

Weedy rice problems and solutions for its management

R. Labrada

Agricultural Weed Officer, Plant Protection Service, FAO, Rome, Italy

Rice areas in several countries in the Western Hemisphere are seriously affected by the presence of several weeds. The most troublesome weeds in rice are species of the genus *Echinochloa*. However, there is an increase worldwide in problems with weedy rice, which reduces crop yields and affects quality more than *Echinochloa crus-galli*. Yield reduction can even be as much as 80 percent (Smith, 1988). Weedy rice is the same species as cultivated rice (i.e. it usually has the same genome), but it behaves differently. It normally grows faster; makes better use of the available N; produces more tillers, panicles and biomass in general; shatters earlier; has better resistance to adverse dry conditions; and possesses longer dormancy in soil (Cohn 2002; Gu, Chen and Foley, 2003).

The problem of weedy rice has grown with the increase in direct-seeded rice in several countries, including parts of Southeast and South Asia. Given the importance of the problem, FAO conducted activities to assist developing countries to reduce weedy rice infestations in rice. FAO began with the organization of a global workshop on the subject, held in Varadero, Cuba (FAO, 1999), with the participation of specialists from 17 countries. The workshop concluded that high weedy/red rice incidence in many rice-producing countries is due to the increase in use of unclean rice seeds, monocropping and wrong cultural practices during the crop cycle. These conclusions point to the need to adopt an integrated management approach, where sources of weedy rice are reduced using several management strategies.

Strategies for the control of weedy rice are diverse and their implementation depends on the specific site conditions. However, any control measure should aim to reduce the weedy/red rice seed bank in soil in the medium or long term.

Following the workshop, various countries from Latin America requested FAO's technical assistance for the implementation of a project aimed at the control of weedy rice.

RESULTS OF FAO WEEDY RICE PROJECT IN CENTRAL AMERICA AND THE CARIBBEAN

The project consisted of participatory training for farmers through the implementation of two farmer field schools (FFS), where farmers learned elements of the ecology of weedy rice and its control. Six countries were involved:

- **Colombia.** Rice is grown on 320 000 ha. The crop is normally grown twice a year and monocropping is a normal practice. Use of uncertified rice seeds of low quality is common in areas of poor farmers.
- **Costa Rica.** The rice area is approximately 40 000 ha distributed in five regions: Chorotega, Brunca, North Huetar, Central Pacific and Atlantic. The area infested by weedy rice is almost 19 500 ha. The major weedy rice species are *Oryza sativa* L. and *O. latifolia* Desv. (known locally as "arrozón"). Incidence is greatest in fields where rice is cropped twice.
- **Cuba.** Rice is the country's major staple, grown in an area of less than 200 000 ha, of which 35 percent is severely affected by weedy rice. In heavily infested areas, yield losses account for up to 89 percent. This problem is aggravated by the reduced production of certified rice seed or the use of bad quality seeds contaminated with weedy rice seeds.
- **Nicaragua.** Weedy rice is present in all rice-producing areas of the country with infestation at more than 80 panicles/m². The main weedy rice species are *Oryza sativa* and *O. latifolia* with infestation of up to 40 percent in rice fields. Farmers do not use certified seeds and no specific method is practised to control this weed.
- **Panama.** Rice is grown on more than 75 000 ha, mainly in the provinces of Chiriquí (54%), Coclé (14%), Panama (Chepo) (11%) and Veraguas (9%). Rice yields are not high due to the use of uncertified seeds with low germination level, and because of high pest incidence, including the problem of weedy rice.

- **Venezuela (Bolivarian Republic of).** The rice area is approximately 140 000 ha, predominantly in the states of Portuguesa, Guárico, Cojedes and Barinas. Weedy rice is one of the major constraints to rice production, with 88 percent of the crop area infested by weedy rice, sometimes with a stand of 17 or 18 plants/m². The main species of weedy rice in Venezuela (Bolivarian Republic of) are *Oryza sativa* L., *O. rufipogon* Griff. and *O. latifolia* Desv.

The project included the education of pilot groups of farmers on weedy rice biology and control strategies. For this purpose, FFS were implemented and farmers met every 2 weeks to discuss the results of their observations in the field. Training covered studies of viable weed seed bank in soil using the methodology proposed by Forcella, Webster and Cardinia (2003), collection of weedy rice biotypes and their germination. Farmers were helped to understand the sources of weedy rice infestation and to design management procedures. The importance of using clean rice seeds free of weedy rice seeds was stressed. This strategy, together with pre-planting control of the weed, was the management approach adopted in most places.

Pre-planting control

In some areas, the pre-planting method consisted of land preparation in dry soils, followed by fast irrigation, puddling, draining the field for the emergence of new weed flushes, application of glyphosate, flooding again and rice seeding over a slight water layer. In other areas, land preparation began with puddling, draining the field, glyphosate application, flooding and seeding as above. The control of weed flushes in some areas was conducted mechanically after drainage. In Nicaragua, this method increased yields by 25 percent and improved the quality of the produce.

In Venezuela (Bolivarian Republic of), after the harvest, crop residues in infested fields were burnt – an operation which encouraged germination of weedy rice seeds remaining in the soil surface. Soil moisture was maintained for a period of 85 days, until infestation reached a level of 130 plants/m². Land preparation was then conducted followed by flooding and drainage; it was left for another 15 days until there was a new weed flush; the same operation was then repeated for another flush, after which the area was flooded over the weed stand and herbicide (oxadiargyl at a rate of 1.15 litres/ha) was

applied and kept for 8 days. The field was drained and 2 days later pre-germinated rice seeds were planted.

Other control methods

The leguminous plant *Sesbania rostrata* Brem. has been tested in Cuba for short crop rotation – it successfully smothered weedy rice.

In all FFS, emphasis was placed on the importance of roguing – either manually or using glyphosate – shortly before harvest to avoid an increase in weed seed bank in the soil. In Venezuela (Bolivarian Republic of), farmers were well trained in procedures for cleaning the machinery coming from rice fields infested by weedy rice.

IMI RICE TECHNOLOGY

The idea of using herbicide-resistant rice for the successful control of weedy rice is not new. Three companies have been working on this matter:

- Transgenic Liberty Link® rice is being developed by Aventis to resist glufosinate- ammonium herbicide.
- Roundup Ready® rice, developed by Monsanto, tolerates glyphosate.
- IMI rice (known commercially as Clearfield®) was engineered through mutation to tolerate imidazolinone herbicides and is being commercialized by BASF.

IMI rice is not a transgenic crop, and has been adopted for use in several countries, including the United States, Costa Rica, Colombia and Uruguay. It is mutated rice developed by radioactive bombardment of a conventional rice plant – a technology that has been used to achieve short-stature rice varieties (Annou *et al.*, 2001).

In the United States, IMI rice is associated with the use of the imidazolinone herbicide, imazethapyr, an ALS inhibitor. The herbicide is applied after planting at 5 ounces per acre (approx. 0.346 kg/ha) in drill-seeded systems, while in water-seeded fields, seeding flood is put on after the first application of the herbicide, the water pulled off and the seedlings are then allowed to establish. Normally one application of this herbicide (non-selective to rice) is enough. That is why farmers apply twice or even use some mixtures with other herbicides, such as pendimethalin and propanil. This treatment can reduce enormously the stand of weedy rice (Rodd 2004).

However, an outcrossing between IMI herbicide-resistant rice and weedy rice has recently been discovered

in Arkansas (Schultz, 2004) – demonstration of the fact that farmers must not abuse herbicide-resistant material. Genetic testing confirmed that weedy rice contains the resistant gene that prevents imazethapyr from damaging rice plants. The resistant hybrids are tall plants with compact, erect and rough leaves. According to extension workers, not planting IMI rice two growing seasons in a row is probably the most important measure to ensure the longevity of this technology.

It is clear that there is no technology that can control 100 percent of any weed population. Normally a low resistant weed population will be selected quickly if the same herbicide is used repeatedly. In addition, the ALS inhibitors are recognized as herbicides with high selection pressure and able to select a resistant weed population in a few years.

One solution to the problem of resistance is to rotate the area with conventional rice or with other crops, but lowland areas for rice are often not suitable for growing any other crop, and the use of conventional rice will depend on the level of imazethapyr residue in the soil.

The technology offers a potential solution to farmers – provided that they use it rationally. The use of more than one crop of IMI rice will be enough to achieve a substantial reduction in weedy rice. Additional reduction of the weed can be achieved using other cultural procedures; but these should not be abused with additional cropping of the IMI cultivar. Crop or rice cultivar rotation has an important role in preserving the usefulness of IMI.

SITUATION OF WEEDY RICE IN ASIA

Until recently, Asia had no problem of weedy rice, due to the fact that transplanted rice was the main planting method. In the United States and most Latin American countries, the situation is different because direct-seeded rice prevails.

With the opening of new factories, people have moved from rural to urban areas, reducing considerably the labour formerly used for planting and weeding. It is for this reason that farmers have been compelled to shift from transplanting to the direct-seeding method.

The area affected varies from country to country. Thailand has more than 2 million ha seriously affected by weedy rice, while more than 500 000 ha are also infested by the weed in the Mekong River Delta in Viet Nam. Malaysia, Sri Lanka and the Philippines have a substantial area affected, as direct-seeded areas are increasing every year. Current agronomic practices will

continue to contribute to making weedy rice the most troublesome weed in rice in the twenty-first century.

Different techniques have been adopted in some Asian countries to manage weedy rice infestation. However, these technologies have not been adopted in many parts of developing Asia, where weedy rice has become a perennial problem for various reasons, including absence of technology transfer and appropriate communication technologies, lack of awareness, and poor farmer attitude. The lack of interaction and communication among scientists on environmentally sound and integrated technologies to control weedy rice has resulted in less attention being paid to capacity-building in the sphere of weedy rice management in Asia.

Since rice is the main staple in several Asian countries, there is an urgent need to implement programmes and projects aimed at weedy rice management. The approach adopted in Latin America by the FAO TCP project on weedy rice can be applied in South and Southeast Asia.

