Maximizing Utilization of Energy from Crop By-products

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ABSTRACT

The availability of crop by-products is huge during harvesting times as related to the vast agricultural land area; however, their utilization is still limited due to lack of knowledge and handling problem. Seasonal effect is obvious especially during wet season when high rainfall hinders proper management of crop by-products. Crop by-products are energy rich feedstuffs in the form of chemical substance such as cellulose and hemicellulose. The utilization of cellulose and hemicellulose as sources of energy can be maximized by the application of technologies to increase the digestibility. Cellulose is polymer of glucose while hemicellulose is polymer of xylose which both can be converted to volatile fatty acids by rumen microbial enzyme activities and subsequently used by the host animal as source of energy. In addition, cellulose and hemicellulose can also be used as substrates for bioethanol production leaving behind residual matter with higher concentration of protein which is also appropriate for ruminant feeds. The fat content of crop by-products such as those in rice bran and corn germ can be extracted for oil production that can be used for human consumption with concomitant production of high nutritive value of residues for ruminant feeds. The oil extraction technologies are available; however the high cost of ethanol and oil production should obtain high attention to make the technologies more applicable at farmers' level.

Key words: Crop by-products, energy, ethanol, residue, ruminant, feeds

ABSTRAK

Upaya Memaksimalkan Penggunaan Energi dari Hasil Samping Pertanian

Jumlah hasil samping pertanian sangat melimpah pada musim panen karena luasan panen yang sangat besar, namun sebagian besar tidak dimanfaatkan yang disebabkan oleh kurangnya pengetahuan atau kesulitan dalam penanganannya. Musim sangat mempengaruhi tingkat pemanfaatan hasil samping pertanian terutama pengelolaan yang tepat pada musim hujan. Hasil samping pertanian merupakan bahan sumber energi dalam bentuk energi kimia, seperti selulosa dan hemiselulosa. Pemanfaatan selulosa dan hemiselulosa dapat dimaksimalkan melalui penerapan teknologi peningkatan nilai kecernaan, terutama apabila digunakan untuk pakan ternak ruminansia. Selulosa merupakan polimer glukosa dan hemiselulosa merupakan polimer xilosa dapat dikonversikan menjadi asam lemak mudah terbang oleh aktivitas enzim mikroba rumen yang akan menjadi sumber energi bagi ternak. Selulosa dan hemiselulosa juga dapat digunakan sebagai bahan dasar pembuatan bioetanol dengan residu yang dapat digunakan sebagai bahan pakan ternak. Kandungan lemak pada beberapa hasil samping pertanian antara lain dedak padi dan dedak jagung dapat diekstrak menjadi minyak goreng dengan hasil samping bahan pakan yang berkualitas tinggi untuk ternak ruminansia. Teknologi penanganan tersebut sudah tersedia, namun masalah tingginya biaya produksi harus mendapatkan perhatian agar dapat diterapkan di tingkat petani.

Kata kunci: Hasil samping pertanian, energi, etanol, residu, ruminansia, pakan

INTRODUCTION

Crop productions are always accompanied by waste products which are not the main objective of the agriculture. The main agricultural production is the primary target of the yield; meanwhile the whole process of photosynthetic in producing the main crop product involves those parts which are left after harvesting the primary yield. All parts of the crop can be considered as energy substrate in the form of chemical energy. The organic compounds as a result of the photosynthetic process contain carbon, oxygen and hydrogen in addition to nitrogen and sulfur. Nitrogen is part of amino acids and some amino acids may also contain sulfur in the protein molecule. The fat component contains much more energy as compared to carbohydrate and protein due to the process of β-oxidation in lipid hydrolysis. In addition to energy content, the crop by-products may also contain minerals and vitamins which are also important as nutrients.

As an agricultural country, Indonesia produces more than 70 millions ton of rice every year which is harvested from around 12 millions hectare of paddy field. These harvested areas may produce more than 50 millions ton of rice straw. It is unfortunate that most of these rice straws are not being utilized as energy source for ruminant feeding; most of them are being burnt and only a small part are being used (Haryanto 2009). Likewise, corn, cassava, sugarcane and vegetables also produce by-products that can be utilized as source of energy feed for ruminants.

Generally, the crop by-products are not utilized by farmers except being dipped back into the soil when they are preparing the land for the next crop plantation. Otherwise, the crop by-products are being abandoned or burnt out. This means that the energy content in the crop by-products have been wasted rather than being utilized for beneficial purposes before the elements are cycled back through the soil by bioremediation process. The chance of utilizing crop by-products as energy source, especially those consisting of cellulose and hemicellulose materials, for ruminant feeds may increase the advantage and the economic value of crop by-products. In Kenya, the proportion and quantity of maize residue used for soil mulch is negatively related to livestock holding. More livestock holding in mixed crop–livestock systems decreases the proportion of maize residue retained as soil mulch and increases its proportion used as feed (Jaleta et al. 2013).

