

SILICA REMOVAL FROM RICE STRAW FOR ANIMAL FEED APPLICATION

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SILICA REMOVAL FROM RICE STRAW FOR ANIMAL FEED
APPLICATION

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Dedicated to my beloved mak and ayah, abang and ammar

Thanks for your endless support and encouragement

Sorry for waiting so long...

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ABSTRACT

The large production of rice straw (731 ton/season) could eventually lead to uncontrolled air pollution due to open burning activity. Although rice straw has been used as animal feed since in the 1980s, it has failed to provide sufficient amount of protein for daily ruminant growth (about 15-20%). Hence, this study explored the use of rice straw waste for animal feed that can provide the amount of protein needed for daily ruminant growth. Moreover, as silica has been discovered as the main hurdle in animal feed processing, the rice straw sample was treated with alkaline hydrogen peroxide (AHP) via batch and continuous systems. Besides reducing the silica content, it is also aimed to maximize the protein content of the treated rice straw. Meanwhile, in the continuous system, a single column packed bed with up-flow system was adapted before carrying out further biological treatment with the fungi, *Neurospora sitophila* for cell protein production. Other than that, physical and chemical characterizations of rice straw sample (obtained from Seberang Perak, Malaysia) were conducted before and after pretreatment processes to determine the effectiveness after each pretreatment process. From the results obtained, a kinetic study was carried out to investigate the removal behavior for each system. From the characterization analysis, the rice straw sample was found to contain a high level of silica (20%) and lignin (20%), but very low-level protein content (6-7%). Besides, the batch process of pretreatment with AHP, as well as the effects of different parameters (i.e. AHP concentrations, particle sizes of rice straw, and temperature) had been studied. From the batch process, the optimum condition obtained was at 60°C with application of 10% of AHP solution for sample with < 0.5mm particle size. At this condition, more than 83.8% of silica removal, 80% of delignification, and 7.88% of reduced sugar production were achieved. On the other hand, as for the continuous AHP pretreatment process, and followed by biotreatment of *Neurospora sitophila* (edible fungus) in the single column, it was found that 84% of silica was removed with 80% of delignification and 8% of reduced sugar production with 10% AHP solution in a 7cm treated and compacted rice straw bed at room temperature. Furthermore, the protein content in the pretreated rice straw increased by a whopping 80%. Meanwhile, the kinetic study revealed that both the batch and the continuous silica removal processes were highly influenced by mass transfer, in comparison to the other steps. Hence, it can be concluded that this study has depicted that the selected processes for silica removal and protein enhancement of local rice straw are indeed suitable for animal feed production. Additionally, the kinetic study has been proven beneficial in understanding the attributes of the removal process.

