Agriculture and Ignorance: A review of the benefits of rice by-products overlooked by Ugandan rice farmers.

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Abstract: **Uganda produces 350,000 MT of rice annually which translates to 472,500 MT of rice straw, 70,000 MT of husks, 35,000 MT of bran, and 49,000 MT of broken rice. Rice straw and husks are usually burned as waste or buried while rice bran is largely used for livestock feeding purposes. Broken rice is fully consumed to an extent that it is imported. The limited utilization of rice by-products by farmers in Uganda indicates that numerous benefits are overlooked and thus missed out. The benefits overlooked range from agricultural importance, biogas potential, weaving, paper production, biochar generation, silica for concrete industries, briquette making, human health, bakery, and catering services. Rice by-products represent profound health, income, agricultural and industrial hidden potential. Judging by the steady increase in the production of rice in Uganda, the generation of waste from rice production will also increase as much as the increase in rice production. Creating awareness about the negative impacts of inappropriate disposal of rice by-products on the environment is pertinent. Potential new uses of rice by-products with the potential to improve farmers' socio-economic conditions when used appropriately and sustainably should be given priority. Creating the perfect basic needs such as logistical facilities, courses and training for farmers, millers, officials as well as research for the by-products development in the country is very critical. There is need to widely emphasize the health and nutritional benefits of rice bran at the farmer level as a cheaper form of treatment in the long run.**

***Keywords*: rice, by-products, bran, straw, husk, burning, environment**

I. INTRODUCTION

Uganda is an agriculture-based economy that is often mentioned as the food basket of the Eastern region of Africa thanks to its potential for producing a spread of foods in large quantities for both domestic consumption and export (FAO, 2018). More than 80% of the total Ugandan population depends on agriculture for their daily livelihood (Anderson *et al.,* 2016). This agricultural sector comprises crop production, livestock, forestry and fishing sub-sectors (Nsubuga *et al.,* 2019). The large and small agro-based activities generate a number of by-products which when added value to can produce other useful products that are environmentally friendly with a higher market value (Kilimo Trust, 2017; Nsubuga *et al.,* 2019). Therefore, value addition and utilization of these by-products could help maximize profits most especially at farmer level and create more jobs along the rice value chain (Finance Tribune, 2015).

Rice production in Uganda dates back to 1904 but gained great importance as a food crop during the 1950s (Bua, 2014; Odogola, 2006). Kunihiro *et al.* (2014) assert that its cultivation in Uganda can be traced to the latter half of the 19th century when it was grown for a handful of Arab and Swahili traders. Uganda National Rice Development Strategy (UNRDS) (MAAIF, 2009) asserts that Rice production in Uganda started in 1942 while Reid (2002) believes that rice was already introduced into the country by end of the 1870s. During the independence year of 1962, McMaster reported that rice was already recognized and reported as one of the food crops produced and promoted in the country by 1921 (McMaster, 1962). Its introduction and cultivation in Uganda point towards feeding the Second World War veterans and government institutions such as schools, prisons and hospitals (Odogola, 2006), Arab and Swahili traders (Kunihiro et al., 2014; Reid, 2002) and European administrators, Indian businessmen as well as Indian rail construction workers, the 'coolies' who built the railway line from Mombasa to Uganda (Lamo *et al.,* 2021). According to Lamo *et al*. (2021), during the 1950's, the Uganda government developed further interest in rice and potential for irrigated rice farming. It is then that rice gained importance as a cash crop (Odogola, 2006). However, according to the Uganda National Rice Development Strategy, production remained minimal until 1974 when farmers appealed to the then government for assistance (MAAIF, 2009). This was followed by the establishment of Kibimba rice irrigation scheme followed by Doho (Lamo *et al.*, 2021; Odogola, 2006) and later on a third rice irrigation scheme was constructed at Olweny swamp in Northern Uganda (Lamo *et al.*, 2021). Subsequently, the cultivation and consumption of rice spread throughout the country with majority of the rice growers being small holders found especially in eastern and northern parts of Uganda while majority of consumers concentrated in major urban areas.

Rice is currently the second most important grain staple after maize in Uganda (Kilimo Trust, 2019). It is recognized by the government as a strategic crop with the potential to remarkably contribute to increasing rural incomes and livelihoods, and improving food and nutrition security

(MAAIF, 2012). The current production level of rice in Uganda stands at 350,000 MT annually (Hong *et al.,* 2021). Over 90% of the national rice output is as a result of contribution by smallholder farmers (Alibu et al., 2016). Eastern Uganda is the largest producer accounting for over 67% of the country's rice harvest (Barungi & Odokonyero, 2016) followed by Northern (23%), and mid-Western parts of Uganda under rain fed and irrigated rice systems (Alibu *et al*., 2016; UBOS, 2015). According to Rice Association of Uganda (RAU) (2018), Rice is produced by about 250,000 farmers, with majority being smallholder farmers (80%) producing both lowland and upland rice varieties (Kilimo Trust, 2019). The major rice varieties cultivated in Uganda include Namche, Komboka, Kaiso, Wita 9, Basmat 370, IR 64, Supa, Buyu, and NERICA (Kunihiro *et al.,* 2014). The productivity of rain fed and irrigated rice among smallholder farmers in Uganda is low at 3.6 and 1.7 t/ha respectively against a potential yield of 5 t/ha (Okello *et al.,* 2019). This is attributed to use of low-yielding rice varieties, limited access improved seed varieties and yield-enhancing inputs, coupled with the limited use of time/labour-saving technologies (Hong *et al.,* 2021). Much as the productivity is low, the Government of Uganda is tirelessly pursuing a rice sector development strategy that is designed to build a self-sufficient national rice industry (IFDC, 2021).

1.1 Rice by-products in Uganda

Agricultural by-products are referred as agricultural wastes which in most cases are just disposed-off with no value added (Nsubuga *et al.*, 2019). Amita (2019) defines a by-product as a secondary product derived from a manufacturing process or chemical reaction during production of main product. Therefore, it is worth noting that by-products are produced after the major processes of the main product have been conducted. Rice processing illustrated in figure 1 can be summarised in several steps including harvesting, transport, reception and pre-cleaning, drying, storage, shelling, milling/polishing and finally, selection and classification (Moraes *et al.*, 2014). The main by-products generated in these processes include: straw, husk, bran and broken rice as illustrated in the diagram below.