It is usually believed that crop by-products have low nutritive value for animal feed which is indicated by low digestibility and low intake when offered without preliminary treatment to improve the palatability and its nutritive value (Haryanto 2012a). There are many simple technologies available for improving the crop by-products nutritive value around the world, either from established research institutions or local wisdom (Haryanto 2012b). Besides using crop by-products directly for ruminant feeds, it is also possible to utilize crop by-products as source of raw material for bio-ethanol production with concomitant production of residual matter that can be used as ruminant feeds.

An estimated global potency of producing bio-ethanol from crop by-products may reach 491 GL (giga liter) per year (Kim & Dale 2004). Asia is the largest potential producer of bioethanol from crop residues and wasted crops, and could produce up to 291 GL of bio-ethanol per year. Rice straw, wheat straw, and corn stover are the most favorable bioethanol feedstocks in Asia. The next highest potential region is Europe (69.2 GL of bio ethanol), in which most bioethanol comes from wheat straw. Corn stover is the main feedstock in North America, from which about 38.4 GL per year of bioethanol can potentially be produced.

The question is how to make these technologies available at farmers' level so that they can take the advantage of crop by-products for other purposes and develop an integrated farming system without significant loss of natural resources. By this means the farmers can increase the economic benefit and alleviate the poor condition in villages.

Crop by-products availability

In addition to the soil nutrition, agriculture system depends on the availability of water as it is very important for the plant to grow and produce better yield. Seasons therefore play very important role in providing the water for agriculture. Usually food crops such as rice can be planted twice a year. If irrigation is available and water requirement can be fulfilled along the year then it is possible to plant it 3 times a year. In the areas of dry and low rainfall, which are known as dry land area the farmers can plant food crop only in rainy season. More suitable food crop for the dry land areas which needs less water, such as maize and cassava can be the primary commodity of agriculture.

By calculating the potential of crop by-product yields for every crop species during time of harvest then they can be assessed, when and how much, the availability of energy source materials that can be managed for ruminant feeds. Technology of crop by-product management and preservation may be important for the farmer to maximize the resources utilization. The technologies should be simple and easily applied under the local condition without additional expensive inputs. Problems of seasons especially during the wet season sometimes hinder the better crop by-products management because there will be difficult to dry the crop by-products before being preserved and stored for a longer period. The problems of labor availability may also be encountered by farmers during the wet season harvest. This will subsequently affect the quantity of crop by-products that can be used because most of them are not properly managed and therefore they will be neglected in the field and left to naturally decay process in the farm land.

Knowing the potential and time of availability of crop by-products in line with the months along the year means that the possibility of providing energy source for ruminant feeds can be translated into how many animal units can be supported by these feed potential. Therefore, farmers can decide the scale of holding ruminants to ensure that they will not lack of feed for their better production. Based on the crop commodities in each farming area followed by application of simple technologies for crop by-product preservation and storage farmers can also decide what breed of ruminants, such as sheep, goat, cattle (dairy or beef) or buffaloes, and how many animal units should be developed.

Crop by-products are, however not the solely source of feed for ruminants; therefore a combination of several feedstuffs that are available locally or those have to be transported from other area need to be done to fulfill feed formula with a high nutritive value. The formula should provide adequate quantity of energy and protein in a balanced condition, in addition to adequate minerals and vitamins to satisfy the animal requirements.

Chemical characteristics of crop by-products

After harvesting the primary products of crop, there will be left behind the parts of crop with no economic value and therefore considered as non valuable material and thrown out. These parts of the crop have advanced development of the components of plant generative tissues which are characterized by high content of cell wall rich of cellulose and hemicellulose fractions. These cell wall components are important for the structural plant tissue strength to resist from the attack of organisms. The structural plant tissues can be divided into two fractions based on the easiness in digestion, i.e. (1) the cell saps which consisted of N-containing substrate, mineral and readily digestible carbohydrate; these fractions are relatively easy to be digested, and (2) the cell walls which consisted of the cellulose, hemicellulose and lignin fractions with variable characteristics of degradability, from non degradable to highly degradable. Cellulose, hemicelluloses and lignin are potentially good substrates for production of single cell protein as animal feeds, fuels, paper, particle board, edible mushroom, and fermentable sugars (Majumdar & Chanda 2001).

Crop by-products such as rice straw, maize straw and corn cobs, sugarcane top, cassava peelings are potential for energy feed due to the fact that these crop by-products are high in structural carbohydrate contents. The ruminants rely on the rumen microbial enzyme activities in coping with these feed materials since ruminants themselves do not have the ability to produce fiber degrading enzymes. Therefore, feeding strategy of crop by-products to ruminants is actually associated with how to manipulate the rumen microbial niches so that they will produce more and more fiber degrading enzymes. Rice straw is relatively unique to other cereal straws in being low in lignin and high in silica. Unlike other cereal straws, taller varieties of rice straws tend to be leafy while the leaves are less digested than stems (Van Soest 2006).

