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Some Observations on Rice Straw with Emphasis on Updates of its Management

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Abstract: Rice is the world's second largest cereal crop after wheat, however, it produces large amounts of crop residues. Only about 20% of rice straw was used for purposes such as ethanol, paper, fertilizers and fodders and the remaining amount is either removed from the field, *in situ* burned, piled or spread in the field, incorporated in the soil, or used as mulch for the following crop. Burning causes air pollution called the "Black Cloud" and loss of nutrients depending on the method used to burn the straw. Rice straw is unique relative to other cereal straws in being high in silica and lignin with low digestibility and protein content. Rice straw in developing countries is used as a main feed for ruminants. Enhancement of the nutritive value of rice straw with physical, chemical or biological treatments has been the focus of recent research work. Physical treatments such as crushing are related to breaking the silicified encrusting layer of straws. Chemical treatment of straw with alkalis such as ammonia and sodium hydroxide, has been commonly used for improving both apparent digestibility, bacterial colonization on cellulose and voluntary intake of straws. Fiber explosion (FIBEX) and soaking straws in wood ash extract processes showed significant increase *in vivo* digestibility. Supplementation with oilseed meal/cakes or rapeseed meal (RSM) and mulberry leaves as protein supplements was found to improve animal performance. Certainly, treatments using fungi and their enzymes for improving the quality of rice straw are relatively scarce. These techniques should be further developed. It was concluded that although several treatments have been used to improve the degradability and voluntary intake of rice straw, such as physical or chemical treatments, the practical use of these treatments is still restricted in terms of safety concerns, costs and potentially negative environmental consequences. Moreover, the application of ligninolytic fungi or their enzymes combined with chemical pre-treatments to rice straw may be an alternative way to shorten the period of the incubation and or decrease the amount of chemicals, affecting some synergy.

Key words: Rice straw · Pollution · Alkalis · Ammonia · Fungi

INTRODUCTION

Rice is one of the most abundant crops in Egypt, 2 million feddans [1] with an average production of about 6.12 million tons per year and 9.5 tons per hectare in 2005 [2]. It is mainly cultivated in the northern east part of the country [3] especially in Kafr El-Sheikh, Al-Sharkia and Al-Dakahlia governorates [4]. In Egypt, processing of rice in the river Nile Delta yields large amounts of rice straw as residue. About 20% was used for other purposes such as ethanol, paper and fertilizers production as well as fodders [3] and the remaining part was left on the fields for burning within a period of 30 days to get quickly rid of leftover debris. The resulting emissions significantly contribute to the air pollution called the "Black Cloud"[5].

Rice Straw as a Source of Pollution: Burning of straw causes atmospheric pollution and nutrient loss although it is a cost-effective method for straw disposal. Also. it helps to reduce diseases that may occur due to reinfection from inoculum in the straw biomass [6]. However, biomass burning has drawn global concerns for its effects on visibility, health and global climate by emitting particulate matters and other gaseous pollutants [7]. Pollutants

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emitted during Biomass burning can produce significant changes in blood parameters as indicated by lymphocytosis, eosinophilia and neutrophilia in sheep [8], oxidative stress [9,10] as well as kidney [11] and liver dysfunctions in buffaloes [12]. Biomass burning releases considerable amounts of some environmental toxicants which function as endocrine disruptors and affect the integrity of reproductive function in mammals and ultimately contribute to infertility [13]. Disappeared estrous activity, increased number of services per conception and high incidence of smooth ovaries with low progesterone level were evidenced in cross bred cows [8,14] with impairment of reproductive health and adverse effects on fetal outcomes is increasingly recognized [15].

Possible Strategies to Improve Rice Straw Utilization: The use of cereal straw for ruminant feeding is constrained by its low digestibility due to high silica and lignin as well as low protein and energy contents when given as the only feed to animals [16] .

Ruminants primarily digest fibrous feeds with the aid of rumen microbial enzymes which bound to feed particles during digestion [17]. Enhancement of the nutritive value of dry roughages with physical, chemical or biological treatments has been the focus of research work [18].