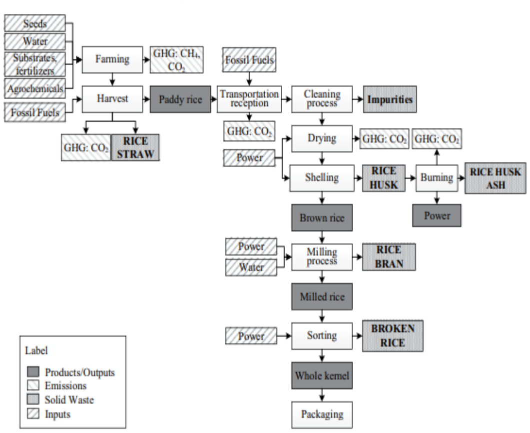

Figure 1: Rice production process with inputs and outputs
Source: Moraes *et al.* (2014)

Each by-product is produced at a different stage of processing as described by (Moraes *et al*., 2014; Pandey *et al*., 2010)

1. Harvesting: is the process that involves collecting the mature rice grains from the field. Harvesting activities include reaping (cutting mature panicles and straw), stacking, and hauling. The production of straw as a by-product occurs in this stage.
2. Transportation, reception and pre-cleaning: Rice is transported as bulk cargo or as break-bulk cargo in bags or any other carrier materials**.** Upon reaching the conservation area, pre-cleaning must be performed in order to separate contaminant materials.
3. Drying: Drying can be done naturally in the sun (solar drying) or mechanically. After drying, the husked rice can be stored safely for some time awaiting further processes.
4. Storage: The rice can be stored in bags or in bulk in silos.
5. Shelling: It is the process of husk removal. This process results into the generation of brown rice and rice husk. Typically, the process through which husks are separated from the rice is aspiration.
6. Milling/polishing: This process consists of removing the germ and the starch-based film that surrounds the caryopsis of the grain. This process generates the white rice or milled rice and rice husk (germ and film removed from around the grain).
7. Sorting/classification: The process of selection is the separation of fragments and defective or broken grains. From this selection, rice is classified according to the type and length of the grain, with whole rice and broken rice being generated. Rice is then ready to be packaged at the end of these processes.

For each tonne of harvested paddy rice, 1.35t of rice straw are generated in the field. In the industrial process, each tonne of processed paddy rice generates 200kg of rice husk, 100kg of rice bran and 140 kg of broken rice (Finance Tribune, 2015; Moraes *et al*., 2014).

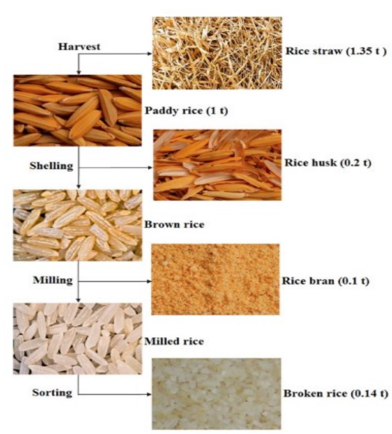

Figure 2: Rice by-products obtainable from the different stages of rice processing
Source: Buggenhout *et al.* (2013); Moraes *et al*. (2014)

With the current production level of rice in Uganda at 350,000 MT per year (Hong *et al.*, 2021), this implies that 472,500 tonnes of rice straw, 70,000 tonnes of husks, 35,000 tonnes of bran and 49,000 tonnes of broken rice are produced annually in Uganda.

Rice by-products such as rice straw, rice husks and rice bran are largely considered as a waste by Ugandan rice farmers. This is evident by the fact that the straws are always burned after rice harvest, husks and bran are either fed to animals but to a larger extent not retrieved from the rice mills. Like in many undeveloped countries, another agricultural waste disposal method in Uganda is burning (Nsubuga *et al.*, 2019). However, a number of possible uses of these by-products could help maximize profits that have dwindled over the years and even create more jobs (Financial tribune, 2015). According to Amita (2019), per tonne of rice straws burnt by farmers, enormous nutrient losses occur including 5.5 Kg of Nitrogen, 1.2 Kg of Sulphur, 2.3 Kg of Phosphorus, 25 Kg of Potash and 400 Kg of organic carbon. There is need to sensitise the different stakeholders in the rice value chain about the importance of rice and its by-products to avoid the negative effects of rice as a climate change promoter (Bua, 2014). This study aims at determining the rice by-products available in Uganda, their current utilization and benefits overlooked as a result of the current utilization.

II. MATERIALS AND METHODS

This study employed a monographic method, and the literature reviewed ranged from mainly journal articles, documents, books and book chapters. These were studied purposely to document the different rice by-products within Uganda, Africa and other parts of the world, their mode of disposal as well as utilization. The literature included both published and unpublished sources accessed from google scholar, agricultural websites, government records, development and Non-Governmental organisation reports. The literature reviewed ranged across a number of years to depict the history of rice cultivation and usage of rice by-products.

III. RESULTS AND DISCUSSIONS

3.1 Major rice by-products in Uganda

The main rice by-products generated through the different processes of rice production are rice straw, rice husks and rice bran (Finance Tribune, 2015). For each tonne of harvested paddy rice, 1.35t of rice straw are generated in the field. In the industrial process, each tone of processed paddy rice generates 200kg of rice husk, 100kg of rice bran and 140 kg of broken rice (Moraes *et al.*, 2014). According to Pandey *et al.* (2010), the most important by-product is husk, comprising of about 20% of paddy rice and rice straw mass. The volume of bran and broken rice generated differs and largely depends on the efficiency of the processes through which the product undergoes.

3.1.1 Rice straw

Rice straw is the vegetative part of the rice plant and major forage in rice-producing areas (Finance Tribune, 2015). It is separated from the grain during the harvest (Moraes *et al.*, 2014). For every tonne of grain harvested, about 1.35 tonnes of rice straw remains in the field (Buggenhout *et al.*, 2013; Moraes *et al.,* 2014). It is about 50% of the dry weight of rice, with significant variation from 40% to 60% according to the method of cultivation, field conditions and harvesting technique (Kadam *et al.,* 2000). With the current production level of rice in Uganda at 350,000 MT per year (Hong *et al.,* 2021), Uganda produces 472,500 tonnes of rice straw annually. For every ton of rice grown in Uganda, a significant amount of husks and straw are created and usually burned as waste or buried (Maltesser International, 2022). Nsubuga *et al.* (2019) agrees with the fact that in many cases, agricultural wastes are disposed by burning which is not environmentally acceptable due to its associated negative consequences. Smoke still dots the horizon as some people burn their rice straw in Nampologoma (Butalejja district) and Iganga districts of Eastern Uganda (Bentley *et al.,* 2013). According to The conversation (2019) , farmers in sub-Saharan Africa burn a lot of crop residues in fields, this was seconded by Campenhout (2021) who found out that Many farmers in Uganda burn rice straws after harvest.