The carbohydrate content of crop by-products are subjected to microbial enzyme digestion and fermentation in the rumen producing short chain fatty acids which are subsequently being absorbed by the host and used as precursor of energy. In addition to short chain fatty acids, the fermentation process also produce CO_2, H_2O and CH_4. The CH_4 (methane) is released to the atmosphere and it has the potency to exert green house effect which may contribute to the increasing temperature of the atmosphere resulting in global warming. Therefore, emission of methane should be reduced or otherwise the methane should be used as renewable alternative energy source which can be utilized for cooking or electric generating purposes.

The fact that crop by-products contain 6-carbon and 5-carbon sugar molecules as the primary component of the cellulose and hemicellulose, these materials can also be used as raw material for bioethanol production. Fermentation process of these materials will produce alcohol (C_2H_5OH) and leaving behind the residuals that can be used as feedstuff for ruminants. Application of fermentative technology may increase the economic value of crop by-products and therefore increase farmers' income.

In addition to the carbohydrate content of the crop by-products, some of them also contain fat in a relatively high concentration, such as rice bran which may contain 15% of fat. This fat can be extracted and separated from the other components to increase the economic value while also increase the nutritive value of the residue. The residue will have a higher concentration of protein after the fat is being extracted. This residual material can be used as ruminant feed with a higher nutritive value.

Cellulose fraction and its glucose components

Crop by-products such as rice straw, maize straw and corn cobs are high in cellulose content. Cellulose is a polymer of glucose in a β–1,4 linkages with more than three thousands glucose residues in a closed matrix with lignin and hemicellulose that make it difficult to be digested. In ruminants, rumen microbes produced cellulolytic enzyme complex that degrade crop by-products into chemical energy.

Rice straw can be fermented by a wood-rot fungus *Dichomitus squalens* as a biological pretreatment, to increase the enzymatic digestibility of lignocellulose and promote cellulose hydrolysis. The fermentation of rice straw by *D. squalens* for 15 days resulted in the enzymatic digestibility of 58.1% of theoretical glucose yield for the remaining glucan. When the fungal-fermented rice straw was used as a substrate for ethanol production in simultaneous saccharification and fermentation processes, the ethanol production yield and productivity were 54.2% of the theoretical maximum and 0.39 g/L/hour, respectively, after 24 hours (Bak et al. 2010). However, rice straw exhibited different susceptibilities towards cellulase to their conversion to reducing sugars. The enzyme from *Trichoderma reesei* effectively led to enzymatic conversion of acid, alkali and ultrasonic pretreated cellulose from rice straw into glucose, followed by fermentation into ethanol. The combined method of acid pretreatment with ultrasound and subsequent enzyme treatment resulted the highest conversion of lignocellulose in rice straw to sugar and consequently, highest ethanol concentration after 7 days fermentation with *S. cerevisae* yeast. The ethanol yield was about 10 and 11 g/L (Belal 2013).

Hydrolysis of rice straw by dilute sulfuric acid at high temperature and pressure was investigated in one and two stages. The first stage hydrolysis to depolymerize xylan to xylose with a maximum yield of 80.8% was achieved at hydrolysis pressure of 15 bar, 10 minutes retention time and 0.5% acid concentration. However, the yield of glucose from glucan was relatively low in first stage hydrolysis at a maximum of 25.8%. The best results of the hydrolysis were achieved, when 0.5% sulfuric acid was added prior to each stage in two-stage hydrolysis. The best hydrolysis were achieved at the hydrolysis pressure and the retention time of 30 bar and 3 minutes in the second stage hydrolysis, where a total of 78.9% of xylan and 46.6% of glucan were converted to xylose and glucose, respectively in the two stages (Karimi et al. 2006).

In order to establish an efficient bioethanol production system from rice straw, a new strategy to ferment the mixture of glucose and xylose by a sequential application of *S. cerevisiae* and *Pichia stipitis* was developed, in which heat inactivation of *S. cerevisiae* cells before addition of *P. stipitis* was employed. Heating at 50°C for 6h was sufficient to give high xylose fermentation efficiency, i.e., 85% of the theoretical yield was achieved in the fermentation of the synthetic medium. At the same time, the xylitol production was reduced by 42.4% of the control process. In the simultaneous saccharification and fermentation of the lime-pretreated and CO_2-neutralized rice straw, the inactivation of *S. cerevisiae* cells enabled the full conversion of glucose and xylose within 80 h. Finally, 21.1 g/l of ethanol was produced from 10% (w/w) of pretreated rice straw and the ethanol yield of rice straw reached 72.5% of the theoretical yield (Li et al. 2011).