Physical Treatment: Physical treatments of crop residues have received an appreciable amount of research. Crop residues can be ground, soaked, pelleted or chopped to reduce particle size or can be treated with steam and/ pressure or X-rays. Many of these treatments are not practical for use on small-scale farms as they require machines or industrial processing [19]. However, small machines to grind or chop rice straw may be feasible. It was reported that the use of steam treatment in a high pressure vessel at different pressures and for a range of different treatment times increased the rate of *in vitro* degradation in the rumen fluid after 24 h and but could not enhance the potential degradability of the fibrous fractions, neutral detergent fibers (NDF), acid detergent fibers (ADF) and hemicelluloses[20]. Steam and /pressure treatment of rice straw is another promising method to improve the quality of cellulosic feedstuffs for animals by solubilization of cellulose and hemicellulose and/or by freeing digestible materials from lignin or silica [21]. By applying the steam explosion process, Kling *et al*. [22] demonstrated that about 60% of the hemicellulose fraction in the sugercane bagasse was hydrolyzed and further, the susceptibility of cellulose to enzymatic hydrolysis increased. Steam pressure without ammonia increases acidity and promotes solubilization of hemicelluloses. The increases in acidity come partly from the release of acetyl groups in the hemicellulose and are likely an explanation of some of the increased digestibility [23] Increases in digestibility are in the same range as for ammonia treatments [24].

Chemical Treatment: Chemicals used to improve the utilization of rice straw may be alkaline, acidic or oxidative agents. Among these, alkali agents have been most widely investigated and practically accepted for application on farms. Basically, these alkali agents can be absorbed into the cell wall and chemically break down the ester bonds between lignin and hemicellulose and cellulose and physically make the structural fibers swollen [25, 26]. These processes enable the rumen microorganisms to attack more easily the structural carbohydrates, enhancing degradability and palatability of the rice straw [27-29]. The most commonly used alkaline agents are sodium hydroxide (NaOH), ammonia (NH_3) and urea.

NaOH Treatment: Several NaOH treatment methods to improve the use of crop residues for ruminant feeding have been developed by [30-32]. The principal advantages of the different NaOH treatments are increased degradability and palatability of treated straw compared to untreated straw [33, 34]. However the application of NaOH can be a cause of environmental pollution, resulting in a high content of sodium in the environment [35].

NH_3 Treatment: Treatment of straw with anhydrous and aqueous ammonia or other ammonia-releasing compounds has been widely investigated to improve degradability [36-38]. Ammonia treatment not only increases the degradability of the straw, but also adds nitrogen [36] and preserves the straw by inhibiting mould growth [39]. Besides, ammonia treatment is an effective means of reducing the amount of supplemental nitrogen, reducing the costs of purchasing protein-rich feedstuffs and enhancing acceptability and voluntary intake of the treated straw by ruminants.

The ammonia treatment slightly decreased NDF and increased ADF contents indicating that the cell wall properties were changed. Moreover, ammoniated rice straw is characterized by low physical strength, higher proportion of small feed particles with more attachment and growth of the rumen bacteria [37]. The reduced particle size and the increased attachment sites could lead to subsequent increased microbial colonization and digestion. So, ammonia treatment increases feed value by making the cell wall more available for the rumen microorganisms and also the increased N content improves microbial growth. El- Khadrawy [40] fumigated rice straw with anhydrous ammonia (30kg/ ton, 3%) followed by storage for 21 days in plastic cover and aeration for 2-3 days before feeding. Egyptian buffalo bulls fed on ammoniated rice straw showed increased body weight and improved semen parameters, ejaculate volume, mass motility, sperm concentration and live / dead ratio. The condition was attributed to higher protein and sugars available in the ammoniated straw compared to untreated one. Microwave irradiation pretreatment of rice straw has been successfully applied in many fields because of either non-thermal or thermal effects arising from the heating. The general idea of this method is to remove or alter hemicellulose or lignin, decrease the crystallinity of cellulose and increase the surface area [41].

FIBEX-treated rice straw is prepared by heating 300 g ammonia/kg straw under pressure 13-15 atm at 110-132°C with for 5-10min.Then pressure is rapidly released to "explode" the fiber and then straw is dried in a flow through dryer. The main advantage of the fiber explosion (FIBEX) process may be better recovery of ammonia and straw. Feeding dairy cows on FIBEX-treated rice straw resulted in increased *in vitro* digestibility by ruminal microorganisms due to a reduced lag time, increased rate and extent of digestion and possible removal of inhibitory agents present in untreated rice straw [42].