3.1.1.1 Why farmers burn straw

According to Rosmiza *et al.* (2012), majority (63.8%) of farmers in Malaysia burn rice straw because its presence in the field would only complicate the process of ploughing the land since straws get stuck in the ploughing machines. This would cause damage to the machinery and hence increase farm operating costs. The other 18.8% burn straw as a traditional and normal practice, 11.8% burn straw to kill crop pests and destroy disease cycles while 5.6% burn straw as a form of state soil fertilization.

Table 1: Reasons why farmers burn rice straws.

Straw Burning's Purposes	Amount	Percentages
Easier and Cheaper Method to Clean Up a Field	102	63.8
Traditional Practices	30	18.8
To Eliminate Diseases and Pests Attack	19	11.8
Soil Fertilization Method	9	5.6

Source: Rosmiza *et al.* 2012

According to Ahmed *et al.* (2015), farmers in Pakistan burn rice residue also because many believe that it has a beneficial effect on yields. They also found out that farmers who burnt straw incurred the least cost in land preparation for the subsequent season. The Manitoba Agriculture and resource development agree with the fact that burning straw is considered a low-cost solution alternative to tilling in the straw, under such circumstances, farmers tend to assume they have no choice but to burn the straw. (El-Sobky, 2017) found out that burning is the cheapest and easiest way for removing large loads of the produced rice straw. They also noted that the burning of straw is as a result of need for a short turnover time between rice and the subsequent crop. Farmers in sub-Saharan Africa burn a lot of crop residues in fields because recycling the waste involves time, labour, and machinery that they can't afford (The conversation, 2019).

3.1.1.2 Effects of burning rice straw

Burning straw causes large amounts of CO, SOx, NOx and particulate matter (Kadam *et al.,* 2000) including producing 13 tons per hectare of carbon dioxide (Rosmiza *et al.,* 2012), while buried waste can cause issues associated with eutrophication (Torregrosa *et al.,* 2021). Various cases of road accidents recorded were due to the poor visibility caused by the smoke from the burning rice straws alongside the roads (Philstar Global, 2006). Globally, only ~20% of rice straw is used for practical purposes, such as production of biofuels, paper, fertilizers and animal feed, since most is either burned in situ, incorporated in the soil for mulching purposes (Hanafi *et al.,* 2012). When the pollutants get into the atmosphere, acid rain formation and ozone layer depletion are expected. This has imposed a risk to human and ecological health (Nsubuga *et al.,* 2019).

According to Rosmiza *et al.* (2012), burning straw affects state air quality by 100 % most especially if the burning is carried out on a large scale by farmers simultaneously. Dispersion of the combustion ash spread by wind cause dusty black floors, clothes and ornamental plants. The airflow of houses is affected because their windows are closed to prevent ashes from getting into the houses.

Table 2: Effects of rice straw burning in Mada region of Malaysia

Aspect	Situation before (pre) development of straw									
	Very Bad		Bad		Moderate		Good		Very Good	
	Total	%	Total	%	Total	%	Total	%	Total	%
Air quality	160	100	-	-	-	-	-	-	-	-
Ashes burning dispersion	150	93.8	7	5.5	3	1.9	-	-	-	-
Smoke disruption	126	78.8	26	16.0	8	5.0	-	-	-	-
Level of Health	55	28.1	25	15.0	91	56.9	-	-	-	-
Field management	11	6.9	26	16.3	9	5.6	55	33.8	60	37.5
Farmers' revenue (income)	-	-	-	-	110	68.8	50	31.3	-	

Source: Rosmiza *et al.* (2012)

They also found out that smoke released from the burning straw affects the visibility of road users which in turn causes a number of major accidents. The state the medical condition is always average during straw burning periods coupled with coughing, burning eyes, skin irritation, and some cases of death in the field due to shortness of breath most especially for asthmatic patients.

3.1.1.3 Benefits missed out by farmers due to the burning of rice straws.

According to Rosmiza *et al.* (2012) nutrient content of the rice straw is high with 25% nitrogen (N) and phosphorus (P), 50% sulphur (S) and 75% potassium (K). Therefore, it is a big loss if the agricultural residue is not being exploited and utilized to the optimum given its high nutritional value. According to Finance Tribune(2015), straw may be used as part of animal feed diet. To determine its gas yields, rice straw has been tested in biogas plants. The use of straw in large-scale biomass power plants is becoming mainstream in Europe. Rice straw mixed up with clay can be used as a building material. Other uses include basketry, bedding, packaging, pulp for paper production, etc. Straw-bale construction has been identified as a sustainable method of building because of the renewable nature and high insulation value of straw (Maltesser International, 2022). According to Siwar *et al.* (2014), rice straw increases the quality of agricultural environment and provides an opportunity to increase farmers' income and investment generation with the formation of upstream and downstream activities through the value-added of the crop residue. Rice straws have notable potential for storing carbon in soils, when converted into biochar and then mixed with soil, it can counterbalance between 16% and 80% of the 4.6 tons of carbon dioxide on one hectare of land. Biochar has the added benefit (The conversation, 2019) of improving soil fertility and crop production in tropical climates. So this strategy to use biochar to remove warming gases from the atmosphere will eventually trickle down and benefit farmers.

According to Rosmiza *et al.* (2012), after sensitizing the farmers about the negative impacts of straw burning on the environment and its potential at improving their socio-economic conditions when used appropriately, smallholder farmers in the Mada region of Malaysia gave straw development tremendous attention. The benefits that they realized after creating awareness among smallholder farmers are displayed in the table below.

Table 3: The benefits realized by farmers after making them aware of rice straw development for agro-based purposes.

