Husbandry and Nutrition

Review

Utilization of Lignocellulosic Residues from Mushrooms in Animal Nutrition

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ABSTRACT

Background: The inclusion of low digestibility mushroom lignocellulosic residues has become a significant part of recycling wastes. The enzymes produced are capable of transforming the substrate, improving it for further use. **Aim.** To conduct a review on the utilization of edible mushroom processing residues in animal nutrition. **Development:** The residues derived from mushroom processing consist in the substrate or *compost* that remained after edible mushroom harvesting. It has the required raw materials (stalks, husks, etc.), as well as some added compounds, such as urea or other sources of nitrogen. Besides, the action of mycelia on the *compost* may enhance its nutritional value. Edible mushrooms contain high-value bioactive compounds, and make an adequate source of prebiotics that have short-chain sugars. A fifth of all mushrooms is left on the bedding, providing nutritional and medicinal values. The nutritional changes were evaluated with techniques like the Weende scheme, and of *in vitro*, *in situ*, and *in vivo* determinations of digestibility. **Conclusions:** The results of this study showed that the residues from edible mushroom processing using low-quality sources (especially harvested rice stalks and husks), may be used for animal nutrition, whose evaluation is necessary through the proper methods.

Key words: nutrition, animals, mushrooms (*Source: DECS*)

INTRODUCTION

Mushrooms comprise a varied group of species that can be grown for commercial and individual use. They is an ecologically healthy source of protein to humans, and are produced on a substrate consisting of wastes, which otherwise could have little usefulness. The substrate is transformed thanks to the mushroom itself, through exogenous enzymes that improve the crop for later use in animal nutrition (Bhardwaj *et al.*, 2021). Food production for humans is a growing need, which increasingly depends on animal raising and animal derivatives. In sustainable agriculture,

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mushrooms have demonstrated to be an important part of recycling of wastes, as their enzymes transform the substrate and make it useful for further utilization (Pratheesha *et al*., 2020).

Therefore, one of the critical applications of residues from mushroom production is in animal nutrition, as these plants can improve the nutritional quality of lignified substrates, such as rice husks and stalks. Besides, it produces certain amounts of foods for human consumption, and the consumption of monogastric species (Palangi *et al.*, 2022).

Overall, most references have focused on mushrooms; however, the number of papers referring to the residues and their added value, are few (Urrego *et al*., 2013).

Hence, this paper aims to review the utilization of residues from growing edible mushroom for animal nutrition.

DEVELOPMENT

Mushrooms as an alternative

There is a growing demand of healthy foods grown to be environmentally friendly, particularly in developing countries. Therefore, the production of foods with high protein contents is a demand, such as the case of edible mushrooms from subproducts of the agroindustry (FAO, 2016; Aguilar *et al.*, 2017).

Every year, the farm industry generates low-nutritional lignocellulosic residues (Márquez, 2021), particularly husks and stalks (such as rice husks) which could be used to feed ruminants. The main shortcoming is their low average digestibility, slow passage through the rumen, low levels of propionate and low contents of fermentable nitrogen and protein. (Heuze and Tran, 2013).

Possible utilization of subproducts in animal nutrition and evaluation methods

In general terms, nutrition is the costliest element in animal production, and using matter, like the residues from mushroom production might help reduce expenses. The inclusion of this subproduct is also a form of protecting the environment (Ojha *et al*., 2019; Palangi *et al*., 2022).

Mushroom farming makes an efficient biotechnological system, which according to Pihna-Guzmanny Nieto (2016), is already producing high yields and productivity, with little environmental controls. The authors note that mushrooms have short growing times, they can develop within a broad range of temperatures, and are capable to use diverse lignocellulosic materials as substrate. The residues derived from mushroom processing is the substrate or *compost* that remained after mushroom harvesting. It has the required raw materials (straws, husks, stalks, etc.), as well as some added compounds, such as urea or other sources of nitrogen. Besides, the action of mycelia on the *compost* may enhance its nutritional value (El-Waziry and Alkoaik, 2016; Narváez *et al*., 2021; Palangi *et al*., 2022).

