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Impact of simulated field drying on *in vitro* gas production and voluntary dry matter intake of rice straw

M.B. Santos[a,b], G.A. Nader[c], P.H. Robinson[a,*], D. Kiran[d,1], U. Krishnamoorthy[d], M.J. Gomes[b]

[a] *Department of Animal Science, University of California, Davis, CA 95616, USA*
[b] *CECAV, Universidade de Trás-os-Montes e Alto Douro, Vila Real, Portugal*
[c] *University of California Cooperative Extension, Yuba City, CA 95991, USA*
[d] *Department of Livestock Production and Management, Veterinary College, Karnataka Veterinary, Animal & Fisheries Sciences University, Bengaluru 560024, India*

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ABSTRACT

Due to the recent expansion of the motor fuel ethanol industry, which is largely based upon traditional food and feed crops, supplies of ruminant feeds have become limited in many areas of the world thereby creating a need for alternatives. Rice straw, a substantial biomass source worldwide, could fill this role if its nutritional value was higher. Our aims were to determine changes in the nutritive value of rice straw during long term storage, and short term field drying, as well as the voluntary DM intake of rice straw by heifers before, during and immediately after field drying. In Experiment I, rice straw was macerated and stored for 82 days after baling, but there was no effect on chemical components or 30 h *in vitro* fermentability of neutral detergent fiber (NDF) due to maceration or storage time. In Experiment II, samples of a late maturity tall (M401) and an early maturity short (M202) rice straw variety were collected prior to harvest, during simulated field drying and when fully dried. The M401 had higher acid detergent fiber (473 *versus* 445 g/kg dry matter (DM); $P<0.01$), lignin(sa) (38 *versus* 34 g/kg DM; $P<0.01$), total Si (55.0 *versus* 43.0 g/kg DM; $P<0.01$) and Si in NDF (372 *versus* 270 g/kg DM of total Si; $P=0.01$). The M202 produced 14.4, 10.6 and 9.1% more gas than the taller M401 at 4, 24 and 72 h of *in vitro* fermentation, respectively. Fresh plants produced 6.8, 15.6 and 8.9% more gas than plants collected during simulated field drying and as dry plants at 4, 24 and 72 h of *in vitro* fermentation, respectively. In Experiment III, voluntary DM intake of rice plants was measured at the same three stages (*i.e.*, fresh, during simulated field drying, dry), and results were consistent with Experiment II, in that DM intake of fresh plants was higher than plants during both simulated field drying and when dry (5.14 *versus* 4.13 *versus* 3.69 kg DM/day; $P<0.01$). That long term storage of straw after baling did not impact levels of its chemical components or 30 h *in vitro* fermentability of NDF, but gas production of fresh plants was higher than that of plants during simulated field drying and when fully dried, supports the hypothesis that the much higher voluntary DM intake potential of fresh rice plants occurred due to changes during field drying that reduced its fermentability. It seems certain that this depressed DM intake was related to the decrease in fermentability of dry *versus* fresh plants, although the cause

Abbreviations: ADF, acid detergent fiber; ADNDF, sequential analysis with acid detergent followed by neutral detergent; CP, crude protein; D, dry rice straw; DM, dry matter; FD, field drying; $dNDF_{30}$, 30 h *in vitro* digestible NDF; Fz, frozen rice straw; GP, gas production; NDF, neutral detergent fiber; OM, organic matter; Pre, pre-harvest rice plants; SFD, rice straw during simulated field drying; SiADF, Si in ADF; SiADNDF, Si in ADNDF; SiNDF, Si in NDF.

* Corresponding author. Tel.: +1 530 754 7565; fax: +1 530 752 0175.
E-mail address: phrobinson@ucdavis.edu (P.H. Robinson).

[1] Present address: Department of Animal and Poultry Science, University of Saskatchewan, Saskatoon, SK S7N 1L5, Canada.

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of the reduced fermentability is not clear. However analyses of Si levels in the detergent fiber fractions provided indications that the location of the Si in the structural carbohydrates may be important in this regard.

1. Introduction

Unstable feed prices, together with increasing plant diversion to biofuel production, has negatively impacted forage availability to the dairy industry in many parts of the world. This has stimulated renewed interest in nutritional studies of plant by-products, particularly cereal straws, as feeds. Rice is the world's second largest cereal crop, first in Asia and third in the USA (FAOSTATS, 2009), but it creates the largest amount of crop residues worldwide (377 million tonnes per year; FAOSTATS, 2009). In California, until 1996, rice crop residues were mostly field incinerated to prevent plant diseases. This strategy is now restricted in California due to air quality concerns and this has created a need for more off-field uses of rice straw.