Aspect	The situation after (post) the development of straw									
	Very Bad		Bad		Moderate		Good		Very Good	
	Total	%	Total	%	Total	%	Total	%	Total	%
Air quality	-	-	-	-	-	-	5	3.1	155	96.9
Ashes burning dispersion	-	-	-	-	-	-	3	1.9	157	98.1
Smoke disruption	-	-	-	-	-	-	3	1.9	157	98.1
Level of Health	-	-	-	-	-	-	35	21.9	125	78.1
Field management	-	-	19	11.9	25	15.6	30	18.8	86	53.8
Farmers' revenue (income)	-	-	-	-	-	-	18	11.3	152	88.7

Source: Rosmiza *et al.* (2012)

3.1.2 Rice husk

The rice husk is the outermost covering of the paddy grain that is separated from rice grains during the process of milling (Finance Tribune, 2015). It is the coating on a seed or grain of rice formed from hard materials, including silica and lignin, to protect the seed during the growing season (IRRI, 2020). It is said to have an average composition of 80% organic matter and 20% ash (Bisht *et al.*, 2020) and around 20-22% of the paddy weight is husk (Finance Tribune, 2015). Rice husk contains approximately 20% silica which is presented in hydrated form (Javed & Naveed, 2008). According to Bisht *et al.* (2020), rice husk is naturally tough, woody, water insoluble, and has abrasive resistance behaviour and silica-cellulose structure. The exterior is mostly silica coated with a thick cuticle and surface hairs, while small amount of silica is presenting the mid-region and inner epidermis. It has different composition of chemical components as shown in the table below;

Table 4: Composition of rice husk

Constituent	Percentage
Cellulose	35
Hemicelluloses	25
Lignin	20
Crude protein	3
Ash	17

Source: Bisht *et al*. (2020)

Ogwang *et al.* (2021) conducted a study to determine the proximate and ultimate properties of rice husks from major rice varieties grown in Uganda. The results were as displayed in the table below.

Table 5: Proximate and ultimate properties of rice husks in Uganda.

Rice variety	Ultimate analysis (%, dry ash free basis)					Proximate analysis (%, dry basis)			BD (kg/m^3)	MC (wt%)
	C	H	S	N	O	Ash	FC	VM		
NERICA 10	35.61	6.05	0.01	0.81	57.52	18.33	18.68	62.99	102.85	7.34
NERICA 4	33.86	5.82	0.21	0.81	59.31	18.94	18.25	62.81	105.98	7.39
K-98	33.01	5.34	0.07	0.82	60.77	27.34	15.90	56.76	134.27	7.50
Pusa	30.67	4.90	0.15	0.58	63.71	28.58	15.69	55.73	124.82	7.35

Notes: FC, fixed carbon; VM, volatile matter; BD, bulk density; MC, moisture content; and wt, wet basis.

Source: Ogwang *et al.* (2021)

Olupot *et al.* (2016) characterized husks from the different varieties of rice in Uganda for bio-fuels and their techno-economic feasibility in gasification. Several techniques to convert rice husks into energy have been suggested including thermo-chemical, bio-chemical and physical-chemical conversion techniques (IRRI, 2022). With the current production level of rice in Uganda at 350,000 MT per year (Hong *et al.,* 2021), Uganda produces 70,000 tonnes of rice husks annually. According to Lubwama *et al.* (2018), the quantity of rice and coffee husks produced in Uganda has increased sharply in recent years due to the increased consumption of coffee and rice. Just like straws, the traditional method of disposing of the husks in Uganda is burning them in open fields, which greatly promotes environmental pollution and climate change. The most common method of disposing of husks in Uganda is open dumping and/or burning (Ogwang *et al.,* 2021).

3.1.2.1 Benefits missed out by farmers due to the burning of rice husks.

Rice husk can be used in the form of husk itself or the silica derived from it can also be used giving different sets of physical, mechanical properties (Bisht *et al.,* 2020). According to Finance tribune (2015), Cellulose, the main constituent of rice husk, is used as raw material for pulp and paper making; combustion of rice hulls affords rice husk ash, which is used in the production of Portland cement; It is also used as fuel to provide energy for rice mill operation, fertilizer, insulation material, filter for fruit juice extraction, fibreboard production, pillow stuffing, and many more. Menya *et al.* (2020) assert that rather than open dumping or burning, rice husks can be combusted under controlled conditions to generate rice husk ash with a high silica content (80%– 90%). The burning of rice husks under controlled conditions produces rice husk ash (RHA), which is used industrially as a raw material because of its high silica content (Nsubuga *et al.,* 2019). According to Olupot *et al.* (2016), rice husks generated in Uganda have an electricity generation potential of 15,310 MWh per year giving an annual diesel saving of $4,903,636 and carbon dioxide saving of 14,045 tCO2 per year. The use of rice husk in power reactors for power generation reduces the negative environmental impact caused by the disposal of waste and contributes to reducing dependence on petroleum and to the use of renewable sources (Moraes *et al.,* 2014). According to IRRI, (2020), rice husk can be used for small applications such as for brick production, for steam engines and gasifiers used to power rice mills, and for creating heat for rice dryers; the excessive silica content of rice husk ash makes it a good additive for the steel and concrete industries; To a lesser degree, rice husk ash can be applied as soil conditioner, activated carbon, insulator, and others. According to Baniya *et al.* (2020), the densified form of rice husk is pellets and briquettes and due to increased density, the combustion performance of these by-products is superior to unground rice husk. Briquettes and pellets are frequently utilized in lieu of fossil fuel in industrial boilers. According to Subashi De Silva & Priyamali,(2020), rice husks can be used as fuel in boilers to produce steam for generator turbines to produce electricity and in brick kilns to fire clay bricks.

3.1.3 Rice bran

Rice bran is the outer layer of the rice grain, removed by polishing brown rice to become white rice (CopRice, 2020). It is a by-product of the rice milling process (the conversion of brown rice to white rice) (Finance Tribune, 2015). Rice bran the part between the husk and the endosperm of the grain, removed during the polishing process of rice and represents 10% of the mass of a grain of rice in the husk, and has an oil content that varies between 15%–20% (Moraes et al., 2014). According to Sapwarobol *et al.* (2021), bran is the brown outer layer of the rice kernel, mainly composed of the pericarp, aleuron, seed coat, and germ which contains 50% carbohydrate (mainly starch), 20% fat, 15% protein, and 15% dietary fibre (DF), mainly insoluble fibre. Rice bran contains 12–22% oil, 11–17% protein, 6–14% fibre, 10–15% moisture, and 8–17% ash. It is rich in vitamins, including vitamin E, thiamine, niacin, and minerals like aluminium, calcium, chlorine, iron, magnesium, manganese, phosphorus, potassium, sodium, and zinc (Sharif *et al.,* 2014). Rice bran is light coloured with a sweetened taste, averagely oily, and has a slightly toasted nutty flavour (Hu et al., 1996) and its texture varies from a fine, powder-like consistency to a flake, depending on the stabilization process (Sharif *et al.,* 2014).