ABSTRAK

Penghasilan jerami padi berskala besar (731 tan/ musim) menyumbang kepada pencemaran udara yang tidak terkawal yang terhasil dari pembakaran secara terbuka. Jerami padi juga gagal untuk menyediakan jumlah protein yang mencukupi untuk tumbesaran harian ruminan walaupun ianya telah mula digunakan dalam penghasilan makanan ternakan semenjak tahun 1980 (15-20%). Oleh itu, kajian ini meneroka penggunaan jerami padi dalam penyediaan makanan ternakan yang boleh menampung keperluan protein dalam tumbesaran harian ruminan. Disebabkan silika adalah penghalang utama dalam proses penyediaan makanan ternakan, perawatan jerami padi menggunakan hidrogen peroksida beralkali dalam bentuk kelompok dan berterusan dijalankan. Tujuan utama kajian ini adalah untuk menambahbaik kandungan protein selain mengurangkan kandungan silika dalam jerami padi. Dalam sistem berterusan, silinder mampatan di mana aliran hidrogen peroksida beralkali dari bawah ke atas digunakan untuk rawatan pembuangan silika daripada jerami padi sebelum rawatan biologi menggunakan kulat, *Neurospora sitophila* di dalam silinder yang sama. Dalam kajian ini penentuan karakter jerami padi secara fizikal dan kimia yang diambil dari Seberang Perak, Malaysia dilakukan sebagai penanda aras keberkesanan rawatan yang digunakan. Dari dapatan kajian ini, kajian kinetik yang ringkas telah dilaksanakan untuk menerangkan tabiat pemisahan silika dari jerami padi yang berlaku dalam setiap sistem. Daripada analisis, sampel jerami padi didapati mengandungi tahap silika (20%) dan lignin (20%) yang tinggi beserta kandungan protein yang sangat rendah (6-7%). Proses rawatan dalam sistem kelompok yang menggunakan hidrogen peroksida beralkali, di mana faktor berbeza yang menyumbang kepada proses pemisahan (kepekatan bahan perawat, saiz jerami dan suhu) dikaji. Daripada proses kelompok, tahap pemisahan yang optimum didapati pada suhu 60°C dengan penggunaan 10 % kepekatan hidrogen peroksida beralkali pada sampel dengan saiz jerami < 0.5mm. Pada keadaan ini, lebih 83.8% silika telah berjaya dipisahkan dari jerami, 80% nilai pengurangan lignin dan 7.88% gula ringkas juga dapat dihasilkan. Dalam sistem berterusan pula 84% nilai silika dapat dipisahkan dan 80% nilai lignin juga dapat dikurangkan dan 8% jumlah gula ringkas dapat dihasilkan dengan 10% agen pemisah dan 7cm mampatan jerami padi terawat pada suhu bilik. Nilai protein di dalam jerami padi terawat bertambah sebanyak 80%. Daripada kajian kinetik, ianya juga didapati bahawa sistem pemisahan silika secara kelompok dan berterusan amat bergantung pada faktor pemindahan jisim berbanding faktor lain. Kajian ini dapat disimpulkan di mana proses yang dipilih amat sesuai untuk pemisahan silika dan penambahbaikkan nilai protein jerami padi tempatan untuk menghasilkan makanan ternakan khususnya. Kajian kinetik yang dijalankan juga sangat bermanfaat untuk pemahaman tabiat dalam proses pemisahan silika dari jerami padi.

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LIST OF ABBREVIATIONS

A	-	Cross-sectional area
AHP	-	Alkaline Hydrogen Peroxide
C_A	-	Concentration of dissolved solid in the bulk of solution
C_{ad}	-	Concentration of silica adsorbed to AHP agent at certain flow time
CAP	-	Catabolite Activator Protein
CP	-	Crude Protein
DM	-	Dry Matter
DSMZ	-	Deutsche Sammlung von Mikroorganismen und Zellkulturen
EM	-	Effective Microorganisms
$Fe(NO_3)_3$	-	Iron Nitrate
FELCRA	-	Federal Land Consolidation and Rehabilitation Authority
FESEM	-	Field Emission Electron Microscopy
FIBEX	-	Fiber Extrusion Technology
FTIR	-	Fourier Transform Infra Red
L.	-	Lactobacillus.
LAB	-	Lactic Acid Bacteria
M_{total}	-	Total mass of silica adsorbed by the AHP agent
MARDI	-	Malaysian Agricultural Research and Development Institute
MBTH	-	3-methyl-2-benzothiazolinone hydrazone hydrochloride
MTZ	-	Mass Transfer Zone
N	-	Normality
N_0	-	Saturation concentration
NDF	-	Neutral Detergent Fiber

OD	-	Optical Density
OPF	-	Oil Palm Fiber
PAH	-	Polycyclic Aromatic Hydrocarbon
PELADANG	-	Lembaga Pertubuhan Peladang Malaysia
SCP		Single cell protein
SSF	-	Solid state fermentation
YEFECAP	-	Yeast Fermented Cassava Chop Protein
μ	-	Solvent viscosity

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The Food and Agricultural Organization Rice Market Monitor (FAO RMM) claimed that the global paddy production for the 2015 season was 738 million tons and this number was predicted to hike up to 750 million tons by end of 2016 (FAO, 2016). Furthermore, the Malaysian FAO had also estimated that the national output had grown by four percent to 2.6 tons (1.7 million tons on milled basis). In fact, Kedah has possessed the highest area of paddy plantation, which is 200 thousand hectares of cultivation area, as presented by the Malaysian Agriculture Department in Figure 1.1. In general, these agricultural wastes are burnt if non-recyclable or non-reusable. Such burning deteriorates the quality of air and causes air pollution; thus posing threat to people's health, as the minute PAH can easily penetrate into one's pulmonary alveoli (Yang *et al.*, 2005).