The enzymes are responsible in degrading cellulose molecule into smaller particles with less number of glucose residues, then subsequently to single glucose that will be subjected to further fermentation to yield short chain fatty acid, CO_2, H_2O and CH_4 as mentioned above. The degradation may start from the end of cellulose chain or from random sites in the middle of the chain depending on the characteristics of the enzymes. These complex enzymes usually consisted of *endo*-1,4-β-glucanase, cellobiohydrolase (1,4-β-D-glucan cellobiohydrolase) and β-glucosidase (cellobiase) with their respective different specificity of action. The rate of cellulose degradation depends on the tightness of its linkage with lignin and it may range from less than 20% to around 60%. Meanwhile the hemicellulose fraction is relatively easily degraded close to 100%. Therefore, the problem of utilizing crop by-products containing high fiber is more on the cellulose fraction rather than the hemicellulose.

Degradation of cellulose to simple sugar (monomer of glucose) is the primary step in preparing the fermentation by the rumen microbes. The process of degradation is initiated by the attachment of the microbes to the feed particles by which the enzyme then can be exerted to the media for the substrate digestion to start. The enzymes are produced in two possible conditions, i.e. outside the cell of microbes and inside the cell. The outside cell enzymes is always available in very low concentration (constitutive) and play as a trigger for the persistent cellulose degradation by which the cellobiose, as the intermediate result of cellulose degradation, will act as inducer for the inside cell enzyme synthesis. The cellobiose will be transported through the cell membrane and then it will further induce the gene to initiate the synthesis of enzymes required for the cellulose degradation. The enzymes will be excreted and subsequently breakdown the cellulose in the outside cells.

Glucose as source of energy

In ruminants, glucose is the primary source of energy after it has been converted to volatile fatty acids by rumen microbe enzymes. Without the action of microbial enzymes, the ruminants will not be able to use the chemical energy from the crop by-products; therefore the role of rumen microbes is the key in utilizing crop by-products for ruminant feeds. Glucose (hexose) will be fermented by rumen microbial enzymes to yield short chain fatty acids containing 2 carbons, 3 carbons or 4 carbons in addition to CO_2 and H_2 which is further converted to methane by the action of methane producing bacteria. The stoichiometry of glucose fermentation by rumen microbial enzymes varied depending on the diet and the microbial species with their specificity in producing fiber degrading enzymes; however, in general glucose degradation follows the equation below (Russell & Wallace 1988):

$$57.5C_6H_{12}O_6 \rightarrow 65HAc + 20\,HPr + 15\,HBu + 35\,CH_4 + 60\,CO_2 + 25\,H_2O$$

Based on the above stoichiometry of glucose degradation in the rumen, the most important step in utilizing crop by-products is how to degrade the fiber fraction into simple sugar in the form of glucose or xylose. The more these substances are available for rumen fermentation, the more energy will be produced that can be used by the host animal. The equation suggests that every molar of glucose will produce 1.13 molar of acetic acid, 0.35 molar of propionic acid, 0.26 molar of butyric acid, 0.61 molar of methane and 0.43 molar of water. The short chain fatty acids then will be absorbed through the rumen wall to the circulatory system and subsequently used for nutrition deposition in the tissue in combination with other nutrients such as amino acids and fat. The methane will be eructated and released to the atmosphere (Haryanto & Thalib 2009).

BIODEGRADATION AND FERMENTATION OF CELLULOSE AND HEMICELLULOSE INTO ETHANOL

As sources of glucose and xylose, cellulose and hemicellulose from crop by-products, respectively can be degraded by the aerobic and anaerobic systems with different final yields. In the rumen, the microbial fermentation in the anaerobic system resulted in the formation of short chain fatty acids as the primary products. However, depending on the microbial species, there is possibility to produce lactic acids when the microbial population is dominated by lactic acid bacteria. This lactic acid production can be carried out in the process of ensilage. There is also possible to degrade the cellulose into ultimate production of alcohol through glucose or monomer production by the use of fermentation using yeast such as *S. cerevisiae*. Alcohol can be used as an alternative energy source, while the residual of the process still can be used as animal feedstuff.

Facilities required for the biodegradation of cellulose in some cases need to be sterile so that the activity of the appropriate microbes can be optimized. This is true for the anaerobic system which requires specific species of microbes for the process to work properly. Besides, the substrate should be made in liquid condition and continuously agitated for a better result. The alcohol production can be collected by gradation filtering to come to 100% pure alcohol. Several factors may affect the alcoholic fermentation by *S. cereviciae*, such as pH of medium, concentration of substrate and temperature (Lin et al. 2012). The alcohol production follows the equation as shown below:

$$4\ C_6H_{12}O_6 \rightarrow 2\ CH_3COOH + 3\ CH_3\ (CH_2)_2COOH + 8\ CO_2 \quad \ldots\ldots\ldots\ldots \quad (1)$$

$$C_6H_{12}O_6 + H_2O \rightarrow C_2H_5OH + CH_3\,COOH + 2\ H_2 + 2\ CO_2 \quad \ldots\ldots\ldots\ldots \quad (2)$$

Those equations indicate that one mole of glucose may be converted into one mole of alcohol with concomitant production of acetic acid, hydrogen and CO_2. Assuming that crop by-products, such as corn cobs, have the rate of fiber degradation into glucose of 40% then the production of alcohol from the *S. cereviciae* fermentation may reach similar molar of alcohol production. Efficiency of alcohol production is optimal when the pH is controlled at 4.0 to 5.0 while beyond these pH values the production of acetic acid or butyric acid will be greater and therefore reducing the efficiency of alcohol conversion from the substrate. Different substrates for the alcoholic fermentation will produce different quantity of alcohol as indicated in Table 1 (Vucurovic et al. 2009).