Unlike other rice by-products, there is a considerate number of farmers who are aware of the basic uses of rice bran in Uganda. However, after milling rice, farmers rarely or even never ask for the corresponding amount of bran from the millers. According to JICA (2013), Farmers who takes rice bran after milling differs among regions i.e. in Western regions, no sample rice millers takes rice bran, leaving its disposal to farmers. On average for the entire samples, the bran is taken by rice mills and farmers about equally (JICA, 2013). As such, in addition to the milling fee as the main source of revenue is milling fee, the sale of rice bran, a by-product of the rice milling process, is a minor source of income for rice millers (JICA, 2013). According to JICA (2013), milling of rice generates rice bran which is largely sold as animal feeds or as material for organic fertilizer. Nearly 56% of households in Uganda use feed ingredients such as maize bran and rice bran as straights (EADD, 2010). This, therefore, means that in Uganda, rice bran is largely used for animal feeding purposes, especially for pigs and poultry. With the current production level of rice in Uganda at 350,000 MT per year (Hong *et al.,* 2021), 35,000 tonnes of bran is produced annually. Buyers of bran are not only local pig and poultry farmers but also feed traders in various places including Kampala and Kenya (JICA, 2013). About 1.1 million own at least 1 pig in Uganda (Pig progress, 2018), hence the households that use bran for feeding do not use considerable amounts per year. Besides, pig farming in Uganda largely follows a free-range system with very limited housing (Pig progress, 2018) thus meaning that pigs largely survive on scavenged feeds and not rice bran.

3.1.3.1 Benefits missed out by farmers on rice bran.

Despite its abundance, rice bran has been considered as an excellent source of nutrients (65% of beneficial nutrients) among other rice by-products (Ilias *et al.,* 2020). It holds several antioxidants that have beneficial effects on human health. Rice bran oil, extracted from rice bran, is widely used in Asian countries (Finance Tribune, 2015). It is a highly nutritious product that is a rich source of energy, protein, vitamins, minerals, fatty acids, and fibre, therefore a valuable ingredient to add to feed to boost the nutritional content. (CopRice, 2020). Rice bran further contains considerable amount of protein (11-17%), fat (12-22%), dietary fibre (6-14%) like β-glucan, pectin and gum; moisture (10-15%) and ash (8-17%). Also it is rich in vitamins including vitamin E, thiamine, niacin, and minerals like aluminium, calcium, chlorine, iron, magnesium, manganese, phosphorus, potassium, zinc and sodium (Raghav et al., 2016). It is also an important source of antioxidants due to the presence of γ-oryzanol, tocopherols, and tocotrienols, which can help in disease prevention and promoting good health (Baniya *et al.,* 2020). Its antioxidant compound gives it extreme health benefits which are also important in improving the storage stability of food. Antioxidant properties are also responsible in lowering the cholesterol levels besides the contribution of fatty acid compositions (Ilias *et al.,* 2020). Rice bran oil is extracted from the hard outer layer of dehulled rice. It is light and quite versatile, it can even be used in cookies and cakes with a mild nutty flavour; In cooking, the oil is used for sautéing, grilling, marinades and salad dressings; Rice bran oil is less viscous, and it does not stick to food, which leads to less absorbance of oil in food products cooked at high temperatures; thus, it is beneficial in reducing overall calories since it also maintains its nutritive quality even at high temperatures (Bisht *et al.,* 2020).

Table 6: Nutritional information on crude Rice Bran (RB) per 100g.

Nutrient	Amount
Energy (kcal)	316
Protein (g)	13.35
Total fat (g)	20.85
Saturated fatty acids (g)	4.17
Monounsaturated fatty acids (g)	7.55
Polyunsaturated fatty acids (g)	7.46
Carbohydrate (g)	49.69

Fibre, total dietary (g)	21.00
Minerals	
Calcium (mg)	57.00
Iron (mg)	18.54
Magnesium (mg)	781.00
Phosphorus (mg)	1677.00
Potassium (mg)	1485.00
Zinc (mg)	6.04
Manganese (mg)	14.21
Selenium (µg)	15.60
Vitamins	
Thiamine (mg)	2.75
Riboflavin (mg)	0.28
Niacin (mg)	34.00
Pantothenic acid (mg)	7.39
Vitamin B6 (mg)	4.07
Folate (µg)	63.00
Choline (mg)	32.20
Vitamin E (alpha-tocopherol) (mg)	4.92
Vitamin K (phylloquinone) (µg)	1.90

Source: Sapwarobol *et al.* (2021)

Rice bran is a by-product rich in relevant bioactive compounds which can play an important role to maintain a healthy status and thus promote a beneficial living style (Spaggiari *et al.,* 2021). Rice bran is a good source of high-quality plant-based protein with high digestibility and hypoallergenicity. The protein content of RB is about 10% to 15%, which consists of 37% albumin, 36% globulin, 22% glutelin, and 5% prolamin (Sapwarobol *et al.,* 2021). According to RxList (2021), rice bran is used for treating diabetes, high blood pressure, high cholesterol, alcoholism, obesity, and AIDS; for preventing stomach and colon cancer; for preventing heart and blood vessel (cardiovascular) disease; for strengthening the immune system; for increasing energy and improving athletic performance; for improving liver function; and as an antioxidant.

3.1.4 Broken rice

During processing, rice undergoes mechanical tensions, which cause some of the grains to break, generating what is known as broken rice. It is also known as rice grits, which is made up of broken and defective rice grains. One of the main challenges for the rice industry is to minimize the amount of broken rice and rice grits (Buggenhout *et al.,* 2013). However, since Uganda is a deficit country, broken rice is fully sold and consumed to an extent that it is even imported. According to JICA (2013), more than 55% of the wholesalers in Kampala sell broken rice imported without import duty from Pakistan. Some rice traders pack and sell completely broken rice at very low prices with a brand name (JICA, 2013). Since broken rice is fully and completed utilized, this study did not analyse it in detail as compared to the above-discussed by-products.

