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Impacts of silica levels, and location in the detergent fiber matrix, on *in vitro* gas production of rice straw

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ABSTRACT

Rice straw can be used as a forage for cattle, generally those whose intake potential exceeds their energy need, to provide economic savings in cattle production systems. This study evaluated how simulated field drying of rice straw, its silica level and location in the detergent fiber matrix, impacts *in vitro* gas production. We also determined how *in vitro* gas production is impacted by removing Si from rice straw entirely by growing it in a Si-free hydroponic solution. In Experiment 1, rice plants grown in controlled conditions were analyzed fresh (*i.e.*, within 60 min of harvest), and when fully dried (*i.e.*, 25 °C for 7 d), for dry matter, ash, acid detergent fiber (ADF), neutral detergent (ND) extracted ADF (ND/ADF), Si in ADF (ADF-Si) and ND/ADF (ND/ADF-Si), as well as *in vitro* gas production. Fresh straw had a higher proportion of ADF-Si (539 *versus* 485 mg/g total Si; $P < 0.01$) and less Si in ND extracted ADF (196 *versus* 340 mg/g total Si; $P < 0.01$), than the same plants after drying, which may have caused the higher *in vitro* gas production of fresh straw. However, in Experiment 2, the ADF-Si, ND/ADF-Si and total Si were not predictive of *in vitro* gas production in a set of 39 commercially grown field samples of rice straw, possibly due to the narrow range of Si values in the samples or because the location of the Si in the fiber matrix, or Si itself, is not predictive of the digestibility of its organic matter (OM). In Experiment 3, rice grown under controlled conditions in Si free or Si containing hydroponic media, in two sub-experiments, had similar gas production per unit OM. The general lack of impact of rice straw Si levels, either total or relative to location in the detergent fiber matrix, on *in vitro* gas production seems to demonstrate conclusively that Si is not causative to the low fermentability of rice straw OM.

1. Introduction

Rice is the second largest cereal crop in the world and produces about 377 million tonnes of crop residues annually (FAOSTATS, 2009). It is used as a feed source for ruminants in most countries where availability of primary agricultural products and by-product feeds are limited. Extensive reviews and evaluations of rice straw and other crop residues have reported methods to improve the nutritive value and utilization of crop residues, including rice straw, as a feed source for ruminants (Sundstøl and Owen, 1984; Dixon, 1988; Schiere and Ibrahim, 1989).

Abbreviations: ADF, acid detergent fiber; ND/ADF, sequential analysis with AD followed by ND; CP, crude protein; DM, dry matter; GP, gas production; NDF, neutral detergent fiber; OM, organic matter; ADF-Si, Si in ADF; ND/ADF-Si, Si in NDADF.

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Varietal differences of rice straw were extensively evaluated and differences shown in straw composition (Abou-El-Enin et al., 1999; Bainton et al., 1991; Vadiveloo, 1992, 1995). The nutrient value of rice straw is much lower than alfalfa hay, generally making it inappropriate for rations for lactating dairy cows, but there is substantial variability in the nutrient levels and feeding value among rice straws. However, in general, California (USA) rice straws range (g/kg dry matter (DM)) from about 600 to 725 neutral detergent fiber (NDF), 436 to 550 acid detergent fiber (ADF) and 33 to 70 crude protein (CP; Nader and Robinson, 2010). Factors which impact rice straw feeding value include plant maturity at harvest (*e.g.*, grain head moisture), the soil in which the rice is grown, rice variety and N fertilizer management. However research by our group has shown that rice straws with ADF values below ~480 g/kg DM have high enough nutritive value to be considered to be feed quality relative to replacement dairy heifers, while those with ADF values above ~500 g/kg DM should be avoided as feed for any class of cattle (Nader and Robinson, 2010).