Rice straw is known to have a low nutritional value and numerous studies have been completed over the years to increase it. Rice straw is unique among feed plants in its high silica (Si) content but, within rice straws, there is a wide range of values (1–100 g/kg dry matter (DM); Epstein, 1999) due mostly to variety and environmental conditions during growth (Khush et al., 1988; Van Soest, 2006). Rice plants need a high Si concentration to enhance strength and rigidity (Ma and Yamaji, 2006), resist disease (Kim et al., 2002; Rodrigues et al., 2005; Ma and Yamaji, 2006), reduce cuticular transpiration and improve water use efficiency (Kim et al., 2002). In the plant, Si is translocated from the soil to the shoot as silicic acid where it is polymerized into silica gel ($SiO_2{\cdot}nH_2O$), with more than 0.9 of total Si being in this form, and it is then deposited in the bulliform cells and under the cuticle (Ma and Yamaji, 2006) as the stable SiO_2 complex. In Si accumulating plants, such as rice, some researchers observed negative effects of higher Si on plant digestibility (Van Soest and Jones, 1968; Bae et al., 1997; Agbagla-Dohnani et al., 2003) and ruminal *in sacco* degradation of rice straw (Agbagla-Dohnani et al., 2003) indicating that Si may, in some way, have a negative effect on plant digestion or degradation. In contrast, Khush et al. (1988) found no effect of Si on *in vitro* organic matter (OM) digestibility.

There are several hypotheses relative to possible mechanisms by which Si negatively impacts digestion of plant cell walls of rice straw. Some researchers have suggested that Si acts as a physical barrier (Bae et al., 1997; Kim et al., 2002), and others that it has an inhibitory action on hydrolyzing enzymes in the rumen (Smith and Urquhart, 1975; Agbagla-Dohnani et al., 2003). Although there are studies that suggest a negative correlation to Si and digestibility, it is generally considered that Si, after being deposited in the plant, does not change chemically and will not react with other plant components, such as non-structural carbohydrates and/or structural carbohydrates (Van Soest, 2006). However, it is possible that Si changes chemical form and/or forms linkages to other structures in the plant that increases or decreases its digestibility, thereby resulting in differing digestibility which also may vary according to the phase of the plant (*i.e.*, green or dried as straw) due to the different chemical forms of the Si in plants in these phases.

It is common that forages lose some nutritional value during field drying and conservation. Losses occur due to plant respiration, leaf crushing, leaching by rain and losses during storage due to oxidation and fermentation that all contribute to a decrease in nutritional value (Lee, 1988). These factors adversely affect the most digestible components of the plant, especially the water-soluble carbohydrates and proteins, which increases the fiber content, reduces OM and crude protein (CP) digestibility, and reduces DM intake (Lee, 1988). The decline in chemical composition and nutritive value upon field drying varies in magnitude and depends on factors such as speed of drying, which can be enhanced by maceration (Nader and Robinson, 2008), and weather conditions (Lee, 1988), who also suggested that the proportional change in nutritive value from fresh plants of dry grasses is −0.016 and −0.030 for OM digestibility and voluntary DM intake, respectively. However when Sharif (1984) compared intake and digestibility of fresh rice plants at harvest (*i.e.*, 590 g/kg dry matter (DM)) to dry rice straw (*i.e.*, 920 g/kg DM) in sheep, he found that they consumed and digested 30% more DM when fed fresh *versus* stored straw. However as these rice plants were not from the same lot, a confounding of lot and treatment occurred which may have impacted the findings.

The aims of our experiments were to determine losses of nutritive value in rice straw during long term storage (*i.e.*, 82 days), as well as during short term field drying of fresh plants to create straw. The possible role of Si in this loss of nutritive value relative to its location in the fibre fractions was also assessed. Finally, voluntary DM intake of rice straw by heifers before, during and immediately after field drying were determined.

2. Materials and methods

2.1. Experiment 1—impacts of long term storage of rice straw on its nutrient value as impacted by maceration

2.1.1. Rice straw treatments

Rice straw baled from two fields, that were part of the study on maceration of rice straw reported by Nader and Robinson (2008), were used in a split-field design that divided each field into control and macerated sections. These 2.4 ha rice fields, near Williams (CA, USA), had been managed similarly during growth and were harvested with a Hardy Harvester (Hardy Co.,