Table 7: By-products generated during processing and main exploitation opportunities

Stage	Waste generated	Main opportunities
Harvest	Straw	Fuel for direct burning, production of briquettes from biomass, animal feed, pyrolysis, ethanol production, animal forage, compost.
Husking	Husk	Fuel for burning, ethanol production, production of blocks and panels, poultry, compost.
Burning	Ash	Production of glass and refractory, production of Portland cement and aggregate in concrete and mortar, production of pure silicon or silica or silicon carbide, filler in polymers, adsorbent, support of metal catalysts, synthesis of zeolites obtained from hydrothermal, production of different types of silicates.
Milling	Bran	Extraction of proteins, starch extraction, animal feed, oil extraction, biodiesel production, adsorbent.
Selection	Broken rice	Production of rice flour, extraction of starch, production of functional foods, production of beer, animal feed, ethanol production, mixture with whole rice.

Source: Moraes *et al.* (2014)

3.2. Government intervention in the rice sector in Uganda

The commitment of the Uganda government to rice production can be traced to as far as the 1950s when the government developed an interest in rice and potential for irrigated rice farming which led to the establishment of the Kibimba rice irrigation scheme followed by Doho (Lamo *et al.,* 2021; Odogola, 2006) and later on a third rice irrigation scheme at Olweny swamp in Northern Uganda (Lamo *et al.,* 2021). These are now nuclear farms that bring together smallholder farmers in rice production with strong support from the government (Odogola, 2006). The government through agricultural and rice sector development and investment plan rehabilitated irrigation schemes in the country including Agoro and Olweny irrigation schemes in 2009 (Akongo *et al.,* 2017).

Rice is considered by the government of Uganda as one of the most strategic agricultural enterprises with a far reaching ability to remarkably contribute to increasing rural incomes and livelihoods and improving food and nutrition security (Barungi & Odokonyero, 2016). As a result, the government has been tirelessly pursuing a strategy to designed and build a strong self-sufficient and sustainable national rice industry (IFDC, 2021). Since the early 2000s, the government launched and promoted New Rice for Africa (NERICA) as upland rice to boost production within the country (Kunihiro *et al.,* 2014). In 2008 the Government prepared the Uganda National Rice Development Strategy with the intention of increasing rice production as a key tool for food security and poverty reduction (MAAIF, 2009). In the same year, Uganda joined the Coalition for African Rice Development (CARD), which aims at doubling rice production in sub-Saharan Africa within 10 years (JICA, 2013). This was followed by the Development Strategy and Investment Plan (DSIP) 2010/11-2014/15 through the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) which had rice as a strategic commodity with the potential to contribute to increasing rural incomes and livelihoods and improving food and nutrition security (Hong *et al.,* 2021). In 2010 the National Crops Resources Research Institute (NaCRRI) established a Regional Rice Research and Training Centre whose purpose was to train farmers, extension agents and researchers and conduct research on appropriate rice technologies in Uganda and East Africa (JICA, 2013).

Through the Uganda National Rice Development Strategy which was developed in 2009 and revised in 2012, the government recognized the challenge of minimal agricultural mechanization and set priorities to increase access to farm inputs that are critical for mechanization (JICA, 2013). The government promoted the adoption of Agricultural machinery and Equipment by providing farmers with machinery and equipment at subsidized prices. The equipment strategy fronted by the government through MAAIF was to majorly provide equipment to small-scale farmers organized in groups to raise the share capital required by the government and provide a guarantee to proper management of the equipment. (MAAIF, 2009). The government has committed funds to train personnel in rice research, irrigation, farmer training, training of district extension and ministry staff, and the private sector (MAAIF, 2009).

The Government of Uganda set a target to produce 680,000 MT of rice by 2020 and generate at least USD 73 million worth of exports (MAAIF, 2015). To support the target, the government continued to provide farmers with free rudimentary tools and others at a highly subsidized price (MAAIF, 2009). The government elaborated a Policy to direct the implementation of irrigation interventions to ensure optimal use of available land and water resources for agricultural production and productivity to contribute effectively towards food security, wealth and employment creation, and export promotion (Hong *et al.,* 2021). The Government identified building capacities of farmers in quality standards and market requirements as one of the key priority actions to spur growth (MAAIF, 2009). The Government continues to promote rice seed production in the different rice-growing regions of Uganda (Barungu & Odokonyero, 2016). As a signatory to the East African Common Market Protocol, the Government committed to liberalizing trade in order to help harness its potential (Hong *et al.,* 2021).

Table 8: Major public sector players in rice value chain and their roles

Value chain stage	Public sector player	Roles
Input supply	National Agricultural Research Organisation (NARO)- National Crops Resources Research Institute (NaCRRI)-Namulonge	• Research and development (Breeding) • Variety Release • Main supplier of breeder seed to seed companies • Provision of extension services
	Operation Wealth Creation (OWC)/NAADS	• Supply of seed, other inputs and mechanization technologies to producers • Extension services - Information and knowledge sharing
	National Seed Certification Service/ National Seed Authority & National Seed Board	• Regulation of the seed industry
	Ministry of Agriculture, Animal Industry and Fisheries (MAAIF)	• Policy formulation and implementation • Issuance of export and import documentation and control or provision of online system for expediting the issuance of SPS certificates • Extension support, inspection and certification of seed • Supply inputs to cooperatives at subsidised cost under ACDP • Coordination and implementation of government agricultural development interventions
	National Plant Protection Organization	• Issue plant health certificates
	Agrochemicals Control (ACC) Division, Department of Crop Inspection and Certification (DCIC), MAAIF	• Regulation of agrochemical industries
	Agricultural Chemicals Board (ACB)	• Registers all agricultural chemicals prior to importation as well as the importers
	Uganda National Bureau of Standards	• Inspect imported inputs for conformity at the borders • Extension services and capacity building in standards • Standards formulation and enforcement
	Uganda Revenue Authority	• Clearing and checking for proper documentation