REFERENCES

- Annou, M., Thomsen, M., Wailes, E. & Garner, G.L.** 2001. Implications of rice biotechnology on optimal rice crop rotation in the Mississippi River Delta region. Southern Agricultural Economics Association, Annual Meeting, Fort Worth, Texas, 27-31 Jan.
- Cohn, M.A.** 2002. Seed dormancy in red rice. A balance of logic and luck. *Weed Sci.*, 50: 261-266.
- FAO.** 1999. *Report of Global Workshop on Red Rice Control*. Varadero, Cuba, 30 Aug. - 3 Sept. 156 pp (available at www.fao.org/ag/AGP/AGPP/IPM/Weeds/download/arrorj.pdf).
- FAO.** 2005. *Final Report TCP/RLA/2913*. Rome, FAO. 20 pp.
- Forcella, F., Webster, T. & Cardina, J.** 2003. Protocols for weed seed bank determination in agro-ecosystems. In R. Labrada, ed. *Weed management for developing countries*, p. 3-18. Addendum I. FAO Plant Production and Protection Paper No. 120. Rome, FAO.
- Gu, X.Y., Chen, Z-X. & Foley, M.E.** 2003. Inheritance of seed dormancy in weedy rice. *Crop Sci.*, 43: 835-843.
- Rodd, M.A.** 2004. *Herbicide-resistant rice varieties expected* (available at www.ricejournal.com/backissues/january2001/story3.asp).
- Schultz, B.** 2004. *Guidelines help protect Clearfield* (available at deltafarmpress.com/mag/farming_guidelines_help_protect/index.html).
- Smith, R.J., Jr.** 1988. Weed Thresholds in southern U.S. rice (*Oryza sativa*). *Weed Technology*, 2: 232-241.

Problèmes liés au riz adventice: solutions proposées

Le riz adventice est le résultat d'une hybridation naturelle entre des variétés cultivées et des variétés sauvages qui a évolué depuis la domestication du riz sauvage. Le riz adventice a été introduit dans de nombreux pays avec des semences de riz importées d'Asie qui ont été ensuite disséminées. Le riz adventice n'a jamais été un véritable problème tant que le riz a été repiqué mais le manque de main-d'œuvre a contraint plusieurs pays à recourir plus fréquemment aux semis directs, et c'est alors que la situation s'est aggravée.

La concurrence du riz adventice peut entraver les rendements, encore plus que le millet à grappe (*Echinochloa crus-galli*), du fait de la production importante de talles et de panicules par plante de la grande quantité de biomasse et de la forte

absorption d'azote prélevée dans le sol. Le riz adventice se développe rapidement et devient plus envahissant avec l'application d'engrais. Le riz adventice s'égrène en général avant le riz cultivé, et les grains pénètrent ainsi dans le sol où ils peuvent rester pendant longtemps.

Le riz adventice n'est pas facile à éradiquer en utilisant un seul moyen technique de lutte car il possède le même génome que le riz cultivé. En général le meilleur moyen de lutter contre le riz adventice consiste à utiliser des semences propres et à effectuer un traitement avant les semis, par exemple une préparation de lit de semences, et d'arracher ensuite les graines de riz adventice qui ont germé par un procédé mécanique ou en utilisant un herbicide adapté, avant les semis de riz.

Une question de grande importance pour le secteur du riz est la possibilité d'élaborer des populations de riz adventice résistant aux herbicides notamment en utilisant du riz résistant à l'imacazolinone (IMI ou Clearfield). Il a été scientifiquement prouvé que l'hybridation entre le riz Clearfield et le riz adventice peut se produire et que le taux de croisement varie selon les cultivars. Ces hybrides de riz adventice ont été trouvés en Arkansas. Il s'agit de plantes de grandes dimensions, aux feuilles compactes, droites et rugueuses. Le riz Clearfield permet de réduire considérablement l'infestation de riz adventice au cours d'une campagne, mais il n'est pas recommandé de l'utiliser pendant deux ou trois campagnes successives afin d'éviter la formation d'hybrides résistant aux herbicides.

Problemas relacionados con el arroz maleza y soluciones para su manejo

El arroz maleza es un producto de hibridación natural entre variedades cultivadas y silvestres, que ha ido evolucionando desde la domesticación del arroz silvestre. El arroz maleza se introdujo en muchos países en la semillas de arroz importadas de Asia y posteriormente se distribuyó. Este arroz no constituía realmente un problema en el arroz trasplantado, pero debido a la escasez de mano de obra en varios países y a la adopción más generalizada de la siembra directa, se ha convertido en un problema grave.

El arroz maleza puede reducir los rendimientos del arroz más que el mijo de los arrozales (*Echinochloa crus-galli*), ya que es muy competitivo debido a la alta producción de esquejes y panículas por planta, el elevado volumen de biomasa y la considerable extracción de nitrógeno del suelo. El arroz

maleza alcanza mayor tamaño y se vuelve más agresivo cuanto más fertilizante se aplica. Las plantas de arroz maleza suelen desgranar mucho antes que el arroz cultivado, lo que le permite acumular fácilmente su banco de semillas de maleza en el suelo. Asimismo, las semillas pueden aguantar largos períodos en el suelo.

No es fácil luchar contra el arroz maleza con una sola técnica de control, pues se trata de una maleza con el mismo genoma que la variedad cultivada. Normalmente, la forma más conveniente de luchar contra el arroz maleza es mediante la utilización de semillas de arroz elaborado y un tratamiento previo a la plantación, como por ejemplo una preparación de semillero falsa, la eliminación mecánica del arroz maleza germinado o la utilización de un herbicida adecuado antes de la plantación de arroz.

Una cuestión de gran importancia para el sector del arroz es el potencial para desarrollar poblaciones de arroz maleza resistentes a los herbicidas, sobre todo con la utilización de arroz resistente a la imidazolinona (IMI o Clearfield). Las investigaciones han demostrado que puede producirse la hibridación entre el arroz Clearfield y el arroz maleza, y el grado de cruzamiento varía entre los cultivares utilizados. Estos híbridos de arroz maleza se han encontrado en Arkansas y son plantas altas de hojas compactas, rectas y ásperas. Aunque la utilización de la tecnología Clearfield reducirá considerablemente la infestación de arroz maleza en una campaña agrícola, no se recomienda utilizarla en dos o más campañas consecutivas para evitar la presencia de estos híbridos resistentes.

Impacts of integrated nutrient management on sustainable rice production with particular reference to Latin American countries

W. Burgos León^a and R. Misra^b

^a Technical Officer and ^b Consultant

Land and Plant Nutrition Management Service, FAO, Rome, Italy

Production under irrigation and the highly-favoured upland systems currently accounts for approximately 70 percent of all rice production in Latin American countries. Production has increased from 16 million tonnes of paddy in 1980 to 26 million tonnes in 2005. However, farmers' yields remain far below the potential of the available varieties. This yield gap is the result of numerous deficiencies, in particular inadequate crop nutrition practices and their inefficient use (rice requires large amounts of nitrogen and potassium). Two countries are representative of the overall situation:

- In Brazil, nutrient balance studies are negative for the three primary nutrients (N, P₂O₅, K₂O), in particular for nitrogen.
- In Peru, improved varieties respond to potassium, especially where adequate nitrogen and phosphorus are provided.

Sustainable rice production requires integrated management of all the available nutrient resources. Integrated nutrient management (INM) ensures the maintenance and possible enhancement of soil fertility through balanced and judicious use of mineral fertilizers combined with organic and biological sources. The results are seen in terms of improved nutrient efficiency, increased crop productivity and minimized nutrient losses to the environment. Rice-based cropping systems are ideal for deriving benefits from INM.

This paper aims to give an idea of the work required to close the rice yield gap in LAC (Latin America and the Caribbean), and recommends the establishment of nutrient balances in rice-based cropping systems, in order to assist farmers to understand and adopt precision nutrient input management.

RICE PRODUCTION IN LATIN AMERICAN COUNTRIES

Production increased from approximately 16 million tonnes (paddy) to over 26 million tonnes in Latin American countries between 1980 and 2005, even though the area cultivated with rice decreased from 8.2 to 6.7 million ha (Table 1). The principal factor contributing to increased rice production in the region is the increased role of irrigated rice and the demise of upland rice, particularly in Central America and Brazil. In spite of the advancements in productivity, yields in the irrigated sector are still relatively low, and far below the yield potential of currently available varieties. There has been little improvement in yield in the unfavoured upland sector for numerous years.

Rice production in South America during the last two decades (with the exception of the last 2 years) has seen a rapid decline in the area planted with rice, accompanied by a steady increase in overall production. Yield advancement permits production to continue increasing, despite the removal of large areas from rice cultivation. During the 25-year period from 1980 to 2005, average

TABLE 1
Rice production and area harvested in LAC and the world

	Area harvested (ha)			Production (tonnes)		
	1980	2002	2005	1980	2002	2005
World	144 665 175	147 700 874	153 511 755	396 871 255	578 011 137	614 654 895
LAC	8 207 132	5 775 004	6 746 722	16 443 588	22 227 167	26 370 717

TABLE 2
Rice yield during the last 25 years in selected South American countries

Country	Yield (tonnes/ha)			
	1980-82 ^a	1990-92 ^a	1999-2001 ^a	2005
Argentina	3.53	4.30	5.40	6.34
Bolivia	1.55	1.95	1.75	2.17
Brazil	1.51	2.10	3.11	3.34
Chile	3.02	4.10	4.80	4.67
Colombia	4.29	4.05	4.84	5.26
Ecuador	3.08	3.14	3.50	4.13
Guyana	3.06	3.29	4.00	3.86
Paraguay	1.87	2.57	4.09	3.04
Peru	4.53	5.14	6.53	6.71
Suriname	4.03	3.79	3.83	3.80
Uruguay	5.19	4.66	6.49	6.77
Venezuela	2.85	4.18	5.04	5.00
South America	1.91	2.58	4.07	4.59

^a3-year averages.