A fifth of all mushrooms stay on the bedding, providing nutritional and medicinal values (prebiotic). Urrego *et al*. (2013) conducted a nutritional characterization of edible mushrooms; they focused on changes in the nutritional value have not only relied on the chemical composition

(CP, CF, NDF), but also on its *in vitro* digestibility, and in animal tests, with a proven effectiveness. Several authors state that the residues can be used not only for ruminants, but also in monogastric species, depending on the initial substrate and management with additional products (El-Waziry and Alkoaik, 2016; Narváez *et al*., 2021).

The residual substrate from edible mushrooms is biomass associated with the metabolic activity of mycelia while growing. Palangi *et al*. (2022) studied the changes in the characteristics of the substrates based on their use for mushroom production. There is a reduction in the levels of fiber, and consequently, an increase in *in vitro* digestibility. According to the results, the substrate where the mushrooms were grown improved their *in vitro* fermentability, and it could be used in ruminant nutrition. Yagi *et al*. (2019) did a study on *Pleurotusostreatus*, and used methods to evaluate hydrolase activity on the extracts. They reported improvements in the quality of those foods for consumption by animals who had been struck by heat stress. A study conducted by Kazige *et al*. (2022) in the Republic of Congo related to food safety assurance (mushroom *Pleurotusostreatus*) showed positive yields when the farming residues were mixed with small amounts of cattle manure.

In a comparative study, Márquez (2021) found that the content of ashes declined by 9%, whereas the crude protein rose in almost 3%. The *in vitro* degradability of dry matter was higher after mushroom development and harvest. The pit-free residue showed 12.4, 29.1, 26.1, and 39.6% improvements in crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and ashes, respectively. The material contains most minerals which makes it appropriate for the nutrition of ruminants. Upon the evaluation of such changes in sugarcane bagasse used as an initial substrate, Narváez *et al*. (2021), measured the changes following the harvest of *Pleurotusostreatus and Lentinulaedodes.* The study determined macro nutrients, the pH, and the C/N ratio. The final biomass contained a significant amount of macro and micro nutrients, which made it adequate for animal nutrition and soil improvements (Stoknes *et al*. 2019).

In an evaluation of palm residue, El-Waziry *et al*. (2016) used chemical determination and *in vitro* gas production. The ruminal fluid was collected from three goats that fed on alfalfa and hay. Gas production was measured at 3, 6, 9, 12, 48, and 72 h of incubation. The CP, ethereal extract (EE), CF, and nitrogen-free extract (NFE) rose following mushroom production. Gas production at 72 h was similar before and after the treatment. There was a significant difference ($p<0.05$) between the substrates before and after the treatment, as to metabolizable and net energy, as well as in organic matter and microbial protein digestibility. Moreover, Urrego *et al*. (2013) conducted a nutritional characterization of edible mushroom residues, and found that they were rich in sterols, vitamin D2, amino acids, and polysaccharides. No mycotoxins were detected. These authors noted the occurrence of possible limitations, such as low levels of fat, P, Cu, Zn, Ca, and NaCl, to be considered when mixing them with other foods.

El-Waziry and Alkoaik (2016) used the Weende scheme, and coincided that in the palm-mushroom residue treatment, the substrate's nutritional value was enhanced, making it a potential source of feeds for ruminants. They agreed that the residues from growing mushroom has a high quality for use in ruminants, and added that the mushrooms also reduced the crude fiber contents in the substrate, while improving overall digestibility.