	Local government	• Supply of inputs and extension services to producers • Implementation of government policies and programs
	High institutions of learning e.g. Makerere University College of Agricultural and Environmental sciences	• Continuous research and development either individually or in collaboration with NARS and the Private Sector
	Agricultural Engineering and Appropriate Technology Research Centre (AEATREC)-NARO	• Capacity building and development of technologies like pedal threshers and improved open sun drying. • Generate, promote and supply agricultural technologies to improve productivity, value addition, income and food security
Production	District Local Government	• Supply of inputs and extension services to producers • Implementation of government policies and programs
	NARO	• Breeder and Foundation Seed Production • Provide extension services
	MAAIF (District Agriculture Office)	• Provide extension services
	Uganda Cooperative Alliance	• Regular training of cooperatives and farmers
	Ministry of Gender, Labour and Social Development (MGLSD)	• Under the Uganda Women Entrepreneurship Programme provides interest free loan for women in organized groups
	Uganda National Farmers' Federation	• Trains farmers and promotes agribusiness • Advocates for farmer interests
	Ministry of Water and Environment	• Rehabilitation of rice irrigation schemes
Aggregation, Storage and Trade:	Ministry of Trade, Industry, and cooperatives	• Houses the Uganda Export Promotion Board, Uganda Warehouse Receipt System Authority and the Uganda National Commodity Exchange (not yet operational) all crucial to promote grain trade • Policy formulation and implementation • Oversees trade and functioning of cooperatives
	Uganda Warehouse Receipt Authority	• Licensing of Storage Facilities • Issuing Negotiable Warehouse Receipts to depositors of commodities • Monitoring & Inspection of operations of stakeholders participating in the WRS • Capacity Building for Key Stakeholders • Fostering access to receipt backed inventory financing
	Uganda National Bureau of Standards	• Certify products and systems • Standards enforcement and surveillance
	Uganda Export Promotion Board	• Export promotion and development • Offer support services e.g. market information, assistance with entering and establishing in new export markets, business linkages, export product development and capacity building
Processing	Uganda National Bureau of Standards	• Certify products and systems • Standards enforcement and surveillance
	Uganda Export Promotion Board	• Export promotion and development • Offer support services e.g. market information, assistance with entering and establishing in new export markets, business linkages, export product development and capacity building
	Uganda Warehouse Receipt Authority	• Licensing of Storage Facilities • Issuing Negotiable Warehouse Receipts to depositors of commodities • Monitoring & Inspection of operations of stakeholders participating in the WRS • Capacity Building for Key Stakeholders • Fostering access to receipt backed inventory financing
	Agricultural Engineering and Appropriate Technology Research Centre (AEATREC)-NARO	• Capacity building and development of technologies like pedal threshers and improved open sun drying. • Generate, promote and supply agricultural technologies to improve productivity, value addition, income and food security
	Uganda Industrial Research Institute	• Championing of innovations and application of applied research, and develops products and industrial processes aimed at enhancing the nation's Industrial capabilities Capacity building of actors in product development
Distribution/ wholesale/ retail	Uganda National Bureau of Standards	• Certify products and systems • Standards enforcement and surveillance
	Uganda Registration Services Bureau	• Registration of traders and businesses
	Uganda Export Promotion Board	• Export promotion and development • Offer support services e.g. market information, assistance with entering and establishing in new export markets, business linkages, export product development and capacity building
	Uganda Revenue Authority	• Border inspection of agricultural produce for export or import and clearance documentation

Source: Kilimo Trust, 2017, 2019; MAAIF, 2015; Mabaya et al., 2018; Musiime, 2015; UBOS, 2015

3.3 Private sector intervention in the rice sector in Uganda

Table 9: Major Private sector players

Value chain stage	Rice
Input supply	
Fertilizer/ chemical manufacturers & distributors	• About 10 fertilizers and a few agrochemical importers exist and function primarily as brokers supplying wholesalers. Local fertilizer manufacture is currently at GrainPulse Ltd and Sukulu Fertilizer Plant (Tororo) • Key Agrochemical distributors - Hangzhou Agrochemicals (u) Ltd, Nsanja Agrochemical Ltd, MTK Uganda Ltd, Bukoola Chemical Industries Ltd, Daps Distribution Company Ltd, SHP SONS UGANDA LTD, Grow More seeds and Chemicals Ltd, Trust Chemicals, - Juanco Group Ltd, Uganda Crop Care Limited • Key Fertilizer distributors - Grain Pulse Ltd, Africa One Ltd, Balton Uganda, Bukoola Chemical Industries Ltd, Grow More seeds & chemicals Ltd, VAP Chemicals Ltd, MTK Uganda Ltd, Sukulu Phosphate Plant (Tororo) • Fertilizer and agrochemical distribution at farmer level is done through agro-input stockists and village agents. About 15-20 large distributors/wholesalers exist supplying about 1,000 retailers, who supply numerous stockists and village agents that reach the farmers • Large farms are the major users of agrochemicals and fertilizers procured either directly from manufacturers or import e.g. from Europe, South Africa. Take up 30% of the market share
Seed manufacturers & distributors	**Seed companies:** These are not licensed as breeders but multiply seed obtained from NACRRI or imported. They use their own farms or contract farmers to produce certified seed, which they pack and sell certified seed to farmers through a distribution network consisting of company outlets, wholesalers, and retailers • A total of 34 seed companies exist (19 produce maize seed (produced 22,000MT in 2017), 17 produce bean seed (produced 3,794 MT) • Seed companies producing for the 3 value chains - Equator Seeds Ltd, Pearl seeds Ltd, NASECO, FICA Seeds, Victoria Seeds Ltd, East African Seeds, Grow More Seeds, Green Firm Africa, CEDO seeds and Chemicals Limited, Safari Seeds Ltd Distribution is done through a network of 2,500 wholesalers, retailers, agro-input stockists and village agents (Mabaya et al., 2018). • Seed merchants also categorized as agro-dealers are registered under the Uganda National Agro-Input Dealers Association (UNADA) • Wholesalers distribute/Sell certified seed to retailers and large farmers while retailers sell to producers
Mechanization	**Local fabricators -** About 134 metal fabricators are registered under the Uganda Small Scale Industries Association (USSIA) (Musiime, 2015). They fabricate and customize production, postharvest and processing technologies **Major local manufacturers** - Tonnet Agro Engineering Co. Ltd, Central Engineering Ltd, Musa Body Machinery Ltd, Ramanand Ltd, Juanco Group Ltd, Technology Research Network Ltd, Munyengera Agro-machinery Ltd, AEATREC -Namalere, Lwoba Holdings **Key importers** - Asia Agro Industries, Auto-Sokoni, Snowmans, ETC Agro, China Huangpai Food Machines and China North Machine Other actors are **mechanization service providers** such as Bongomin Group Ltd (specific to rice), MarkBurridge Guest farms, Agricultural Tractor Services, several village agents, cooperatives e.g. Bweyale ACE, New Kakinga Agro-input shop and Nsemex Agro-Service Providers, Off takers e.g. Equator seeds Ltd
Production	
Key producers	• Produced by about 280,000 farmers • 80% of the producers are smallholder farmers • Highest production is in the eastern region (67%) and northern region (23%) • Highest producing districts - Budaka, Butaleja, Tororo, Bugiri, Iganga, Gulu, Otuke, Amuru, Nwoya • Large producers - AGRISERV-UK Amatheon Agri NV- Germany Investment, FOL Logistics (U)ltd, Vinayak Agro, Omer Farms
Aggregation, Storage and Trade	
Key local aggregators (farmers, agro dealers or off takers)	• Due to the scattered and small nature of producers, aggregators and cooperatives are crucial to assemble large volumes for large traders • The aggregators include village agents, rural traders and trader agents • Several rice cooperatives, also crucial to aggregation, and storage exist and these include Manafwa Basin Rice Farmers Cooperative Society, Buhanika Rice Farmers Cooperative Society, Agoro rice scheme cooperative society, Doho Rice Scheme Cooperative, among others
Exporters	• Export is mostly by processors/millers with the major products being milled rice and bran
Importing companies, imported products and import sources	• Major importers - SWT Millers, FOL Group (U) Ltd, Upland Rice Millers Ltd, Eastern Rice Millers Ltd, Pearl rice millers, Royal rice ltd, Sunad Ltd, and large traders, for example, Jascom trading LTD, R I distributors, Marcopolo Traders Uganda LTD. • Uganda is a net importer for rice, importing up to 79,000MT and 108,000 MT (milled rice equivalent) from Africa and outside Africa valued at USD 29 million and USD 48 million respectively in 2018 • Products – Of the rice imports, 52.3% was broken rice, 26.3% milled rice, 13.2% brown rice, 8.2% paddy. • Sources – of the imports, 44.5% came from EAC (Tanzania) and the rest came from international markets (largely from Pakistan & Thailand)
Processing	
Largest processors and different products processed	• Over 800 small scale millers, about 15 Medium-scale millers, and a few large scale millers exist Large scale millers - TILDAH/Kibimba, SWT Millers, FOL Group (U) Ltd • Examples of Medium-scale millers – Upland Rice Millers Ltd, Diners Group Ltd, AK Purongo Ltd, Eastern Rice Millers Ltd, Pearl rice millers, Royal rice ltd, Sunad Ltd, Kehong Peyero Ltd, etc. • Major products – milled rice (primary product), rice bran, rice flour
Distribution/ wholesale/ retail	