Source: FAOSTAT.

yield in South America increased from 1.9 to 4.59 tonnes/ha. The large decrease in the area of low-yielding upland rice in central Brazil, combined with yield improvement in irrigated rice in southern Brazil, contributed significantly to the rapid increase in average yield in South America (Table 2).

Although increases in national yield are the norm for most South American countries, not all countries are advancing at the same rate. Yield improvement in Bolivia was insignificant during the last 25 years, as a result of the concentration of production in the unstable upland sector. Yield improvement in Ecuador was also slow and the poor progress may be attributed to the lack of investment in irrigation management. National yields in Colombia also grew slowly over the last two decades. In the 1980s, Colombia was the country benefiting most from the introduction of high-yielding, semi-dwarf plant types, recording one of the highest national average yields in South America. However, Colombia failed to keep pace with other countries (in terms of yield improvement) and the average national yield is currently inferior to that of Uruguay, Peru and Argentina.

YIELD GAPS

Production under irrigation and the highly-favoured upland systems currently accounts for approximately 70 percent of all rice production in LAC, and high-yielding genotypes occupy more than 90 percent of these areas. However, farmers' yields remain far below the potential of the available varieties. The average yield of irrigated rice is approximately 5 tonnes/ha, but there is

high variability between and within production zones. Even within a relatively homogenous area with the same variety, farm yields are highly variable. In many production zones, progressive farmers routinely obtain yields of 7 tonnes/ha.

In late 1999 and early 2000, FAO commissioned a study to explain the discrepancy between farmers' yields and readily obtainable yield (Pulver, Tran and Nguyen, 2000). The difference between readily obtainable yield and average farm yield is referred to as the "yield gap". The study reported that the yield gap in 12 major rice-producing countries ranges from 1 to 3 tonnes/ha and averages 1.3 tonnes/ha. The yield gap is apparent in all irrigated rice production areas.

The yield gap in irrigated rice is the result of numerous deficiencies, in particular inadequate crop management practices which fail to allow high-yielding genotypes to express their yield potential. The yield gap is most striking in countries where new, high-yielding varieties are planted.

MINERAL FERTILIZER USE AND YIELD GAPS

Inadequate and inefficient use of mineral fertilizers is one of the main reasons for the prevalent yield gaps. Table 3 gives the mineral fertilizer use in LAC. Total fertilizer use in 2002 was 13.2 million tonnes in LAC, compared to 141.5 million tonnes in the world (9.3 percent). Brazil accounted for 58 percent of fertilizers used in LAC in the same year.

NUTRIENT BALANCE IN LAC

Brazil

Agriculture in Brazil results in the removal from the soil of a substantial quantity of nutrients that should be replenished by fertilization, especially in the case of nitrogen. In the long term, this situation can become detrimental to the sustainability of agriculture. In the work of Yamada and Lopes (1999) and in the data for 2002 (Table 4), the input of nutrients is based on mineral fertilizers alone; no account is taken for manure and/or nitrogen fixation in cover crops in crop rotation.

Effect of potassium and magnesium on rice grain yield in coastal Peru

With its favourable sunny climate, coastal Peru has the potential for high rice yields. Yields are higher than in the surrounding countries due to substantial nitrogen use. However, a great deal of yield potential is lost because

INTEGRATED SYSTEMS

SYSTÈMES INTÉGRÉS

SISTEMAS INTEGRADOS

TABLE 3
Mineral fertilizer use in LAC ('000 tonnes)

Country	Nitrogen			Phosphate			Potash		
	1980	1990	2002	1980	1990	2002	1980	1990	2002
Argentina	62.6	101.4	432.6	44.1	51.5	283.3	8.7	12.6	23.5
Bolivia	1.4	2.3	6.1	0.7	2.5	6.6	0.7	0.3	0.9
Brazil	905.4	796.6	1 816.0	1 988.4	1 201.6	2 807.0	1 306.5	1 209.6	3 059.0
Chile	50.8	164.0	210.0	68.8	113.7	170.0	13.0	28.8	75.0
Colombia	151.2	311.8	335.4	81.1	126.7	135.9	80.0	163.8	220.2
Ecuador	40.7	39.4	134.3	14.3	9.0	38.4	17.5	19.6	56.7
Guyana	4.2	8.0	14.4	1.3	2.2	3.1	0.2	1.8	0.3
Paraguay	1.3	3.6	34.9	3.4	11.1	68.4	1.5	3.1	49.8
Peru	84.8	84.2	209.4	19.7	12.7	51.8	13.6	8.2	12.6
Suriname	1.2	0.6	5.1	0.2	0.2	0.0	0.2	0.2	0.5
Uruguay	21.1	27.6	54.2	56.2	41.2	70.6	3.6	3.0	4.0
Venezuela (Bolivarian Republic of)	113.0	205.0	190.0	77.5	119.0	50.0	50.5	110.0	60.0

Source: FAOSTAT.

TABLE 4
Nutrient balance in Brazil, 2002 (kg/ha)

Region	N	P ₂ O ₅	K ₂ O
North	-21.4	-7.4	-10.9
Northeast	-11.8	-3.8	-3.9
Centre-west	-8.6	-8.5	-4.7
Southeast	-20.4	-4.8	-1.4
South	-20.9	-17.4	-10.9
Average	-16.6	-8.3	-6.3

phosphorus, potassium and magnesium are inadequately supplied (PPIC, 2004). The crop uptake of K is quite high but much remains in the straw. Improved varieties respond to K, especially when given adequate N and P. Response to K is generally greater on sandy soils.

Two sites at Pitipo and Vista Florida, in the rice production area of Chiclayo, were selected for testing different combinations of nutrients (PPIC, 2004):

- K₂O: 0, 37, 74 and 111 kg/ha
- MgO: 0, 15 and 30 kg/ha
- N: 260 kg/ha (with all treatments)
- P₂O₅: 46 kg/ha (with all treatments)

In 2003, in terms of grain quality, the proportion of whole grain in the sample equalled 49 percent for the control treatment (0 K, 0 Mg) and 63 percent for the treatment supplying 37 kg K₂O/ha plus 15 kg MgO/ha.

In 2004, there was a significant response to increasing K rates across Mg rates as follows:

- 0 kg K₂O = 9 592 kg/ha
- 37 kg K₂O = 9 716 kg/ha
- 74 kg K₂O = 10 023 kg/ha
- 111 kg K₂O = 10 217 kg/ha

The interaction between K and Mg was evident in the percentage of undeveloped grain in the sample. The treatment supplying 0 kg K₂O and 0 kg MgO had 12 percent undeveloped grain and the treatment supplying 111 kg K₂O and 30 kg MgO had 8 percent undeveloped grain.

As an example of fertilizer use in this region, in terms of kg/ha of N, P₂O₅, K₂O and S, the rate is 138-30-0-18 in the north coast (Comunidad San Juan Bautista de Catacaos, Piura) and 267-46-0-36 in Vista Florida-IDAL.

INTEGRATED PLANT NUTRITION MANAGEMENT (IPNM)

A fertile soil provides a sound basis for flexible food production systems that, within the constraints of soil and climate, can grow a wide range of crops to meet changing needs. Integrated plant nutrition management is an indispensable tool for supporting high crop production systems through soil fertility improvement while giving due consideration to ecological concerns.

The basic principle underlying the concept of IPNM is the maintenance and improvement of soil fertility through integration and optimization of all possible plant nutrient resources (i.e. organic, inorganic and biological) appropriate to individual farming situations in their ecological, social and economic perspective, for increased crop productivity and quality. For developing IPNM practices, the cropping systems rather than an individual crop, and the farming systems rather than the individual field, are the focus of attention. The objectives of IPNM are to:

- maintain or enhance soil productivity through balanced use of mineral fertilizers combined with organic and biological sources of plant nutrients;
- improve the stock of plant nutrients in the soil; and
- improve the efficiency of plant nutrients, thus limiting losses to the environment.

IPNM offers great potential, therefore, in terms of:

- saving of resources;
- environment protection; and
- economic cropping.

Components

Soil, mineral fertilizers, organic matter and atmospheric nitrogen, fixed by microorganisms or carried down in precipitation, are the major sources of plant nutrients. The natural plant nutrients found in the soil are deposited from the air or water, through nitrogen fixation and the weathering of soil mineral particles. Vegetation consumes a proportion of these nutrients; some are geographically redistributed by runoff; and some are lost by volatilization, fixation and leaching. Farmers harvest the natural supply of these nutrients for their crops and reorganize their distribution in space and time through their production systems.

Soil resources

Soils contain natural reserves of plant nutrients in quantities that depend on soil composition and the stage of weathering. These reserves are often in forms which are unavailable to plants and only a small portion is released each year through biological activity or chemical processes. This release is much too slow to compensate for the removal of nutrients from agricultural production, especially in the humid tropics where soils are strongly weathered. The quantities (or stock) of plant nutrients available for a crop are determined by:

- the supply of nutrients to the crop from internal and external sources;
- the uptake of nutrients by the crop; and
- losses of plant nutrient to the environment.

To enhance the soil nutrient supply, it is necessary to reduce nutrient loss by suitable soil management practices: improving problem soils to mobilize availability of nutrients and adopting appropriate crop varieties, cultural practices and cropping systems to maximize the utilization of available nutrients.

Organic resources

Organic manures are valuable by-products of farming and allied industries, derived from plant and animal sources. Available organic resources include farmyard manure and animal droppings, crop waste and residue, sewage sludge and other human waste, as well as various forms of industrial waste. Improvements in the use of organic nutrient sources can be sought through enhanced and improved organic recycling and better product quality. Organic nutrient resources are not only an effective means of supplementing nutrient availability, but they also improve the bio-physico properties of the soil, enhance fertilizer-use efficiency and are beneficial to the environment.

The following composting method is promoted in Ecuador within the framework of the FAO Special Programme for Food Security (TCP/ECU/8922).