Urea Treatment: Rice straw can also be treated with urea, which releases ammonia after dissolving in water. For practical use by farmers, urea is safer than using anhydrous or aqueous ammonia and also provides a source of nitrogen (crude protein) in which straw is deficient [19]. Urea can be obtained easily in many developing countries as it is easy to handle and transport [35] and cheaper than NaOH or NH_3. Vadiveloo [43] reported that rice varieties with a low degradability responded better to urea treatments than higher quality straw, increasing *in vitro* dry matter degradability from 45-62%. Urea treatment may therefore be most suitable for small-scale farmers to improve the quality of straws, particularly varieties showing a low degradability.

Lime Treatment: Lime [Ca O /Ca (OH) 2] is a weak alkali agent with a low solubility in water. It has been reported that lime can be used to improve the utilization of straw and supplement the ration with calcium, which has been found to be in a negative balance in cattle fed only rice straw [44-46]. Although lime treatments either by soaking and ensiling increase the degradability of straw, the dry matter intake decreases due to a reduced acceptability of the treated feed by animals.

Feeding Rice Straw Supplemented with Other Components: Supplementation of rice straw with oilseed or rapeseed meal or mulberry leaves as protein supplements may increase digestibility, feed intake and improve animal performance [47, 48]. The growth rate of growing lambs fed on ammoniated rice straw diet supplemented with small amount of rapeseed meal (RSM) was dramatically increased [49]. Supplementation with mulberry leaves had more benefits as indicated by an increased intake of basal diet, less consumption of concentrate and an increased income. However, supplementation of rice straw with rapeseed meal and mulberry leaves together had negative effect on lamb growth [50]. Supplementation of straws with wood ash extract by soaking showed significant increase *in vivo* digestibility of and dry matter intake by goats. Wood ash extract contains minerals such as calcium, potassium and sodium that give it alkaline properties [51] and improve nutrients digestibility of low quality roughages through solubilisation of silica and weakening of bonds between lignin and cellulose [52] .Wood ash extract has greater potential than urea in improving the digestibility of low quality roughage as it contains high levels of ash and does not have adverse effect on metabolic parameters [53]

Biological Treatment of Rice Straw: The use of fungi and/or their enzymes that metabolize lignocelluloses is a potential biological treatment to improve the nutritional value of straw by selective delignification [54]. Nevertheless, it is currently too early to apply this method in developing countries due to the difficulties and lack of technology to produce large quantities of fungi or their enzymes to meet the requirements. Many serious problems are considered and should be overcome [19] as fungi may produce toxic substances. It is also difficult to control the optimal conditions for fungal growth, such as pH, temperature, pressure, O2 and CO2 concentration when treating the fodder. With recent developments in fermentation technology and alternative enzyme production system, the costs of these materials are expected to decline in the future. Hence, new commercial products could play important roles in future ruminant production systems [55] .

White-Rot Fungi Treatment: White-rot fungi, belonging to the wood-decaying basidiomycetes, as lignocellulolytic microorganisms are able to decompose and metabolize all plant cell constituents (cellulose, hemicellulose and lignin) by their enzymes [56]. Many species of white-rot fungi which are effective lignin degraders have been used to assess their ability to improve the nutritive value of fodder for ruminant nutrition [57, 58] but fungal metabolism can dissipate carbohydrate [59]. Rice straw was treated with fungi species, Cyathus, Phanerochaete and Pleurotus by incubation in the solid state for 30 days. Cyathus and Phanerochaete increased digestibility up to 40% with modest losses in carbohydrate up 10%, while Pleurotus decreased digestibility and with large losses of cell wall carbohydrates [60, 61].