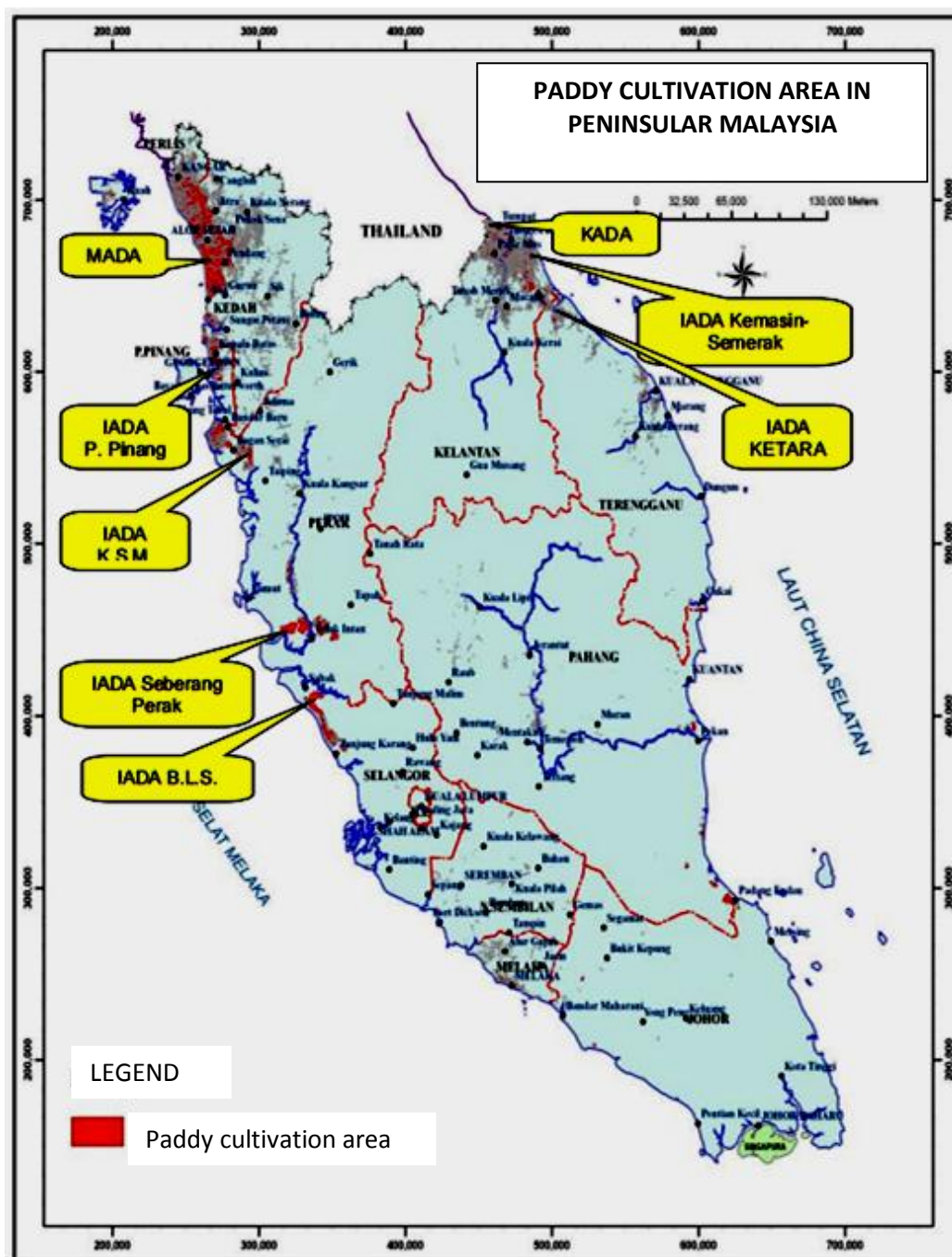


Figure 1.1 Map of paddy area in Malaysia 2013 (Soil Management Division, Department of Agriculture, Peninsular; MADA: Muda Agricultural Development Authority; IADA: Intra-Asia Discussion Agreement; KADA: Kemubu Agricultural Development Authority)

Therefore, instead of burning, rice straw can be potentially applied for silage production. However, it is a challenge to use rice straw as a silage due to the low protein content in rice straws that poses as a barrier to be directly fed to animal, especially for ruminant. This is because; a minimum requirement of nutrient content has been determined by the Malaysian Department of Veterinary. Basically, ruminant needs more than 15% of protein content for growth, as well as to produce standard quality of milk and meat. The crude protein content of rice straw is way below than the requirement, as reported in rice straw source from other countries, such as at 5.4% and 5.8% in India and China (Jian-Xin *et al.*, 2001), 4.6% in California (Nader & Robinson, 2008), 5.7% in Japan (Fang *et al.*, 2012), and 5.65% and 2.5% in Ghana and Thailand respectively (Wanapat *et al.*, 2009). Thus, vast protein improvements are required (above 100% from original values) to achieve the target (Van-Soest, 2006).

Protein is the most crucial nutrient for weight gain and gestation. From prior investigations, a combination of treatments can efficiently improve the performance of rice straw as an animal feed. For instance, the combination of chemical and supplementation (52.92% rice straw + 30% cassava + 15% cotton seed meal + 2.08% urea) offers 12% of crude protein (Sommart *et al.*, 1999), which is similar to chemical and biological combination, as conducted by Van-Soest (2006), Chen *et al.*, (2008), Su *et al.*, (2012), and Fang *et al.