Mushrooms contain highly bioactive compounds, and make an adequate source of prebiotics that have short-chain sugars, such as glucose, fructose, galactose, and N-acetylglucosamine, which stimulate the growth of beneficial microorganisms. In a study of the prebiotic effect, Balakrishnan *et al*. (2021) determined the loss of prebiotic properties resulting from the stimulation of the probiotic effect, the inhibition of pathogenesis, and gastrointestinal tolerance (amylase, bile extracts, and HCL). The prebiotics from the mushrooms stimulate the intestinal microbiota, thus conferring benefits to the host. Prebiotics from the mushrooms are thought to be an alternative to prevent or control pathogens. These prebiotics can improve animal health in the same way as probiotics.

The prebiotic effect of mushrooms was also reported by Kumar *et al*. (2021), who claimed that further studies are still needed in terms of mushroom residue utilization.

Harvested rice residues

Rice husks and stalks are among the most commonly found lignocellulosic residues. They contain 32-43% cellulose, 19-25% hemicellulose, 5-12% lignin, and 18.8% ashes. This structural complexity and low digestibility of rice residues is explained by the presence of lignin that blocks the attack of microorganisms present in the rumen. Lignin acts as a barrier that must be removed so that the microorganisms are capable of hydrolyzing the carbohydrates (Balasubramanian, 2013). It is a potential good source of energy, though very poor in protein (2-7%), and high silica contents. A study on this substrate conducted by Sawangwan (2018), showed an evaluation of the prebiotic activity of seven edible mushrooms, and the presence of total carbohydrates and reductor sugars. HPLC was used for measurements after three hours of extraction; the extract from the residual medium containing the mushrooms (*Hericiumerinaceus*, *Pleurotusostreatus* and *Lentinulaedodes*) was analyzed. The polysaccharide-hydrolase activity of the extract used to digest the stalks was measured. The digestibility of the neutral detergent fiber was compared by sugar composition analysis in the residual NDF after the hydrolysis with sulfuric acid and trichloroacetic acid. The antioxidant activity of the extract was determined as well. The results suggested that the additive might be effective to improve the efficiency of the feeds supplied to weakened animals or animals affected by heat stress (Yagi *et al*., 2019). In general terms, it can be used as a source of energy for ruminants, though it requires previous treatment. The utilization of mushrooms and exoenzymes is a practical and economically effective method with promising usefulness in ruminant nutrition (Malik *et al*., 2015).

A mushroom treatment of lignocellulosic materials and rice husks caused a rise in the levels of protein and fermentable substrate in the rumen. Besides, the daily consumption of animals rose, and their health improved as well (Mahesh and Mohini, 2013).

Rice husks and stalks have been identified as an energy feed, though their high fiber contents limit their use. They have been chemically and biologically treated (through mushrooms) to make it a better feed for ruminants. In experiments to compare the treatments, both showed the potential to optimize its use in ruminant nutrition. Chemicals, however, cannot be environmentally friendly (Naseer *et al*., 2017). A study on the effect of husks and stalks as substrate for mushrooms concluded that the treatment improved its nutritional value significantly (Ikpe *et al*., 2019).

Upon a study of the remaining *compost* following rice harvest through *in vitro* and *in situ* digestibility tests and animal response, the authors found that the nutritional value depended on several factors, such as the ingredients added, which could impact on its acceptance and nutritional balance (Bilik *et al*., 2020).

The residues from the production of edible mushrooms for animal nutrition can also be part of the *compost* ingredients to improve soil quality, and increase crop yields. The fertilizers that include these residues have a high quality (Unal *et al*., 2019; Palangi, *et al*, 2022).

CONCLUSIONS

The results of this study showed that the residues from mushroom-processing using low-quality sources (especially harvested rice stalks and husks), may be used for animal nutrition, whose evaluation is necessary through the proper methods.

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AUTHOR CONTRIBUTION STATEMENT

Research conception and design: SJMS, LCZ, DPC; data analysis and interpretation: SJMS, LCZ, DPC; redaction of the manuscript: SJMS, LCZ, DPC.

CONFLICT OF INTEREST STATEMENT

The author declares the existence of no conflicts of interests.