• Materials:

- animal manure: from cows, pigs, poultry, horses, donkeys, ducks etc.
- crop residues and weeds: maize, bean, faba bean, groundnut, coffee and weeds
- others: industrial waste, ash and phosphate rock
- wood cuttings
- top soil from the forest or from an uncultivated or sparingly cultivated area
- fresh water

• Layers:

- 1 layer of crop residues (20 cm)
- 1 layer of top soil (2 cm)
- 1 layer of manure (5-10 cm)
- ash or phosphate rock (50 g spread per m²)
- fresh water (sprinkled)

Repeat the above steps until a height of about 1-1.2 m is reached. It is recommended to first construct a lattice of old branches, positioning two or three wood cuttings vertically in order to facilitate ventilation. An appropriate size for the heap is 2 × 1-1.2 × 1-1.2 m.

- **Water:** Once a week, water must be added to the heap, but not in excess in order to avoid the leaching of nutrients.
- **Air:** After 3 weeks, the heap must be mixed to ensure that all materials reach the centre.

- **Temperature:** During the process, the temperature rises to 60°-70°C and most weed seeds and pathogens are killed. The ideal temperature is 60°C.
- **Duration:** 2-3 months.

Biological resources

Legumes contribute to soil fertility directly through their unique ability – in association with Rhizobia – to fix atmospheric nitrogen. There are good prospects for enhancing exploitation of biological resources, i.e. Rhizobium-legume symbiosis and other associations such as Blue-green algae, Azolla, Actinomycetes, Azotobacter and Azospirillum in rice-based cropping systems. Rhizobium-legume associations are by far the most important sources of fixed N. Average N fixation rates are around 100 kg N/ha/year, but levels of 200 kg can be obtained by adequate selection of Rhizobium strains.

On non-irrigated cultivated land, grain legumes are essentially considered, such as cowpea, groundnut, bean, chickpea, green gram, lentil and pigeon-pea. N₂-fixing cyanobacteria make a significant contribution to paddy rice growing systems. Sesbania, a leguminous tree grown in rice fields as green manure, can fix up to 500 kg N/ha/year. The most commonly used in rice cultivation is the Azolla-Anabaena association. This association fixes N in the order of 100-200 kg/ha/year.

Mineral fertilizer resources

The role of mineral fertilizers in plant nutrition for sustaining and increasing agricultural production is well recognized. In order to further improve fertilizer-use efficiency, reduce losses to the environment and promote the judicious use of mineral plant nutrient sources, the integrated plant nutrition systems (IPNS) approach aims to:

- provide recommendations for a cropping system rather than a single crop in the system;
- improve all the production factors and eliminate limiting factors, including secondary and micro-nutrients; and
- minimize nutrient losses in the field through appropriate timing and methods of application.

Operational approach

A simplified operational approach is as follows:

- Carry out a benchmark survey to assess actual availability of farm residues and other organic sources which are not appropriately used at present

and could be used effectively for agricultural production.

- Select major multiple cropping systems (including one grain or forage legume) – depending on agro-ecological conditions, produce markets, dietary preferences etc.
- Follow appropriate soil management and conservation practices, including improvement of problem soils and crop management practices.
- Schedule nutrient application rates, including secondary and micronutrients for the cropping system as a whole.
- Apply N, P, K and micronutrients to the crop which makes best use of the nutrient in question; the following crop benefits from the residual effect.
- Use all available organic materials for the farm lands; establish programmes for quick-growing trees for fuel wood on common lands and along the borders of farms, thereby reducing dependence on cattle dung for fuel; install biogas plants where appropriate.
- Adopt suitable technologies for good quality compost production from easily available farm or agricultural wastes and other organic sources; apply compost and farmyard manure (FYM) in the most appropriate season.
- Where appropriate, practise alley-cropping or green manuring or introduce a legume crop (grain or fodder) in the cropping system, inoculating, if necessary, with efficient Rhizobium strains.
- Introduce effective strains of Azolla and blue-green algae in rice-based cropping systems in appropriate agro-ecological situations.
- Assess nutrients supplied through organic sources and apply the balance of the recommended dose through mineral fertilizers, taking into account a 15 percent increase in efficiency of the mineral fertilizers due to the complementary effects of the organic sources and mineral fertilizers.
- Monitor soil nutrient status against crop yield performance and make any necessary adjustments to the fertilizer schedule.
- Perform an economic evaluation of the integrated system.

The precise model for each country depends on the agro-ecological conditions, cropping systems and available plant nutrient resources, as well as the infrastructural,

organizational, research and development support available.

Long-term experimental results

The sustainability of the rice cropping system is important for food security. Intensive cropping with no return of crop residues and other organic inputs results in loss of soil organic matter (SOM) and nutrient supply and is assumed to be non-sustainable. Seven treatments comprising various combinations of green manure (GM; *Sesbania cannabina* L.), wheat straw (WS), FYM and urea were applied to study the effects on yield and yield trend, P and K balance, and soil fertility, as part of a rice-wheat experiment (1988-2000) on loamy sand in Punjab, India (Table 5).

Rice yields were comparable with GM + urea, WS + GM + urea, and urea alone, but yields were reduced when FYM was supplemented with N. With the exception of one year, the integrated use of FYM and GM produced rice yields which were equal to or higher than with other GM-based treatments. WS incorporation reduced average rice yields by 7 percent compared with WS removal. After 5 years of continuous application, FYM and WS were on a par in terms of increasing rice yields. Organic materials applied to rice had no residual effect on wheat yield, with the exception of FYM, which increased yield

by about 6 percent compared with urea alone. Rice yield declined by 0.02 to 0.13 tonnes/ha per year, but wheat yields remained unchanged. Soil carbon increased with the application of WS and FYM. Potassium balance was highly negative. Although the causes of yield decline are unknown, inadequate K application and changes in the climatic parameters are possible reasons.

Apparent nutrient balance

The apparent P balance at system level was negative in all treatments except for those containing FYM. The P balance in T1 (control, 0N) was near zero because of less P removal by rice. The negative P balance in T2 (urea-N, 150 kg N/ha) averaged 10.4 kg P/ha/year), suggesting that the current fertilizer P recommendations are not adequate for maintaining long-term soil-supplying capacity.

The apparent K balance was negative in all treatments. The average K balance ranged from -78 kg in the control (T1) to -151 kg K/ha/year in urea N (T2). When WS or FYM was recycled (T4-T7), the K balance was still negative, although less so. Despite substantial inputs from irrigation water, the K balance was negative. The total K uptake by the rice-wheat system averaged 285 kg K/ha/year in T2, which is maintained at a relatively high rate of K uptake, despite the application of insufficient

TABLE 5
Long-term effects of organic and inorganic fertilizers on grain yield of rice and wheat

Year	Treatment number ^a						
	T1	T2	T3	T4	T5	T6	T7
	Rice grain yield (tonnes/ha) ^b						
1988	3.97 e	6.29 bc	6.56 b	6.24 cd	6.94 a	5.81 d	7.05 a
1989	4.64 b	6.57 a	6.48 a	6.40 a	6.56 a	6.30 a	6.70 a
1990	3.67 d	6.19 a	6.15 a	5.65 b	6.35 a	4.60 c	6.10 a
1991	4.23 d	6.49 b	6.47 b	6.28 b	6.66 ab	5.72 c	6.90 a
1992	4.10 d	5.70 b	5.80 b	5.20 c	5.60 b	6.04 c	6.50 a
1993	3.44 d	5.59 b	5.54 b	4.82 c	5.50 b	4.80 c	6.10 a
1994	2.79 b	4.08 a	3.92 a	3.93 a	3.92 a	3.93 a	4.04 a
1995	2.64 d	5.20 ab	5.50 a	4.60 c	5.34 a	4.63 c	4.94 b
1996	3.90 d	5.52 a	5.30 ab	5.00 bc	5.23 abc	4.83 c	5.64 a
1997	4.36 b	6.64 a	6.25 a	6.32 a	6.57 a	6.38 c	6.59 a
1998	3.97 d	5.02 bc	5.05 abc	5.06 abc	5.24 ab	4.90 c	5.35 a
1999	4.02 c	5.54 b	5.42 b	5.16 b	5.26 b	5.17 b	5.98 a
	Mean wheat grain yield (tonnes/ha) ^b						
1988-2000	4.37 bc	4.41 bc	4.41 bc	4.32 c	4.44 b	4.65 a	4.71 a

^aT1 - control, 0N; T2 - urea-N, 150 kg N/ha; T3 - GM + urea-N (total N additions in T3, T5 and T6 were adjusted to 150 kg N/ha with urea); T4 - WS + urea-N; T5 - WS + GM + urea-N; T6 - FYM + urea-N; T7 - FYM + GM (no inorganic N was applied to T7).

^bValues within each row followed by the same letter do not differ significantly ($P < 0.05$) by Duncan's multiple range test.

Source: Singh *et al.*, 2004.

INTEGRATED SYSTEMS

SYSTÈMES INTÉGRÉS

SISTEMAS INTEGRADOS

amounts of K. However, the large negative K balance suggests that the system will not be able to sustain the K supply in the long term. The major fraction of K uptake, however, remains in rice straw; thus, recycling of straw will dramatically change the K balance, keeping it within reasonable limits.

Example of a project in Bolivia

Project GCPF/BOL/018/NET, “Soil management and plant nutrition in farming systems – Fertilisuelos”, became operational in July 1987. The main activities were:

- Promotion of the correct use of mineral fertilizers based on soil analysis and trials and demonstrations conducted in farmers’ fields with potatoes, maize, rice and wheat.
- Development of a capitalization process at farm level based on the use of agricultural inputs made available on a seasonal credit basis.
- Training of farmers and extension agents.

In addition to these activities, the project focused on the identification of the limiting factors responsible for the low yields of food crops in the three cropping zones of the country, i.e. the highlands, the valleys and the lowlands. Since then, a new set of technical innovations has been tested through a network of demonstration farms emphasizing:

- more rational management of manure and other recyclable organic residues;
- higher fodder production from pastures and use of fallow land, and corresponding improvement of soil fertility; and
- improvement of cultivation practices, e.g. land preparation to increase soil water reserves, plant density, weed control and erosion control.

