge is limited regarding the ruminal degradation profile of ferulic and *p*-coumaric acids in non-alfalfa crop residues commonly used as important forages, especially in China. In the present study, corn stover, wheat straw, rice straw, Chinese wild ryegrass, which are common feeds on dairy farms in China, were chosen as tested forages. The objective was to determine the *in situ* rumen degradation kinetics of ferulic acid and *p*-coumaric acid in these forages in comparison with alfalfa hay and to explore their association with phenolic acid content in forage cell walls.

2. Materials and methods

The experiments in the present study were conducted at the Experimental Stall of State Key Laboratory of Animal Nutrition of China Agricultural University (Beijing, China). The whole experiment was carried out in accordance with the practices outlined in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching of the China Agricultural University Animal Care and Use Committee.

2.1. Forage sample

Corn (*Zea mays* L.) stover, rice (*Olyza sativa* L.) straw, wheat (*Triticum aestivum* Linn.) straw, alfalfa (*Medicago sativa* L.) hay and Chinese wild ryegrass (*Leymus chinensis* Trin.) were collected from different dairy farms of China. Five samples for