The efficiency of ethanol production is affected by the concentration of the substrate, the enzyme concentration, pH, temperature and time of incubation. To make the process of saccharification and fermentation easier, the crop by-products should be ground so that the enzymes from the yeast can be closely attached to more sites due to larger surface area of the substrate particles. Recently isolated anaerobic bacterium *Caloramator boliviensis* with an optimum growth temperature of 60°C can efficiently convert hexoses and pentoses into ethanol. When fermentations of pure sugars and a pentose-rich sugarcane bagasse hydrolysate were carried out in a packed bed reactor with immobilized cells of *C. boliviensis*, more than 98% of substrates were converted. Ethanol yields of 0.40-0.46 g/g of sugar were obtained when sugarcane bagasse hydrolysate was fermented (Crespo et al. 2012).

Saccharification and fermentation process may be carried out simultaneously or separately. The major difficulty in simultaneous saccharification and fermentation (SSF) method is the difference between the optimum temperature for saccharification (45°C to 50°C) and that of fermentation (25°C to 35°C). SSF requires microorganisms that survive in high temperatures. Generally yeasts and bacteria are used in fermentation. *S. cerevisiae* is more resistant to ethanol and other inhibitors in hydrolysate. Therefore, it is crucial to find species of this yeast that can efficiently ferment sugars to ethanol in temperatures more than 35°C (Edgardo et al. 2008). Depending on the characteristics of substrate for ethanol production, the saccharification and fermentation may be different with different efficiency. The fungus used for the process of saccharification may also varied in which *Trichoderma longibrachiatum* has lower efficiency than *Aspergillus niger* when sugarcane bagasse was used as the substrate (Shaibani et al. 2011).

Hydrolysis of sugarcane bagasse with low enzymes loading (3.50 FPU/g dry pretreated biomass of cellulase and 1.00 CBU/g dry pretreated biomass of beta-glucosidase) of the alkaline hydrogen peroxide treated bagasse led to the higher glucose yield: 691 mg/g of glucose for pretreated bagasse after hydrolysis for 1 h at 25 degrees C with 7.35% (v/v) of peroxide. Ethanol yields from the hydrolyzates were similar to that obtained by fermentation of the glucose solution. However, further studies, considering higher biomass concentrations and economic aspects should be performed before extending to an industrial process

(Rabelo et al. 2011). Meanwhile, Cooper and Weber (2012) explained that two processes are primarily used to make ethanol from grains: dry milling and wet milling. In the dry milling process, the entire grain kernel typically is ground into flour (or “meal”) and processed without separation of the various nutritional component parts of the grain. The meal is slurried with water to form a “mash”. Enzymes are added to the mash, which is then processed in a high-temperature cooker, cooled and transferred to fermenters where yeast is added and the conversion of sugar to ethanol begins. After fermentation, the resulting “beer” is transferred to distillation columns where the ethanol is separated from the residual “stillage”. In the wet milling process, shelled maize is cleaned to ensure it is free from dust and foreign matter. Next, the maize is soaked in water, called “steepwater”, for between 20 and 30 hours. As the maize swells and softens, the steepwater starts to loosen the gluten bonds within the maize, and begins to release the starch. The starch-gluten suspension then passes through a centrifuge where the gluten is spun out. The gluten is dried and used in animal feed. The remaining starch can then be processed in one of three ways: fermented into ethanol, dried for modified maize starch, or processed into maize syrup. Wet milling procedures for wheat and maize are somewhat different. For wheat, the bran and germ are generally removed by dry processing in a flour mill (leaving wheat flour) before steeping in water (Cooper & Weber. 2012).