The project established that significant increases in crop yields can be obtained through the application of the recommended technical packages. Potato yields improved from 12 tonnes/ha (mineral fertilizer plots) to 22.8 tonnes/ha (IPNS plots). Similarly, maize yields improved from 3.6 to 4.9 tonnes/ha and rice from 3.0 to 5.6 tonnes/ha. The advances made in the management of manure and the results of organomineral fertilization revealed the possibilities of recycling local sources of organic matter in a more efficient manner.

In rice, the effects of organomineral fertilizer and plant density were tested. The treatments are shown in Table 6.

TABLE 6
Treatments

	N-P ₂ O ₅	+	Manure (tonnes/ha)	Plant density (pl/m ²)
	15-15	+	5	260
	30-30	+	5	260
	60-60	+	5	260
Control:	Farmer's plot without fertilizer			130

With 30-30 + 5 tonnes/ha manure, farmers’ plot yield was 2-3 tonnes/ha, while yield in the plots with adequate density of 260 pl/m² was 5-6 tonnes/ha.

The project successfully demonstrated that, with correct utilization of organic resources, it is possible to:

- conserve the soil fertility;
- make agricultural production more sustainable; and
- minimize the costs and economic risks associated with high dosage of fertilizers.

Extending IPNM for wider adoption

Farmers should be motivated to make optimum use of organic, inorganic and biological fertilizers. They need to be made aware of their nutrient-supplying potential and the resulting physico-chemical and biological benefits for the soil, with enhanced productivity.

Departments of agricultural extension, private enterprises and NGOs (non-governmental organizations), together with research and educational institutes, have a vital role to play in the promotion of IPNM practices to farmers. Efforts should focus on creating awareness and expertise in farmers in the efficient use of those fertilizers, locally-available organic manures and biofertilizers which are most suitable to the needs of the area and the cropping systems as a whole.

In order to promote adoption of the technology, a programme could be set up to establish knowledgeable groups of farmers who have been trained in appropriate IPNM techniques, and who have the necessary potential to transmit expertise to fellow farmers. One possible means of achieving this is the organization of farmer field schools (FFS).

For the effective implementation of improved agricultural practices, adopting a holistic approach, extension workers must be effective and innovative managers. Farmers require exposure to improved

technology and practical training; they must be adaptable and capable of organization with the collaborative efforts of research and extension services.

Coordination of the efforts of all agencies and institutions would lead to speedy and effective implementation of the programme. National governments have the role of central coordinating agency.

CONCLUSION

There are good possibilities for closing the yield gap in irrigated rice in Latin America and the Caribbean. Suboptimal nutrient supply has been identified as one of the major reasons for the yield gap. Integrated plant nutrition for rice-based cropping systems ensuring optimum and efficient use of organic, mineral and bionutrient resources could, therefore, be an effective instrument for closing the rice yield gap. It is also important that nutrient balances in rice-based cropping systems are established.

REFERENCES

- FAOSTAT.** FAO Statistical Database (available at www.fao.org/faostat/).
- PPIC.** 2004. Research Database, PPI/PPIC and FAR (available at www.ppi-ppic.org/far/farguide.nsf).
- Pulver, E.L., Tran, D.V. & Nguyen, V.N.** 2000. Yield gap in irrigated rice in Latin American and Caribbean. In *Proc. of the Expert Consultation on Yield Gap and Productivity Decline in Rice Production*, FAO, Rome, Italy.
- Singh, Y., Singh, B., Ladha, J.K., Khind, C.S., Gupta, R.K., Meelu, O.P. & Pasuquin, E.** 2004. Long-term effects of organic inputs on yield and soil fertility in the rice-wheat rotation. *Soil Sci. Soc. Am. J.*, 68: 845-853.
- Yamada, T. & Lopes, A.S.** 1999. Balanço de nutrientes na agricultura Brasileira. In J.O. Siqueira, F.M.S. Moreira, A.S. Lopes, L.R.G., Guilherme, V. Faquin, A.E. Furtini & J.G. Carvalho, eds. *Inter-relação fertilidade, biologia do solo e nutrição de plantas*, p. 143-161. UFLA/DCS, Viçosa, Brazil, SBCS, Lavras.

Incidence de la gestion intégrée des fertilisants sur la production durable de riz, en particulier dans les pays d'Amérique latine

Le riz irrigué et les systèmes privilégiés de culture pluviale représentent approximativement 70 pour cent de la production totale de riz en Amérique latine et dans les Caraïbes. L'adoption de génotypes à rendement élevé est importante dans la région. Cela dit, les rendements obtenus dans les exploitations restent bien inférieurs au potentiel de rendement. L'écart de rendement est évident dans les systèmes de production du riz irrigué. Si l'on réduit cet écart il sera possible de renforcer de manière très nette la sécurité alimentaire dans les pays d'Amérique latine et des Caraïbes.

La mauvaise fertilisation des cultures explique en grande partie les écarts de rendement. Une amélioration de la gestion des fertilisants aura donc des répercussions importantes sur la

production durable de riz qui requiert une gestion intégrée de toutes les ressources disponibles en nutriments: sols, matières organiques, minéraux et engrais biologiques. La gestion intégrée des nutriments assure le maintien et parfois même l'amélioration de la fertilité du sol par une utilisation équilibrée et adaptée des engrais minéraux associée à des apports organiques et biologiques, qui se traduit par une meilleure efficacité des éléments nutritifs, une productivité accrue des cultures et une réduction des pertes en éléments nutritifs affectant l'environnement.

Les systèmes de culture reposant sur le riz permettent de tirer parti de manière idéale de la gestion intégrée des nutriments. La fixation biologique de l'azote (FBA) par une algue vert-bleu dans les eaux de décrue et par une bactérie

hétérotrophe dans les zones radicalaires du riz peuvent contribuer de manière significative à l'équilibre en azote. Les apports organiques en azote, comme le fumier et l'engrais vert peuvent être utilisés de manière efficace en association avec des engrais minéraux. Il est également possible d'accroître les quantités d'azote par le biais de l'azolla, malgré certaines contraintes, comme l'augmentation des coûts de main-d'œuvre.

La gestion intégrée des nutriments a permis d'obtenir, dans certaines parties du monde, des résultats encourageants pour la production rizicole. Les expériences menées dans certains pays en vue de soutenir la production rizicole par le recours à la gestion intégrée des nutriments sont présentées dans le présent article.

Repercusiones de la gestión integrada de nutrientes en la producción sostenible del arroz con referencia especial a los países de América Latina

La producción en régimen de regadío y los sistemas de tierras altas más favorecidos representan en la actualidad cerca del 70 % del total de la producción de arroz en América Latina y el Caribe. Los genotipos de alto rendimiento tienen una cobertura importante en la región, pero los rendimientos de los agricultores siguen estando muy por debajo del potencial de rendimiento de los cultivos. La brecha de rendimientos resulta evidente en los sistemas de producción de arroz en régimen de regadío, por lo que salvar esta brecha se presenta como la oportunidad más prometedora de reforzar la seguridad alimentaria en América Latina y el Caribe.

La nutrición inadecuada de los cultivos constituye uno de los motivos principales de la brecha de rendimientos. Mejorar la gestión de los nutrientes de cultivos tendrá una repercusión importante en la

producción sostenible del arroz, para la cual se requiere la gestión integrada de todos los recursos de nutrientes disponibles, es decir, el suelo, los productos orgánicos, los minerales y los biofertilizantes. La gestión integrada de nutrientes garantiza el mantenimiento y la posible mejora de la fertilidad del suelo gracias a la utilización equilibrada y prudente de fertilizantes minerales combinados con fuentes orgánicas y biológicas, lo cual se traduce en una mejora de la eficacia de los nutrientes, el incremento de la productividad de los cultivos y la reducción al mínimo de las pérdidas de nutrientes al medio ambiente.

Los sistemas de cultivos basados en el arroz ofrecen una oportunidad ideal para extraer beneficios de la gestión integrada de nutrientes. La fijación biológica del nitrógeno natural a través de algas verde-azuladas en aguas de inundación y

mediante bacterias heterótrofas en la zona de raíz del arroz puede suponer una importante aportación al balance del nitrógeno. Las fuentes orgánicas de nitrógeno, como el estiércol de granja y el abono verde de legumbre, pueden utilizarse de forma eficaz como insumos de nitrógeno junto con el nitrógeno de los fertilizantes minerales. También cabe la posibilidad de complementar las necesidades de nitrógeno mediante la azolla, pese a presentar algunas limitaciones, como los costos adicionales de mano de obra.

Las prácticas de gestión integrada de nutrientes en determinadas partes del mundo han revelado resultados alentadores en relación con la producción del arroz. Aquí se muestran las experiencias de algunos países en el sostenimiento de la producción del arroz a través de la aplicación de prácticas de gestión integrada de nutrientes.

Using wholegrain rice to promote small and medium enterprises (SMEs)

D. Mejía L.

Officer, Agricultural and Food Engineering Technologies, FAO, Rome, Italy

Rice is the staple food with the highest level of consumption in the world and the third highest production after wheat and maize. Ninety percent of global rice production occurs in tropical and subtropical Asian countries. In several countries of Africa, Latin America and the Caribbean, rice is a major staple and is produced in considerable quantities. It is estimated that by 2025, 10 billion people will depend on rice as a principal food and demand will reach 880 million tonnes. The rice sector is an important part of the economy in many Asian countries, providing employment and contributing to the gross domestic product (GDP).

Nevertheless, the evolution of the price of paddy rice in recent years has not been particularly advantageous for small farmers. Higher paddy prices have motivated rice-producing developing countries to create opportunities for adding value to traditional milled rice and its by-products. The Agricultural and Food Engineering Technologies Service (AGST) of FAO has a mandate to support such activities; in addition to technical support and organization, funding support is required to improve the development of small rice enterprises.

The International Rice Commission (IRC) comprises 61 member countries. Its international conference, organized every 4 years, is an important event for members to share recent experiences related to rice production and post-production.