*, (2012). Besides, the combination of chemical and supplementation (100 g rice straw + 100 g ammonia bicarbonate + 300 ml water + 5% Chinese milk vetch silage) gives 20.2% of crude protein (Liu *et al.*, 1997), (rice straw + ammonia bicarbonate + rapeseed meal + water) provides 21% of crude protein (Liu *et al.*, 2001), (1 kg rice straw + 500 ml water + 45 g urea + 10 ml of 20% sulphuric acid + concentrates that consist of rice bran + ground corn + avoparcin) results in 17.1% of protein content (Soodeen-Karamath & Youssef, 1999). Other than that, the physical and chemical combination (Shen *et al.*, 1998; Ware & Zinn, 2005), as well as the combination of physical, chemical, and supplementation (40% of chopped rice straw + 60% of concentrates that consist of corn + soy bean meal + rapeseed meal + urea + premix), gives 13.8% protein content (Wang *et al.*, 2011). Lastly, Fiber Explosion (FIBEX), which consists of treatment via steam with ammonia concentrates, also offers 18% of rice straw (Weimer *et al.*,

2003). Nonetheless, such combination methods lead to higher costs for the production of animal feed.

Therefore, probe into new alternatives and unconventional protein sources has taken place to fulfill the needs of protein for ruminant. For instance, in 1996, a new protein source was discovered, termed as 'single cell protein' (SCP) or microbial protein development, mainly deriving from yeast, bacteria, and fungi to enhance the protein level in biomass (Rasoul-Amire *et al.*, 2011). This microbial protein production can be considered as an effective alternative, especially for the production of animal feed from agricultural wastes. In fact, early studies showed that cellulose from agricultural waste possesses high potential as substrates from SCP application (Martin, 1991; Bekatorou *et al.*, 2006; Nasser *et al.*, 2011).