Key distributors/wholesalers/retailers	• Involves large traders, millers as well as a myriad of wholesalers and retailers • Large traders – Traders and Millers such as Upland Rice Millers Ltd, Diners Group Ltd, AK Purongo Ltd, Eastern Rice Millers Ltd, Pearl rice millers, Royal rice ltd, Sunad Ltd, Kehong Peyero Ltd, etc • There is a key distribution network of traders in the Kikuubo market in Kampala crucial to rice distribution with outlets of millers and importers as well as independent traders
Key products sold	Major products – milled rice (primary product), rice bran, rice flour

Source: Kilimo Trust, 2017, 2019; MAAIF, 2015; Mabaya et al., 2018; Musiime, 2015; UBOS, 2015

Table 10: Major development partners supporting rice value chain in Uganda

Rice Value Chain Node	Development partners and their roles
Input supply:	• Research & development – AfricaRice, JICA, IRRI • Extension and capacity building - AfricaRice, JICA, IRRI, ISSD, Sasakawa Global, Kilimo Trust, KOICA, IFDC • Policy – AGRA, JICA • Input distribution - AfricaRice, JICA, IRRI, ISSD, Sasakawa Global, Kilimo Trust, KOICA, IFDC, World Bank (funding to ACDP) • Uganda Seed Trade Association **-** Engaged in advocacy and training of seed dealers • Uganda National Agro-Input Dealers Association – National apex body for agro dealers and represents their interests
Production:	• Extension and capacity building - AfricaRice, JICA, IRRI, ISSD, Sasakawa Global, Kilimo Trust, KOICA, IFDC, Rikolto, Palladium • Policy and advocacy – Rice Association of Uganda
Aggregation, Storage and Trade:	• EAGC - Advocacy, promote grain trade, support standards development, capacity building, certifying warehouses, provide market information • TGCU - Policy advocacy; Secure trade agreements; Capacity building of members • Capacity building and provision of storage and PHH infrastructure – Kilimo Trust, AGRA, Sasakawa Global, USAID, Palladium, Rikolto, IFDC • Uganda Small Scale Industries Association (USSIA) – Represent interests of MSMEs
Processing:	• Uganda Small Scale Industries Association (USSIA) - Representing interests of MSMEs all over Uganda (advocacy) • Uganda Manufacturers Association - Advocates for manufacturers interests and pushes for platforms to improve competitiveness • USADF - Fund agricultural enterprises through cooperatives through grants • aBi Development – Finance to agro-processors • Facilitate market linkages and capacity building – IFDC, Kilimo Trust, AGRA, Rikolto • Policy and advocacy – Rice Millers Council of Uganda
Distribution/ wholesale / retail:	• EAGC - Advocacy, promote grain trade, support standards development, capacity building, certifying warehouses, provide market information • TGCU - Policy advocacy; Secure trade agreements; Capacity building of members • Capacity building and provision of storage and PHH infrastructure – Kilimo Trust, AGRA, Sasakawa Global, USAID, Palladium, Rikolto • Uganda Small Scale Industries Association (USSIA) – Represent interests of MSMEs

Source: Kilimo Trust, 2017, 2019; MAAIF, 2015; Mabaya et al., 2018; Musiime, 2015; UBOS, 2015

IV. CONCLUSION AND RECOMMENDATION

Given the heavy investment in the rice value chain by the government of Uganda, private sector and development partners, the rice industry will remain growing in the coming decades. The increase in the generation of waste from rice production will also increase as much as the increase in rice production. Therefore, the currently existing concern to seek feasible alternatives at the farmer level for the waste generated to remain sustainable is critical. Rice by-products represent massive health, income, agricultural and industrial hidden potential. Creating awareness about the negative impacts of inappropriate disposal of rice by-products on the environment and its potential towards improving their socio-economic conditions when used appropriately and sustainably is critical. Potential new sources of rice by-products available on the basis of the importance of environmental protection, rural development and farming community should be given priority. Availing the perfect basic needs such as logistical facilities, courses and training for farmers, millers, officials as well as research and development for the by-products development in the country should be emphasized. Lastly, there is need to widely emphasize the health and nutritional benefits of rice bran at the farmer level as a cheaper form of treatment in the long run.

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