Asian rice farmers traditionally use wholegrain rice and its by-products at artisan level. This experience could be shared with other countries and used as a basis to promote development of the agro-industry sector. Some governments and research institutions have carried out activities and developed strategies to promote small industry through the integral and efficient use of paddy rice. In recent years, AGST-FAO has prepared technical reports on this subject, identifying ways to strengthen the small rice industry sector:

The use of high-yielding varieties (HYVs) presents new challenges in terms of infrastructure development,

and also in terms of innovative technologies for adding value to rice and its by-products (a good source of employment and income generation).

The establishment of viable agroprocessing enterprises in rural areas producing rice is crucial, not only in Asia but in other developing countries of Africa and Latin America; investment in technologies that are affordable and add quality and commercial value to rice products and by-products will enhance the demand for farm produce.

The revision of whole grain rice utilization is important for promoting the small rice industry (rice by-products are currently under-used, resulting in problems of handling and pollution).

BACKGROUND

Carbohydrate demand declines as income increases; likewise, if income is low, the demand for rice increases. For some Asian countries, the decline in rice consumption is a matter for concern, since it is the traditional staple food and a major source of energy, protein, thiamine (B1), riboflavin (B2), niacin, iron and calcium (Hadiwigeno, 1997). The negative trend of rice consumption is partly due to an improvement in living standards. There is, therefore, a risk that rice may develop a negative image and be perceived as food for the poor. The changes in food consumption patterns depend on three major factors:

- taste and preference (especially for protein foods);
- income; and
- price of rice in relation to price of substitutes.

In the face of a decline in boiled rice consumption as living standards improve, some food research institutions have been modernizing the processes related to rice food, to promote consumption of new, improved rice products and convenience rice foods (Hadiwigeno, 1997).

The total production of paddy or rough rice was around 615 million tonnes in 2005. About 365 million tonnes of milled rice are produced in developing countries and

INTEGRATED SYSTEMS

SYSTÈMES INTÉGRÉS

SISTEMAS INTEGRADOS

18 million tonnes in developed countries (Table 1). In addition to the milled rice derived from the main processed product, there is also a large volume of by-products, including the husk, bran and broken grains. Therefore, small rice farmers could benefit from useful technologies for rice products and by-products. Efficient technologies can enhance quality and safety in milling rice processing and offer great potential in terms of the utilization of by-products. In both cases, there is added value which increases returns. Strengthening the rice small industry sector is in line with the Millennium Development Goals (MDG) which aim to reduce extreme poverty and eradicate hunger in poor countries.

It is important to apply modern or innovative processing technologies to traditional rice products. This applies in particular to those countries which have entered the General Agreement on Tariffs and Trade (GATT) and must upgrade the uniformity, quality and shelf-life of the product and comply with various requirements (e.g. specification of ingredients). Therefore, the improvement of rice-processing small and medium enterprises (SMEs) – whether for rice products or by-products – is a matter of great importance within FAO's Technical Cooperation Programme, and specifically within AGST.

The main approach is to enhance capacity-building for rice in developing countries by facilitating the interchange and transfer of technologies to add value and create opportunities for income generation and employment among farmers or people associated with these activities within the food chain of rice and rice by-products. The appropriate technical use of paddy rice should be seen as

an important action to be carried out by rice farmers and agroprocessors to convert it into an efficient and profitable business through implementation of cost-effective and environmentally friendly methods and technologies. In some countries (e.g. Indonesia), small-scale rice industry development has had a significant impact on the GDP, resulting in the reduction of poverty to some extent. Thus, the promotion of the small-scale food industry is a helpful alternative to be exploited in developing countries in order to improve the rice agricultural sector socio-economically. Although the small-scale food industry – like any other small enterprise – cannot increase the per caput income very rapidly, it can open up more job opportunities than medium or large-scale industries; this is clearly demonstrated in Indonesia, where rice milling is the most important small-scale food processing industry (Damardjati, 1995).

Many rice-producing countries are poor and need to develop national strategies to enhance the capacity for improving the efficiency of technologies used to add value to rice and its by-products. In this regard, small and medium rice agro-industry development represents a valuable alternative, not only for the small and medium rice producer but for others interested in using rice in a more integral and efficient manner.

WHOLEGRAIN RICE STRUCTURE, PROPERTIES AND COMPOSITION

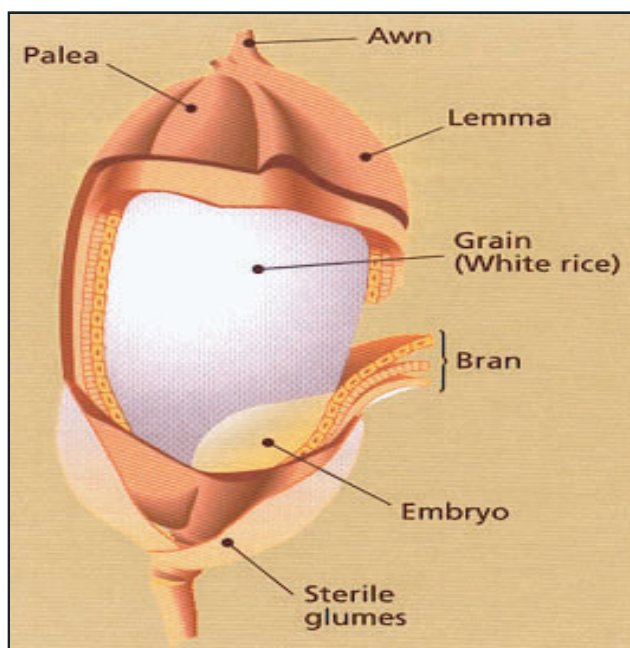
Freshly harvested rice is called paddy grain or rough rice. The pearly white grain used for cooking is the centre of the rice seed and it is covered and protected by the husk

TABLE 1
Paddy rice world production and milled rice, utilization, export and import

Region	Rough rice production 2005 (tonnes)	Milled paddy rice (tonnes)		
		Rice milled equivalent- domestic supply (2003)	Export (2004)	Import (2004)
Developing countries	589 390 422	364 783 250	21 689 813	16 602 715
Latin America and Caribbean	26 370 717	16 753 623	533 866	1 242 881
Africa	18 565 960	19 326 043	828 569	5 807 222
Near East	10 830 748	10 558 944	964 002	4 810 867
Far East	539 820 645	322 461 872	20 176 024	5 460 446
Developed countries	25 264 473	17 756 051	2 596 464	3 169 513
United States of America	10 012 190	3 976 280	1 675 042	447 728
Europe	3 235 900	3 872 178	1 454 778	838 960
Japan	10 989 000	7 969 912	-	-
Total for Asia	556 018 828	337 799 621	20 385 158	10 225 470
World	614 654 895	382 539 301	24 286 277	19 772 228

Source: Yap, 1995 (adapted); FAOSTAT, 2006.

FIGURE 1
Rice grain section showing protective layers



Source: RIRDC, 2003.

or hull which is composed of the palea, lemma and sterile glumes. Inside the husk, the familiar white grain is covered by a layer called bran. The embryo, a small structure at the base of the grain, is also contained within the bran layer. Together, the grain, embryo and bran are called brown rice (Figure 1).

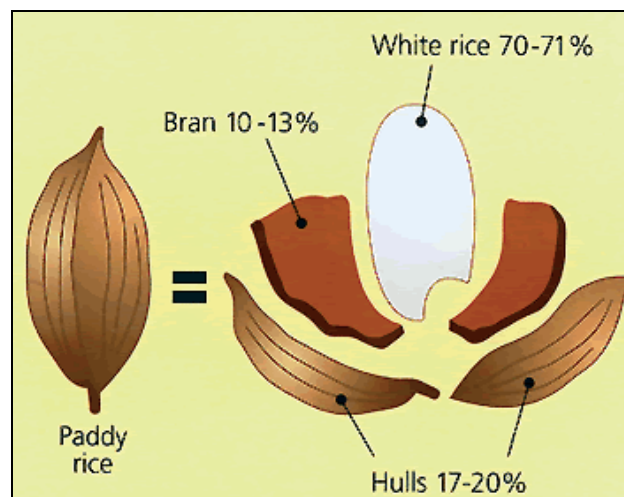
Rough or paddy rice consists of an outer protective layer covering the husk (17-20 percent), the bran (10-13 percent) and the white rice (70-71 percent). Paddy rice is the whole grain as taken off the plant at harvesting; the white rice grain which is eaten accounts for less than three-quarters of the weight of a paddy rice grain which also includes the hull and bran (Figure 2). The palea, lemma and sterile glumes are removed from paddy rice in the first stage of the milling process, called de-hulling. Machines rub off the bran and embryo to leave polished rice or white rice. A polished rice grain contains approximately 94 percent starch and 5 percent protein.

Rice is the staple food in at least 17 countries in Asia and the Pacific, nine countries in North, Central and South America and the Caribbean, one country in North Africa and seven countries in sub-Saharan Africa (FAO, 2004). In developing countries, rice accounts for 715 kcal/caput/day, providing 27 percent of the dietary energy supply,

20 percent of dietary protein and 3 percent of dietary fat. The brown rice is the edible part of the rice grain. Levels of dietary fibre, minerals and B vitamins are highest in the bran and lowest in the aleurone layers. Rice is a good source of B vitamins (thiamine, riboflavin and niacin), but contains little or no vitamins C, D or beta-carotene (precursor of vitamin A) (Kennedy, Burlingame and Nguyen, 2002). The amino acid profile of rice is high in glutamic and aspartic acids, but low in lysine (Juliano, 1997). The anti-nutritional factors, most of which are concentrated in the bran, are phytate, trypsin inhibitor, oryzacystatin and haemagglutinin-lectin. The availability of iron and zinc in typical Asian rice diets is generally low: they come mainly from plant sources, and rice and legumes contain phytate which binds minerals and proteins including enzymes (Calloway, 1995). Table 2 shows the composition of rice and its edible fraction.