Table 1. Parameters in batch fermentation as affected by *S.cerevisiae* cells immobilized on various carrier at 30^{o}C

Table carrier	Medium	Initial sugar (g/l)	Ferm. time (h)	Residual sugar (g/l)	Ethanol (g/l)	Ethanol productivity (g/ld)	Conversion (%)
Mineral kissiris	Glucose	113.0	16	7.5	48.0	74.3	93.4
Delignified cellulosic materials	Molasses/ sucrose	172.0	36	10.2	104.0	69.3	94.0
	Glucose	350.0	67	68.0	144.0	51.5	80.5
Gluten pellets	Glucose	119.0	15	12.5	39.5	63.2	89.5
	Grape must	206.0	17	18.9	83.7	118.0	90.1
Dried figs	Wort	129.0	18	0	47.4	64.0	100.0
	Glucose	120.0	45	1.4	45.0	24.0	98.0
Quince pieces	Grape must	185.0	28	0.1	84.0	72.0	99.9
Apple pieces	Grape must	206.0	80	30.8	85.0	26.0	85.0
Orange peel	Glucose	125.0	9	4.0	51.4	128.3	96.8
	Molasses/ sucrose	128.0	14	2.0	58.9	100.1	98.4
	Raisin extract	124.0	12	2.3	55.3	110.4	98.1
Watermelon rind pieces	Grape must	202.0	64	Tr	87.0	45.8	100.0
Corn ground tissue (5 g/l)	Glucose	78.6	24	1.4	38.6	38.6	98.2
Corn ground tissue (10 g/l)	Glucose	86.7	24	1.4	39.6	39.6	98.4

Source: Vucurovic et al. (2009)

Residues of bioethanol production

With respect to the bioethanol production from crop by-products or grains, the residues of the process are available and can be used as animal feedstuffs. As mentioned previously, the medium (substrate) of ethanol production, either in dry or wet milling system will have residues after the process of saccharification and fermentation. In the high fiber crop by-products, the primary residues will have higher concentration of undigested fiber while for grain-form substrate there will be more gluten or starch. These materials can be prepared for feed formulation. Sometimes the liquid substrate which is still containing the ethanol is also used as animal feeds. This feedstuff is higher in the energy content; however, feeding high content of ethanol may affect the volatile fatty acid production in the rumen. Feeding glycerin (glycerol) may increase the propionate production, and therefore will change the acetic to propionic ratio.

Residues from bioethanol production can be dried without the liquid yield and then ground to be used as feedstuff and known as dried distillers grain (DDG) when the substrate is grains, or when the liquid yield is mixed to the residues then it is known as dried distiller grain with soluble (DDGS). The chemical compositions of fermentation products are different to the raw material before the fermentation. Chemical analysis from the US samples indicated that on average, ground corn contained 70.23% starch, 7.65% protein, 3.26% oil, 1.29% ash, 87.79% total carbohydrate (CHO), and 17.57% total nonstarch CHO in dry matter basis. After fermentation, starch content decreased to about 6.0%, while protein, oil, and ash contents increased over 3-fold. Amino acids increased 2.0-3.5-fold. Total CHO content decreased by 40%, and the content of total non-starch CHO increased over 2.5-fold (Han & Liu 2010). The recommended amount of DDGS for feeding lactating dairy cows is up to 20% of total ration dry matter; higher amounts (40 to 50% of ration dry matter) can be successfully fed as an energy source to finishing cattle. The fiber in DDGS, which often replaces high starch feeds, does not eliminate acidosis but minimizes its problems (Schingoethe 2006).

The use of wet distiller or dried distiller grain with soluble have been evaluated in beef cattle. The use of wet distiller with soluble in increasing quantity (10 to 40% of diet dry matter) for beef cattle showed to positively affect the average daily gain (ADG) from 1.71 to 1.79 kg as compared to control 1.60 kg (Erickson et al. 2012). Feeding DDGS at 10 to 40% of the diet dry matter resulted in the ADG range from 1.63 to 1.80 kg as compared to 1.57 kg in the control group. Wet distillers by-products averaged 69% higher the energy value of corn (2.53 Mcal of NEg/kg) when fed to yearlings and 28% higher the energy value of corn (1.96 Mcal of NEg/kg) when fed to calves. The increase of energy values cannot be explained by increasing digestibility, but they may be due to a combination of factors (acidosis reduction, increased energy utilization or yeast end products) that increase the net energy content of distillers by-products (Larson et al. 1993).

As a matter of fact the bioethanol production may be carried out at farmers' level to increase the beneficial uses of crop by-products; however, the available technologies and the cost of production have to be considered in more detail so that better economic values can be taken by farmers.

Fat content and its economic advantage of crop by-products

In general, the crop by-products in the form of straws are low in fat content. The by-products of grain, however, may contain higher fat, such as rice bran contains about 15% fat. This high fat content may shorter the storage time since it will be rapidly oxidized resulting in rancid condition. Therefore, the use of rice bran should be limited by time of storage and hence, it will be better to use rice bran as soon as possible after rice polishing process. To increase the economic value of rice bran, it is possible to extract the fat by which the final residues of defatted rice bran is a feed-grade material of higher in protein content and can be stored for a longer time. The rice bran fat (oil) can be used for human consumption or for functional food and cosmetic purposes. The high content of antioxidant in the rice bran oil makes it appropriate for cholesterol reduction in human.