Similarly, rice straw also contains high amount of complex structure that is comprised of hemicelluloses, cellulose, lignin, and silica, hence making the aspect of digestibility rather low due to the large degree of ester bonding in hemicelluloses (Van-Soest, 2006). Thus, in order to remove this carbohydrate, lignin, and silica complex structure, several types of pretreatment methods, such as alkali, steam explosion, grinding, ammonia fiber via substitutions to silicic acid and silicon dioxide, could be carried out (Nader & Robinson, 2008).

The silica substance may become a major contributing factor to the resistance for the degradation of rice straw, which is hindered by the process of maximizing sugar reduction (Bae *et al.*, 1997; Agbagla-Dohnani *et al.*, 2003). This factor, unfortunately, has been neglected in numerous treatment studies. During the degradation process, hemicelluloses and lignin are normally removed. The high content of biogenic silica in the wall of epidermal cell layer, which results from the application of fertilizers, irrigation, and harvest time, could influence the degradation process of rice straw (Shen *et al.*, 1998). Moreover, treatments for silica removal are indeed required due to the larger amount of silica content in rice straw, which cannot be simply dismissed. Furthermore, Sun *et al.*, (2000) discovered that rice straw contains average silica content that ranges from 0.05 to 20.00%.

In addition, some studies detected that the highest level of silica is found in rice straw, followed by wheat straw, sorghum, rye, maize, and barley (Tamai & Jian, 2003). The silica is converted to silicic acid and later, transported to the plant structures. Besides, the silica concentration is higher in older tissue leaves compared to stem (Mecfel *et al.*, 2007). In fact, one should note that silica (group 14 in the periodic table) is not an essential mineral for a plant, but it offers several benefits, such as increased resistance to chemical and physical stresses, added strength and stiffness, as well as increased pest resistance.

Silica, which is typically known as silicon dioxide, is probably the first limiting factor in straw rice quality because silica has diverse metabolic functions and it is involved in carbohydrate synthesis that generates a negative association with digestibility (Van Soest, 2006). Normally, the level of silica in rice straw is about 8.3% (Gu *et al.*, 2013) and 9-10% (Bae *et al.*, 1997), depending on the plant location and other factors. Based on several other sources, 20% of silica content in rice straw makes it an attractive source for amorphous silica production. The amount of silica present in the various components of the rice plant consists of 0.5g/kg of polished rice, 50g/kg for rice bran, 130g/kg for rice straw, 230g/kg for rice hulls, and 350g/kg for rice joints (Van Soest, 2006). Hence, silica can be applied in solar cells, drug delivery, and for application in the biomedical field (Rehman *et al.*, 2013). Nevertheless, silica impedes soda and craft processes related to paper production. Compared to other crops, the variances of silica content depend on the photosynthetic mechanisms of the grass and the amount of water transferred to the grass. For example, cereal straw contains high silica level, where wheat straw possesses 4-10% of silica, while rice straw has a higher value of silica, which is 9-14%, and other cereals like barley, oat, and rye straws possess 1-6% of silica level (Pekarovic, 2005).

Additionally, silica can exist in amorphous (glass) and a variety of crystalline (quartz, tridymite, and cristobalite) forms. Normally, it is deposited as amorphous silica, which is mainly located in the epidermal cell. On top of that, silica normally covers the outer surface of the plant stem and morphologically, silica is the thickest

outer layer of plant bodies, especially in rice straw. Meanwhile, in living plants, silica is present in three basic forms: insoluble silica, colloidal silicic acid, and silicate ions, but almost 90% of it is present as insoluble silica. In other sources, the epidermal surface of rice straw contains high concentration of silica and it is covered by cutin and waxy layers. Furthermore, silica is extremely soluble in alkaline condition and must be removed from recovery cycle, especially in the pulping process to avoid mechanical error during the process.

In fact, other studies also showed that the digestibility of roughages could be increased via alkali treatment, where partial solubilization of hemicellulose, lignin, and silica occurs first (Bae *et al.*, 1997). Besides, silica always functions as the physical barrier, which prevents bacterial attachment and causes inefficient digestion of plant cell wall carbohydrates.