In recent years, in some countries (e.g. Japan), rice bran has been associated with good health, thanks to several active components, including: rice bran oil (reduces cholesterol), γ -Oryzanol and Ferulic acid (antioxidants), Inositol (for liver function and healthy hair) and sterols (for cholesterol metabolism). These components offer potential in both the food and the cosmetic industry (Tsuno-Co., 2004). Moreover, the hypocholesterolaemic effects of stabilized rice bran reduce plasma cholesterol due to the presence of a unsaponifiable fraction and the effect of rice bran hemi cellulose (Suzuki *et al.*, 1962).

FIGURE 2
Paddy rice components



Source: RIRDC, 2003.

TABLE 2
Composition per 100 g of rough rice and its edible fraction

Nutrient (in 100 g)	Rough rice	Brown rice	Milled rice	Rice bran	Rice hull
Moisture	14	14	14	14	14
Protein (g)	5.5-7.7	7.1-8.3	6.3-7.1	11.3-14.9	2.0-2.8
Fat (g)	1.5-2.3	1.6-2.8	0.3-0.5	15-29.7	0.3-0.8
Ash (g)	2.9-5.2	1.0-1.5	0.3-0.8	6.6-9.9	13.2-21
Crude fibre (g)	7.2-10.4	0.6-1.0	0.2-0.5	7-11.4	34.5-45.9
Dietary fibre (g)	16.4-19.2	2.9-3.9	0.7-2.3	24-29	66-74
CHOS (g)	64-73	73-87	77-89	34-62	22-34
(Kcal)	378	363-385	349-373	394-476	265-332
Lysine (g/16g N)	3.1-4.7	3.7-4.1	3.2-4.0	4.8-5.4	3.8-5.4
Thiamine (mg)	0.26-0.33	0.29-0.61	0.02-0.11	1.20-2.40	0.09-0.21
Riboflavin (mg)	0.06-0.11	0.04-0.14	0.02-0.06	0.18-0.43	0.05-0.07
Niacin (mg)	2.9-5.6	3.5-5.3	1.3-2.4	26.7-49.9	1.6-4.2
Calcium (mg)	10-80	10-50	10-30	30-120	60-130
Phosphorus (mg)	0.17-0.39	0.17-0.43	0.08-0.15	1.1-2.5	0.03-0.07
Iron (mg)	1.4 - 6.0	0.2-5.2	0.2-2.8	8.6-43	3.9-9.5
Zinc (mg)	1.7-3.1	0.6-2.8	0.6-2.3	4.3-25.8	0.9-4.0
Density (g/cm ³)	1.17-1.23	1.31	1.44-1.46	1.16-1.29	0.67-0.74
Bulk density (g/cm ³)	0.56-0.64	0.68	0.78-0.85	0.20-0.40	0.10-0.16

Source: Juliano, 1985.

POST-HARVESTING OF RICE ASSOCIATED WITH QUALITY

During post-harvest operations related to rice, an efficient on-farm handling, storage, processing and distribution system is essential to ensure acceptable quality and safety of the grain. Environmental conditions during grain ripening and drying in the field may affect the processing characteristics of the rice grain (Juliano, 1996). Early-maturing (90-100 days) tends to be more immature than medium-maturing rice (130-140 days). Immature grains reduce head rice yield and result in completely chalky grains. Thinner grains also tend to have lower amounts of brown rice and total and head-milled rice than normal grains (Wadsworth and Hayes, 1991). Drying is the most critical post-harvest operation, particularly in the wet season, for maintaining the quality of the rice grain (Juliano, 1996). Aflatoxin is produced mainly in the bran polish fraction of brown rice (Ilag and Juliano, 1982).

During post-harvest operations, numerous factors can affect quality:

- Stack-burning (yellowing) occurs when wet grain, particularly unthreshed grain, is piled without any provision for ventilation. Microbial respiration of the thermophilic fungi may heat the rice to over 60°C (Phillips *et al.*, 1988). The resulting milled rice becomes hard, translucent and yellow, regardless of variety, due to the effects of heating rather than direct microbial infestation. Yellowing reduces the lysine

content of rice by about 10 percent, resulting in a drop in net protein utilization (Eggum *et al.*, 1984).

- Rice hull tightness provides better protection for the brown rice from infestation by insects and microorganisms. Parboiled rice usually has a loose hull as a result of starch gelatinization and swelling (Juliano, 1997).
- Grain breakage during milling is caused by the preformed fissures in brown rice which result from moisture absorption stress during storage and milling (Kunze, 1985). The critical moisture content is that below which grain fissure is 15-16 percent for susceptible rice and 12-14 percent for resistant varieties (Juliano and Perez, 1993). Immature grains become small, thin and chalky broken. Chalky portions of rice with high amylose content in the endosperm are subject to grain breakage because of the presence of air space and the loose arrangement of the cell contents.
- Ageing occurs during the first 3-4 months after harvest in rough, brown or milled rice at temperatures above 15°C, when the endosperm:
 - becomes harder, resulting in higher total and head-milled rice yields and more volume expansion and water absorption during cooking (with fewer solids in cooking gruel);
 - becomes slightly yellow; and
 - loses its aroma.

- Shelf life – due to damaged aleurone cells, milled rice and brown rice also experience fat rancidity as a result of lipase action on fat to produce free fatty acids and the oxidation of the released unsaturated fatty acids by the action of lipoxygenase. The major carbonyl compound produced is hexanal, detectable by Japanese consumers 1 month after milling. Fresh, well-milled rice is, therefore, the preferred raw material for processed rice products because there is a lower content of surface fat subject to rancidity. Shelf-life is longest for rough rice, followed by brown rice; it is shortest for milled rice. Thermally-processed rice products are more stable and tend not to suffer from this type of oxidation.

De-hulling and milling of paddy rice

One of the main processing methods applied to paddy rice is milling, and the efficiency of milling is calculated as a percentage of the whole grain obtained after milling. The main operations involved in paddy rice milling are:

- cleaning;
- de-husking or de-hulling to obtain brown rice;
- whitening of brown rice to obtain white rice; and
- polishing of white rice to finally obtain polished white rice.

An efficient rice mill will produce more than 50 percent head rice, 5-15 percent large brokens and 5-15 percent small broken kernels. In the Engelberg or huller-type mills, de-hulling and milling are done in a single step, resulting in increased grain breakage and by-products which are a mixture of hull and bran (IRRI, 2006).

The weight of the whole white grains left after milling is calculated as a percentage of the total weight of the paddy rice. Breakage of grain occurs during milling for various reasons, including the presence of chalky or opaque grains which are generally softer than translucent grains and consequently prone to breakage during milling. Parboiling increases the percentage of head rice because it gelatinizes the starch in the grain, which results in firmer grains after drying.

Two types of rice mill are generally used in developing countries:

- Village mill, with three main outputs:
 - milled rice (mixture of whole grains and large and small brokens);
 - husk; and
 - bran.

- Commercial mill, with a multi-pass system producing six outputs:
 - head rice (the main product of grading);
 - broken grains (a co-product of grading);
 - brewer's rice (a by-product of sifter);
 - coarse bran (a by-product of first whitener);
 - fine bran/meal (a by-product of second whitener/polisher); and
 - husk or hull (a by-product of husking).

Head rice is milled rice with a length greater or equal to three-quarters of the average length of the whole kernel. Head rice recovery varies from 25 to 65 percent in the standard rice milling industry (IRRI, 2006).

Two major advances in rice milling are the humidifying rice-milling machine and the rice moisture conditioner for high-moisture milling (Satake, 1990). The brown rice is humidified through pressurized water mist via a hollow shaft. An additional 0.3 to 0.4 percent moisture then softens the surface, resulting in: more efficient bran removal (i.e. higher total and head-milled rice yields); a 2°C lower temperature rise; and minimum moisture loss. More glossy milled rice is obtained and gelatinization of surface starch during milling has been observed (Kohlwey, 1992).

The rice milling industry can promote small and medium agrobusinesses through improved quality control of paddy rice and the milling process. Rice quality improvement should be in line with consumer preferences and affordability. Quality is not the only means for promoting rice at national and international level in order to obtain higher prices. Other potential niches for rice milled products exist, for example organic rice and brown rice:

- Organic certification requires special conditions for production, but it opens up market opportunities.
- Brown rice (or husked rice) is minimally processed and retains the bran layers with high nutritional properties; it is recommended to apply parboiling and vacuum and opaque packaging for increased shelf-life.

PROCESSED RICE PRODUCTS

In developed countries, there is a high level of consumption of processed rice products made mainly by large rice-processing enterprises. Developing countries, on the other hand, produce a smaller quantity of processed rice products, and there is therefore a good opportunity

to promote the small rice industry. Processed rice products include pre-cooked and quick-cooking rice, noodles, rice cakes and pudding, expanded or puffed rice, baked rice products, fermented rice, rice flour and starch, and are derived from brown rice, milled rice, cooked rice, broken rice, dry-milled flour and rice starch.

Precooked and quick-cooking rice

Precooked rice is used for rice-based convenience food products. These are hermetically sealed in laminated plastic or aluminium-laminated plastic pouches and pasteurized at 120°C under pressure (Juliano and Sakurai, 1985). Before consumption, the aluminium-laminated plastic pouch is warmed directly in hot water for 10 to 15 minutes; plastic pouches may be punctured and heated in a microwave oven for 1 to 2 minutes.

Frozen cooked rice packed in airtight plastic pouches has been in great demand in some countries (e.g. Japan). Likewise, precooked frozen rice is also delivered to chain restaurants, where it is heated in microwave ovens and served. Deep-freezing without dehydration helps prevent cooked rice from retrograding (hardening) (Juliano, 1997).

Other products can be made from precooked rice, for example, dry precooked rice cereal: cereal slurry is prepared, cooked, dried in a double-drum drier, flaked and packaged.

Noodles

Flat and extruded round noodles are traditionally prepared from wet-milled flour that has been ground with a stone or metal mill. The starting material can be whole or broken grains with low fat content. Freshly milled rather than aged rice with a high amylose content is recommended. To make flat rice noodles, a wet-milled rice batter with a consistency of 42 percent rice by weight is placed on a noodle-making machine (Juliano and Sakurai, 1985). In Viet Nam, Thailand and Taiwan, rice paper and egg roll wrapper are prepared from wet-milled high-amylose rice batter.