Rice bran oil (RBO) is popular in several countries such as Japan, India, Korea, China and Indonesia as cooking oil. The nutritional qualities and health effects of rice bran oil are also established which is rich in unsaponifiable fraction, which contains micronutrients such as vitamin E complexes, gamma-oryzanol, phytosterols, polyphenols and squalene. However, the high free fatty acids (FFA) and acetone-insoluble content make it difficult to process (Ghosh 2007). The isolation of oryzanol from crude rice bran oil (RBO) was achieved by a two-step crystallization process. In the first crystallization, oryzanol was concentrated in the liquid phase along with free fatty acid (FFA), monoacylglycerol (MG), squalene, tocols, and phytosterols, whereas the solid phase contained mainly triacylglycerol (TG) and steryl esters. Oryzanol-rich product obtained from the first crystallization was subjected to the second crystallization where the oryzanol-rich product was kept at room temperature (20.5 ± 1.5^{o}C) for 24 h. Hexane was added as anti-solvent to the oryzanol-rich product and kept at 5 ± 1^{o}C for another 48 h (Zullaikah et al. 2009). The phytochemical compounds oryzanols, tocopherols, tocotrienols and ferulic acid were identified in the crude methanolic extracts (CME) of defatted rice bran by HPLC. The defatted rice bran extracts and their phytochemical constituents when assayed by cytochrome c and NBT methods showed positive superoxide radical scavenging effects (Renuka Devi & Arumughan 2007).

Technology for de-fatting rice bran is available, either by cold press machine or extraction technique. The cost of extracting fat from rice bran may be expensive and may not be appropriate for a small scale production. Therefore, efforts to de-fat rice bran should be carried out in an integrated system of rice milling unit (RMU) and rice bran oil industry under medium or higher scale of production.

Feed nutritive value of defatted crop by-products

It is expected that by defatting crop by-products, the nutritive value of the remaining material will be better, because the protein concentration will be higher and the effect of the fat in the whole ration to the fiber degrading microbes will be reduced; therefore the digestibility of fiber will increase and hence increasing the energy availability as a result from fermentation products. Crop by-products with a relatively high content of fat such as rice bran, wheat bran, cottonseed, corn germ or palm kernel cake, can be used as high protein residues for feedstuff after being defatted. Effect of using defatted crop by-products in the ration of ruminants has been promising as indicated by higher productive performance and carcass quality.

Rice bran contains approximately 13.5% oil in the dry matter. *In situ* esterification of high-acidity rice bran with methanol and sulfuric acid catalyst has been investigated by Gunawan et al. (2011). The results suggest that under the conditions of methanol to rice bran ratio of 5 mL/g, sulfuric acid concentration in methanol of 1.5 vol. %, and reaction time of 60 minutes, the esterification could yield fatty acid methyl esters with a high purity and recovery. By applying such *in situ* esterification with n-hexane/water extractions, Indonesia actually has the potential to produce bio diesel from rice bran up to 96,000 ton per year (Gunawan et al. 2011).

In the rural areas where rice milling unit can be integrated with rice bran oil industry, there will be available residual products of higher nutritive value. Similarly, where corn germs are available, these can be used as the basic material for production of oil. Europe has been utilizing the residues of bioethanol production using grains or crop by-products as animal feedstuffs.

FEEDING RUMINANTS WITH RESIDUAL OF CROP BY-PRODUCTS

Energy from crop by-products should be used rather than being burnt. One possibility of energy utilization from crop by-products is for ruminant feed; even though it needs improvement in the nutritive value. Several methods to improve the utilization of rice straw by ruminants have been investigated. Some physical treatments are not practical, while chemical treatments, such as NaOH, NH_3 or urea, currently seem to be more practical for on-farm use. Alternative treatments are the use of ligninolytic fungi (white-rot fungi), with their extra cellular ligninolytic enzymes, or specific enzymes degrading cellulose and/or hemicellulose (Sarnklong et al. 2010).

Rice straw is different to other cereal straws in being low in lignin and high in silica. Unlike other cereal straws, taller varieties of rice straws tend to be leafy while the leaves are less digested than stems (Van Soest 2006). Rice straw chemical composition varied as indicated by Neutral-detergent fibre (NDF) contents ranging from 56.6 to 68.6% with a mean value of 62.7%. Acid-detergent fibre ranged from 33.6 to 43.2% with an average of 37.7%. Lignin averaged about 4% and nitrogen ranged from 0.44 to 0.86%. The mean ash content was 18.6% with a fairly constant contribution of 72% silica. Treating the rice straw with anhydrous ammonia increased the nitrogen content by 0.53% and increased the NDF digestion by 24% (Abou-El-Enin et al. 1999). From 32 varieties of rice straw, the mean proportion of blade, sheath and stem was 32.4%, 25.5% and 41.0%, respectively, in whole straw. Stem had a significantly higher *in vitro* digestibility (IVD) (58.9%), lower insoluble ash (6.9%) and lower total ash (18.9%) but a higher neutral detergent fibre (NDF, 62.7%) and lower crude protein (CP, 3.4%) than blade or sheath. For whole straw, the range in composition was: NDF, 54.2 to 63.2%; CP, 2.0 to 5.3%; insoluble ash, 6.2 to 14.4; total ash, 16.6 to 25.1% with IVD, 44.4 to 64.7% (Vadiveloo 1995).