On the other hand, the desilication process refers to the elimination of silica, which normally occurs in craft pulping industry plant. Numerous techniques for desilication are available, such as black liquor desilication with carbon dioxide (flue gasses), two-stage causticizing method, green liquor desilication with lime, and the use of sodium carbonate as a silica-leaching agent, which can lead to 50-75% of desilication rate (Pekarovic *et al.*, 2005). Furthermore, silica also gives small dissolution effect in pure water, especially in the presence of other species like sodium chloride or when higher temperature is applied (Xiao *et al.*, 2010). In comparison to the use of pure water, the rate of silica dissolution is higher by 18-30 times with the presence of other organic electrolyte. In fact, the parameters that have been investigated to attain optimum desilication process are temperature, time, and chemical charge. As a result, temperature and time portrayed the strongest influence, but unfortunately, removed several organic compounds in that process.

The previous section depicts some evidences pertaining to silica that could be dissolved with strong alkaline. This process is known as ‘depolymerisation’, and further catalysis with hydroxyl ion could result in a five-coordinate center by weakening the other oxygen bonds. The rate of this reaction depends on the ability

of hydroxyl ion, the silica structure, and the pH of the solution. Besides, prior studies have shown that the removal increases in line with the alkalinity level of the solution (Iler, 1979). Other than density of materials; surface area, temperature, and pressure also can affect the rate of silica removal (Zotov & Kepler, 2002).

Nonetheless, the use of strong alkaline alone is inadequate to cater the amount of hydroxyl ions needed for high silica removal. In fact, hydrogen peroxide functions as both the proton donor and the proton acceptor (Zeglinski *et al.*, 2006). These hydrogen peroxide molecules establish the ability to form stronger bonds with silicon than water molecules do if they function as proton acceptor. This further generates hydroxide radicals that enhance the removal rates. Hence, the discussion above portrays that hydroxyl ions may react with silica in rice straw and form silicic acid, Si(OH)_4 . The mechanisms show that Si-O- sites react with -OH sites to form silicic acid in abundant (Manivannan & Ramanathan, 2009). Later, the high amount of silicic acid leads to higher formation of silicate ion via condensation process by incorporating hydroxyl ion. Thus, the presence of silicate ions increases the solubility of silica, thus completing the removal process.

1.2 Problem Statement

In addition, the statistics shows abundance of rice straw due to the increasing production annually, making it the most waste that needs to be recycled into other products with high value like silages (animal feed products). However, it is important to acknowledge that conventional silage fermentation (anaerobic fermentation) has failed to at least maintain the protein level in rice straw without any supplementation for animal feed (concentrated) application. Moreover, it takes at least months to complete the fermentation process.

The high quality of silage must retain the original level of protein with high nutrient level that has the ability to stabilize the essential characteristics without being contaminated with fungus or mold. Silage is normally served with supplements called concentrations (combination of high nutrient supplements) that enrich the protein content, thus increasing the cost of feed. In part of that, using urea as additives can increase the protein content in rice straw, but it has adverse effects upon ruminants. Therefore, microorganisms like bacteria and effective microorganisms (EM) have been employed as alternatives. The results of microbiology application, in fact, have indicated that the best approach is applying edible fungus that can secrete enzyme by utilizing carbon from lignocellulosic material, such as rice straw, through the progress of SCP.