Treatment with Enzymes: Enzymatic hydrolysis of rice straw is an interesting way to produce sugars from cellulosic wastes because of its mild operating conditions, regarding pH and temperature and the absence of by-products [62, 63]. Xylan-rich cell walls which contain significant amounts of lignin, are also generally resistant to enzymatic hydrolysis and require severe chemo-mechanical pretreatments such as steaming, radiation, acid hydrolysis and alkali digestion before the polysaccharides become accessible to enzymes and can be hydrolysed to monomeric sugars in high yield [64]. Recently, treatment of chopped (2-3 cm) rice straw with soya bean, watermelon, pumpkin, jack bean and winged bean seeds containing urease reduced the treatment time to less than 5 days and produced IVOMD values similar to 14 to 21 days compared to untreated (IVOMD of 40%) and urea-treated straw alone [65] .

Rice Straw as a Fertilizer: Rice straw is the only organic material available in significant quantities to most rice farms. About 40 % (N), 30-35 % of (P), 80- 85% of (K) and 40 -50 % of (S) taken up by rice remains in vegetative plant parts at crop maturity. Straw is also an important source of micronutrients such as zinc (Zn) and the most important influence on the cumulative silicon (Si) balance in rice. Whereas mineral fertilizers are used and straw is incorporated, reserves of soil N, P, K and Si are maintained and may even be increased. Whereas S-free mineral fertilizers are used, straw may be an important source of S, thus, straw burning should not be practiced. In contrast, burning effectively transforms straw into a mineral K nutrient source and only a relatively small amount of K is lost in the process. Straw is removed from the field, burned in situ, piled or spread in the field, incorporated in the soil, or used as mulch for the following crop. Each of these measures has a different effect on overall nutrient balance and long-term soil fertility. In areas where harvesting has been mechanized (e.g. Thailand, China and northern India), all the straw remains in the field and is rapidly burned in situ, therefore, losses of S, P and K are small [66]. In Indonesia and Philippines, straw is heaped into piles at threshing sites and burned after harvest. The ash is usually not spread on field and transferred from the periphery of the field to the center, or even from surrounding fields to the center field where the residues are burned. Over time, this practice results in the accumulation of nutrients (K, Si,Ca, Mg) in some parts of the field and nutrient depletion in other parts. Incorporation of straw and stubble into wet soil (during plowing) results in temporary immobilization of N and a significant increase in methane (CH_4) emission from rice paddy, a practice that contributes to green house gases. Incorporation of large amounts of fresh straw is either labour-intensive or requires suitable machinery for land preparation and may result in the build-up of disease problems. Transplanting should be carried out two to three weeks after straw incorporation.

Rice Straw as a Source of Fuel: Rice straw biomass can be used as renewable energy to reduce air pollution by applying some suitable technologies. The general idea is to remove or alter the hemicellulose or lignin, decrease the crystallinity of cellulose, increase the surface area [41] and increase the material digestibility throurgh enzymatic hydrolysis to liberate the monosaccharides which are subsequently converted to different valuable products such as ethanol. [67]. Thus, different methods including uncatalyzed steam explosion, liquid hot water, dilute acid, flow-through acid pretreatment, lime, wet oxidation and ammonia fibre/freeze explosion, have been developed for the pretreatment of lignocellulosic biomass [68]. Additionally, most of these pretreatment methods require high-temperature or high-pressure reactions and the application of chemicals which may be toxic to the enzymes or the fermentative microorganisms. The removal of these toxicants is always costly and complicated. Microwave irradiation, different from the conventional heating methods, has been successfully applied in many fields. Ooshima *et al*. [69] demonstrated that microwave irradiation played a positive role in biomass digestion. It has become desirable to investigate the key operating parameters affecting the pretreatment so as to optimize the conditions for a further efficient hydrolysis of biomass. Zhu *et al*. [70] stated that it is difficult to fairly evaluate the influence of microwave irradiation on structures of straw concerning the silicon removal and the physicochemical surface characteristics without adding other chemicals, such as alkali, acid or H_2O_2 in the microwave pretreatment process.

It was concluded that although several treatments have been used to improve the degradability and voluntary intake of rice straw, such as physical or chemical treatments, the practical use of these treatments is still restricted in terms of safety concerns, costs and potentially negative environmental consequences. Moreover, the application of ligninolytic fungi or their enzymes combined with chemical pre-treatments to rice straw may be an alternative way to shorten the period of the incubation and or decrease the amount of chemicals, affecting some synergy

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