The use of fungi or enzyme treatments may be more practical and environmental-friendly approach for enhancing the nutritive value of rice straw and can be cost-effective in the future. Using fungi and enzymes might be combined with the more classical chemical or physical treatments (Sarnklong et al. 2010). The degradation potential and ligninolytic enzyme production of two isolated *Panus tigrinus* strains (M609RQY and M109RQY) were evaluated by growing those strains on rice straw and rice husk under solid-state fermentation conditions. The results indicated that the strain M609RQY degraded the lignin 11.25% on rice husk and 67.96% on rice straw (Ruqayyah et al. 2013).

The cultivation of four *Pleurotus* species including *Pleurotus florida*, *Pleurotus djamor*, *Pleurotus sajor-caju* and *Pleurotus ostreatus* and the effect of these species on the chemical composition, cell wall degradation and digestibility of rice straw have been evaluated by Jafari et al. (2007). Rice straw was soaked in water for 24 h, pasteurized at 100^{o}C for 6 h, then inoculated with spawns of four *Pleurotus* fungi (*P. florida*, *P. djamor*, *P. sajor-caju* and *P. ostreatus*) and packed in the plastic bags and incubated in a fermentation chamber at 23-27^{o}C and 75-85% relative humidity for 60 days. The results showed that fungal treatment increased the Crude Protein (CP), silica, Ca and P contents of the rice straw but the hemicellulose, Organic Matter (OM), Acid Detergent Fiber (ADF), NDF and Acid Detergent Lignin (ADL) contents decreased. The ability of *P. sajor-caju* and *P. ostreatus* were higher than the other species in decreasing the hemicellulose, NDF, ADF and ADL contents (Jafari et al. 2007). The use of straw in dairy cattle diets has increased greatly in recent years in US, primarily in dry and transition cow diets and replacement heifer diets, but there are some usage even in diets for lactating cows. The type of straw used is primarily wheat straw, chopped prior to feeding and fed at a low inclusion rate in total mixed rations (TMR) (Shaver & Hoffman 2010). In Ethiopia, crop residues contributed to 26 to 40% of the total annual maintenance feed requirement of ruminants.

Through the use of improved seeds and other inputs that boosted both grain and residue yields, and by the application of better ways of collection and storage that minimized wastages, farmers could derive more benefits from these valuable feed resources (Alemu et al. 2006).

Technology for crop by-products handling

Many technologies have been developed to cope with the utilization of low quality crop by-products; however some technologies are not practical due to the requirements of machinery or other infrastructure that are difficult for the farmer to work. In some cases, the cost of process is expensive which end-up with not applicable in existing farmer condition. It is generally believed that crop by-products are of no use because the economic values are very low. Difficulties in providing adequate labors for crop by-product handling, and the effect of unfriendly seasons, especially in dealing with drying during rainy season, which is required for the storage and transportation system are other problems.

Harvesting implies in-field gathering and removal of selected crop materials or products and their delivery to a storage site or transport vehicle. Harvest may include sizing and densification and is interrelated with other activities required to meet user needs, activities that may include additional transport, drying, and storage. The desired type and sequence of these activities based on operational costs, energy consumption, environmental effects, and personnel and management considerations depends on biomass form, conversion process, scale of operation, and harvest/utilization schedules (Larson 2003).

In rice or corn based agriculture the mechanization of plant management, started from land preparation to harvesting may overcome the problems of labor and time; however it will be appropriate only in flat and vast area. While mechanization may not be appropriate in the hilly and narrowly terraced area. Therefore, mechanization should be better carried out in intensive and large scale rice management areas. For rice crop areas covering an approximately 1000 hectares need to be handled by 100 principle labors to manage 5000 tons of rice straw every harvesting time. It means that one principle labor should take care of 50 tons of rice straw (approximately 10 trucks) which require a processing area of about 250 squared meters. The handling of rice straw includes collecting from field, transporting to the processing location, treating the rice straw, either technically or biologically, packaging and storage before being distributed to the livestock farming areas. The application of the aforementioned activities will enable farmers to keep more number of cattle year-round as the requirement of feeds can be assured available any time.

CONCLUSION

The potential of crop by-products in the form of cellulose and hemicellulose could be converted into several products such as bioethanol, methane, and animal feedstuffs for the production of meat, milk or egg. The global trend of bioenergy utilization as compared to the diminishing used of fossil energy may drive the attention for further research in the utilization of crop by-products. The agricultural production should be directed to the targeted condition to yield food, feed, and fuel which is sustainable in adequate quantity for the local requirements. Technologies required for the utilization of crop by-products should be further developed, nevertheless should be suitable and practicable by farmers' existing condition. All of these activities will drive the development of village bioindustry era.

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