Nevertheless, the high silica content (from the very complex structure) of rice straw must be removed first through a pretreatment method because it becomes a distraction for carbon source production to be consumed by fungus, along with the secretion process. Normally, rice straw protein improvement should begin with the delignification process. The lignin is removed to enhance the enzymatic attack on the rice straw structure. Past researchers, unfortunately, failed to highlight the issues concerning silica upon rice straw structure. In the first place, silica (SiO_2) has an important role in plant yield, especially rice (Sahebi *et al.*, 2015), for it is a beneficial nutrient supply through fertilizer. Some studies also depicted that the grain yield of plants with silica is double than plants without silica. Physiologically, the silica layer has the ability to increase the resistance towards fungi, bacteria, and insect pest attack (as illustrated in Figure 1.2). The silica is still located at the same place even after the plant becomes a waste (after harvest) and even increases by storage time (increased directly with maturation time). However, after becoming waste, the silica becomes non-beneficial due to its application as an inert substrate. Therefore, during post-application, especially when fungi/yeast/bacteria grow on the straw surface without any resistance, the process of silica removal must be carried out as a preparation. Silica removal pretreatment must first be performed before other post-treatment is conducted on inert substrate like animal feed and biofuel production.

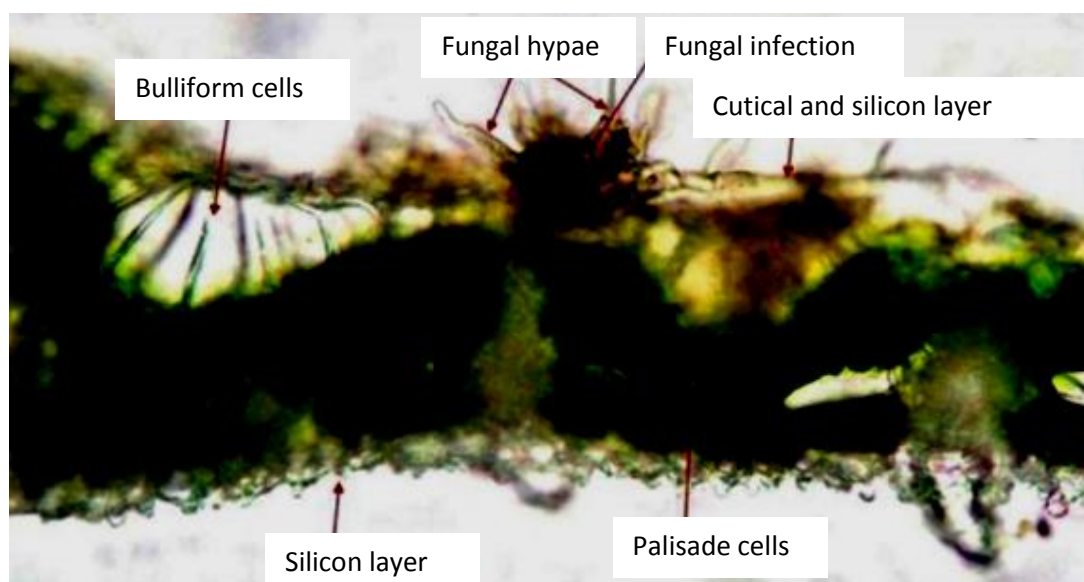


Figure 1.2 Role of silica deposition in bamboo leaf during fungal attack
(Mahbod *et al.*, 2015)

Leaching is the process of extracting a soluble constituent from a solid using a solvent. Therefore, this process is suitable to represent the silica removal method from rice straw with alkaline hydrogen peroxide (AHP) as a solvent. This is a technique used either to extract a valuable constituent from the solid or to remove a solid from a soluble material. Hence, in order to clarify the mechanisms of silica removal during this process of pretreatment, it is important to perform a kinetic study before focusing on the edible fungus application in order to determine if the rate of removal process is highly influenced by diffusion or chemical reaction. Hence, the results can be highly valuable for scaling up or for further optimization study.

Moreover, batch system data are more suitable for small-scale treatment volumes, but inconvenient for large-scale application due to several factors. Therefore, in order to get more realistic laboratory results, the packed bed column study is essential since it has greater resemblance to the flow condition in the later full-scale application. Moreover, it is also significant to predict the behavior of column breakthrough curve, which can offer a functional life span of the column bed. Summing it up, the fundamental mechanisms of silica dissolution process from rice straw must deeply focus on the batch system to attain the main objective, which is to

remove silica, as well as to enrich the protein content of rice straw via microbial protein production technology in continuous system.