Rice plants have the ability to accumulate Si from soil into its plant structure. Silicon is taken up by roots of rice plants in the form of silicic acid as an undissociated molecule (Takahashi and Hino, 1978) mediated by a specific transporter. Immediately after uptake, silicon is translocated to the shoot in the form of monomeric silicic acid and deposited on cell wall material as a polymer of hydrated amorphous silica (Ma and Yamaji, 2006) forming Si-cuticle double layers and Si-cellulose double layers on the surface of leaves, stem and hulls (Yoshida, 1965). The Si content of the rice plant is important for production of grain as it improves water efficiency by reducing transpiration, protects against fungi, bacteria and insects, and keeps the leaves and stems erect to decrease lodging and increase photosynthesis (Kim et al., 2002). Silica has long been thought to be a limiting factor to rice straw nutritional quality for cattle (Van Soest, 2006). Comprising 100–150 g/kg DM of the plant (as SiO_2), it has been postulated that Si is either a large amorphous opal (*i.e.*, SiO_2) which is simply inert mass and takes up space in the rumen with no nutritive value, or that Si is chemically associated with lignin, cellulose and/or hemicelluloses, thereby impeding digestion beyond taking up space in the rumen (Van Soest, 2006). Early studies showed a negative effect of Si on forage digestibility in ruminants (Carlisle et al., 1977; Balasta et al., 1989), which may be due to the physical barrier formed by the external Si layer, as proposed by Kawamura et al. (1973) and Harbers et al. (1981), or to inhibition of action on hydrolyzing enzymes. In contrast, Smith and Urquhart (1975) and Shimojo and Goto (1989) found that the *in vitro* digestibility of rice straw is negatively affected by increasing amounts of soluble Si in the tissue. However, in a study of European rice straws, Agbagla-Dohnani et al. (2001) found no relationship between microbial degradation of rice straw and its ash or Si content, although the Si contents of 52–81 g/kg DM were low for rice straws. Wang et al. (2006) and Santos et al. (2010) suggested that the morphological location of Si in a plant causes differences in *in vitro* gas production of rice straw.

The aims of this study were to determine if the location of Si in the detergent fiber matrix is related to reduced *in vitro* gas production in dried *versus* fresh rice straw plants, determine if detergent matrix Si fractions could be used as a predictor of gas production in rice straws, and to determine if removal of Si from rice straw impacts its *in vitro* gas production by growing rice straws in a Si-free hydroponic media.

2. Materials and methods

2.1. Experiment 1 – impacts of plant physiological stage and drying on in vitro gas production and recovery of silica in detergent fiber fractions

2.1.1. Rice plant propagation

Rice plants were grown in individual pots at the California Rice Experiment Station (Biggs, CA, USA) under controlled conditions in a greenhouse with a photoperiod of 11 h 30 min/d, in a 60 and 80% relative humidity (±5% units) environment during the day and night, respectively, and with a temperature of 28 and 26 °C during the day and night, respectively. Plants were grown in 6 groups with 6 replicate pots each, where the 6 groups were planted at intervals of 7 d and transported in an enclosed truck box to the University of California (Davis, CA, USA) simultaneously when the plants ranged from 126 to 146 d of age. Plant head moisture was used to determine the physiological stage of the plant. Upon arrival at UC Davis, the 36 plants were stored overnight in their pots in a laboratory at room temperature (*i.e.*, 25 °C).

2.1.2. Rice plant harvest and preparation for in vitro analyses

Plants were harvested in sequence from group 1 to group 6 by two persons by cutting at a height of ~20 cm, removing all dead leaf sheaths, and placing in individual sealable plastic bags. Rice grains in their hulls were then hand stripped from the plant and collected for subsequent head moisture determination. As the plants were being harvested, samples were chopped by three other persons with office paper cutters (EPI 26315 Elmer's Products, Inc., Columbus, OH, USA) to create particles between 0.5 and 2.0 mm in length, which were placed in individual plastic containers with sealable tops. These samples had weights of 2.5–6.0 g. These samples (treatment designation 'Fresh') were immediately (*i.e.*, within 60 min of harvest) sub-sampled and assays initiated for *in vitro* gas production, ADF and ND extracted ADF, as well as DM and ash.

The balance of the chopped sample was spread on a thin layer of aluminum foil and allowed to dry (treatment designation 'Dried') at room temperature for 7 d (*i.e.*, 25 °C), after which assays for *in vitro* gas production, ADF and ND extracted ADF, as well as DM and ash were completed, exactly as for the 'Fresh' samples.