1.3 Objectives

As a whole, this study is aimed to maximize the required protein content in rice straw-based silage through the combination of Alkaline Hydrogen Peroxide (AHP) and edible fungus (*Neurospora sitophila*) treatments. As such, the following are the objectives of this research work.

- 1) To investigate the effects of the various hydrogen peroxide (H_2O_2) concentrations in alkaline condition, particle sizes, and temperature in batch AHP process towards silica removal, delignification, and sugar reduction production in pretreated rice straw
- 2) To investigate the AHP pretreatment in continuous system, as well as to investigate the effects of various hydrogen peroxide (H_2O_2) concentrations and the length of rice straw bed in alkaline condition towards the percentage of silica removal, delignification, and sugar reduction production.
- 3) To study the kinetic mechanisms of silica removal from rice straw via alkaline hydrogen peroxide (AHP) pretreatment (batch and continuous) to enhance the production of reduced sugar.
- 4) To investigate the effectiveness of microbial cell protein production in pretreated rice straw by edible fungus application called *Neurospora Sitophila*

1.4 Scope of Study

From each objective, the scope of study is listed in the following:

- 1) To study the kinetics effect of the various hydrogen peroxide (H_2O_2) concentrations in alkaline condition (0-10%), particle sizes (less than 0.5 mm, 0.5-1.0 mm, and more than 1.0 mm), and temperature (30- 60 °C) on the percentage of silica removed at a fixed solid and liquid ratio, shaking speed, and volume in the batch system.
- 2) To study the kinetics effect of various hydrogen peroxide (H_2O_2) concentrations (0-10%) and length of rice straw bed in alkaline condition (7cm and 12cm) on the percentage of silica removal at fixed feeding rate, particle size, temperature (limitation of the equipment), and volume in continuous system (fixed bed column).
- 3) To study the behavior of kinetic mechanism for silica removal from rice straw through the application of diffusion/chemical reaction shrinking core models in batch process and STATISTICA software program, as well as the nature of equilibrium for silica removal from rice straw via breakthrough curve analysis using Thomas and Adams-Bohart models.
- 4) To study the biomass and the morphological aspects on adhesion effect of fungus on the solid surface of rice straw, as well as protein enrichment application study for various conditions of pretreated rice straw at a fixed weight when *Neurospora sitophila* was applied.

1.5 Significances and Original Contributions of This Study

The significances of this study can be divided into a three aspects: the effectiveness of silica removal, the kinetic behavior of that process, and the protein enrichment of treated rice straw sample. The original contribution of knowledge would be in terms of the high association between silica removal and reducing sugar enrichment trend, which are profoundly significant in this study. This is because; prior studies only focused on reducing sugar enrichment for further application without considering the kinetic behavior of the treatment process. This knowledge is not only for animal feeds application, but it is also essential for the production of alcohol and biofuel from various types of agricultural wastes. Furthermore, as the AHP pretreatment for reducing sugar and the usage of *Neurospora Sitophila* for protein enrichment had been separately proven previously by prior researchers, the kinetic study, especially the value of the kinetic coefficient for silica removal, is important for research and development in the agricultural industry like scaling up and optimization study. Besides, the usage of this continuous system for both processes that occur in the same vessel is also essential for other applications. For instance, acceleration of alcohol products from corn waste by using strains of bacteria or fungus.

Second, this study contributes to the research development in Malaysia. Research pertaining to agricultural study, especially for animal feeds application that focuses on knowledge enhancement and economic developments, is still limited. The continuous system developed in this study, hence, can be expanded into a pilot plant study, whereas factory scale for business purposes. Finally, this study is also beneficial for various levels of farmers in the stance of economic development, including conventional farmers and government or private sectors (MARDI, FELCRA, and PELADANG). Furthermore, the application of *Neurospora Sitophila* for nutrient enhancement of animal feeds has been widely applied in various nations, thus it can be identified as a functional and reliable technology for Malaysian farmers in near future.

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