Rice cakes and pudding

Rice cake is traditionally prepared from waxy milled rice by washing the milled rice, steaming at 100°C for about 15 minutes to 40 percent moisture content, grinding and kneading and then packing in plastic films; it is then pasteurized for 20 minutes at 80°C and left to cool (Juliano and Sakurai, 1985).

Japanese rice pudding consists of waxy rice flour, cornstarch, sugar, water and flavouring mixed and steamed at 100°C and served with sweet bean curd, green tea, coffee, cherries and other fruits (Juliano and Sakurai, 1985). Another type of pudding is prepared by cooking the rice in boiling water, straining and mixing it with milk prior to completion of cooking. Egg yolk, sugar, vanilla and light cream are amalgamated with a variety of fruit combinations. Rice with sweet milk is very popular in Latin America, where it is mixed with cinnamon and scent nail and consumed warm or cold.

Expanded rice products

Puffed and popped rice are traditional breakfast cereals and snack foods. Flaked or beaten brown rice and parboiled milled rice may be converted into puffed rice by heating in hot air or roasting in hot sand. With normal parboiled milled rice, the puffed volume is directly proportional to the intensity of the parboiling (Villarreal and Juliano, 1987).

Continuous explosion-puffing of brown rice was developed in Japan in 1971. The grains are dispersed in a long heating pipe and conveyed by a high-velocity stream of superheated steam (Sagara, 1988). After the rice has been heated and dried in 3 to 10 seconds, it is discharged into the atmosphere through a rotary valve and explosion-puffing takes place. A brown rice expansion ratio of 5.4 is obtained at 6 kg/cm² pressure and an outlet steam temperature of 200°C. The puffed product has a starch digestibility of 94 percent after 15 minutes' boiling.

Baked rice products

There has been progress in bread baking in Japan, using a mixture of 10 to 20 percent rice flour and wheat flour, depending on the gluten strength of the wheat flour (Tani, 1985). A mixture of 60 percent rice flour, 30 percent wheat flour and 10 percent vital gluten has also produced good results. Similar dilutions of wheat flour with rice flour and other starchy flours have been developed for bread-making in other countries. It is important that the gelatinization temperature of the starch be low (<70°C) (Bean and Nishita, 1985).

Fermented rice products

Waxy rice wines are prepared by fermenting steamed waxy milled rice with fungi and a yeast starter (Juliano and Sakurai, 1985). A sweet product is produced, which

is converted to alcohol as fermentation progresses. The liquid is removed by decantation. Rice wine production in Taiwan uses either *Aspergillum oryzae* or *Rhizopus* sp. for saccharification (Chang, 1988).

Rice vinegar results from the completion of the rice starch fermentation and is a traditional Japanese and Chinese product (Iwasaki, 1987). Acetic acid fermentation is carried out by mixing seed vinegar with rice wine and takes 1 to 3 months. The product is ripened, filtered, pasteurized and bottled (Lai, Chang and Luh, 1980).

Rice flours and starch

Rice flour can be made from both waxy and non-waxy rices and from both raw and gelatinized rice. It is milled by rolling, pounding, shock-milling, stone-milling, milling in a lateral steel mill and wet-milling in a stone mill.

Rice starch production involves mainly wet-milling of brokens with 0.3 to 0.5 percent sodium hydroxide to remove protein (Juliano, 1984). Broken grains are steeped in alkaline solution for 24 hours, then wet-milled in pin mills, hammer mills or stone-mill disintegrators with the alkaline solution. The starch is used exclusively for human consumption, largely for baby foods and also in extruded noodles.

USE OF RICE BY-PRODUCTS

The main rice by-products from the rice milling process are the bran, broken grains and hull. Rice by-products are a renewable source of energy; they are carbon neutral and can help reduce waste and the problems associated with environmental contamination. Some processing methods and potential agro-industries are briefly described below.

Rice bran

Rice bran offers limited potential as food due to:

- the prevalence of small one-step milling machines which incorporate significant quantities of hull in the bran;
- the unhygienic conditions of the rice mill which increase microbial contamination; and
- the inability to stabilize the bran resulting in a rancid product.

The available literature, however, indicates a wide range of uses for rice bran. Bran accounts for 5 to 8 percent of the rough rice weight, while polish accounts for an

additional 2 to 3 percent. Yield is influenced by the type of mill, the variety of rice and the pre-treatment (drying or parboiling) (Juliano, 1997). Stabilization is essential, considering the potential of rice bran oil for food utilization.

Extruded rice bran

With extrusion cooking, the rice bran can be heat-treated without interrupting the flow of the material since the extrusion equipment can be integrated in the processing line to produce stable rice bran. For example, an extruder which treats 500 kg per hour at 12 to 13 percent moisture content, cooking at 130°C and holding at 97° to 99°C before cooling gives a product which is stable for at least 30 to 60 days (Randall *et al.*, 1985). Other extruders exist with similar conditions to stabilize the bran. The treated bran should be put into a vacuum in opaque packaging and stored in a cool place in order to increase shelf-life. This type of product can be used for breakfast formulas.

Rice bran flour

Stable rice bran can be converted to flour; it has good functional properties and can be used with other processed foods, such as breakfast cereals and other products prepared with flour materials. Wheat flour was replaced at a level of 40 and 60 percent to make muffins which were rated as acceptable (Hudson, Chui and Knuckles, 1992).

High protein bran flour

Given its hypoallergenic property, rice bran flour is a potential source of protein for infants allergic to milk or soy. The rice bran is de-fatted and sieved through a 100 mesh to obtain a light flour fraction containing 5 to 12 percent of crude fibre. Further grinding of the coarse-sieved fine (<84 µm) fraction through a senior flour mill and sieving produced flour containing 15 percent protein, 5-6 percent starch, 12-13 percent ash and 1-1.5 percent fat (Houston and Mohammad, 1966).

Bran protein concentrate

There are several processing methods to obtain bran protein. For example, in the alkali extraction process, 7.5 volumes of NaOH at pH 11 are mixed and 80 percent protein is extracted from de-fatted bran for 1 hour at 25°C; neutralization to pH 5.5 with hydrochloric acid produces precipitation containing 40 percent protein, representing 50 percent of the total protein (Chen and Houston, 1970).

Bran protein isolate

A highly purified rice protein isolate (RPI) can be obtained by heating rice bran in boiling water in the presence of a commercial heat-resistant alpha amylase (Kiriyama and Morita, 1992).

Feed

Traditionally, rice bran has been used for feed and in spite of its high fibre content, it is a high energy feed. Rice bran is more suitable for sheep and swine than cattle and chicken (Crampton and Harris, 1969). In Viet Nam, fish feed is made by mixing with a mass of cooked rice flour (made from broken rice) and passing through a pellet mill.

Ethanol

Rice bran has been used as a medium for screening *Sacharomyces* species for ethanol production. Shochu (Japanese alcoholic beverage) distillery waste and aromatic rice bran are used to make a fermented product with a characteristic wine-like red colour containing about 12 percent ethanol (Teramoto *et al.*, 1994).

Rice bran oil

Oil is one of the most important by-products obtained from rice bran. The bran is about 20 percent oil with a high free fatty acid content (Del Rosario, 1997).

Other products

Other rice bran products with industrial potential include Inositol (a vitamin essential for babies), vitamin B concentrate, Oryzanol (antioxidant), dietary fibres, phytic acid (natural mineral chelater) and others (Del Rosario, 1997).

Broken rice grains

The rice industry trades two types of broken grains:

- Large brokens of length less than three-quarters but more than one-quarter of the average length of the whole kernel, representing 5 to 15 percent of the total milled rice.
- Small brokens or “brewer rice” of length less than one-quarter of the average length of the whole kernel, representing 5 to 15 percent of the small broken kernel.

Depending on the country standards, rice grades in the market contain 5 to 25 percent of broken kernels (IRRI, 2006). Some uses of broken rice are described below.

Beer

Small broken rice or brewer’s rice is a valuable adjunct in beer production, due to the low protein and lipid content, which gives a natural aroma and flavour, and produces a clear taste. Prior to use, it is important to ensure that it is free of foreign seeds, insects, mold, soil and traces of bran (which is rich in lipids) (Yoshizawa and Kishi, 1985).

Fructose and glucose syrups

Fructose syrup can be made from broken rice using alpha-amylase, gluco-amylase and glucose isomerase. A glucose yield of 80 percent can be obtained from broken rice (90 percent starch base); it is then converted to 50 percent glucose, 42 percent fructose and 5 percent maltose. Glucose syrup production is also reported using alpha-amylase and gluco-amylase and giving a yield of 80 percent (Cheng and Chang, 1984). In both cases, broken grains are subject to gelatinization of starch prior to enzymatic hydrolysis.

Flour and pre-gelatinized rice flour

Broken grains can be milled into flours of different granulations for domestic consumption. Likewise, pre-gelatinized rice flour is produced by extrusion, pressure or steam cooking of the broken grains which are then ground into several types of pre-gelatinized rice flour (Sheng, 1995).

Feed

Broken grains have been used in many rice-producing countries for swine and poultry directly or in feed formulations.

Starch

Starch from broken rice can be produced by wet-milling with 0.3 to 0.5 percent of sodium hydroxide solution to remove protein. The broken grains are steeped in alkaline solution for 24 hours and then ground with the solution. The batter is stored for 10 to 24 hours and filtered to remove the fibre. The slurry is centrifuged to remove the starch, which is then dried. The protein can be recovered by washing and precipitation.

Maltodextrin

Maltodextrin can be made from rice flour by incubating the substrate at 80°C using heat labile amylase (Griffin and Brook, 1989).

Distilled liquors/spirits

Shochu is a Japanese liquor prepared by a non-cooking saccharification method using raw starch degraded by enzymes from *C. paradoxa*, followed by fermentation and distillation operations (Nishimura *et al.*, 1993).

Rice hull

The availability of rice hulls varies from country to country, depending on the type and size of the rice mills and their locations. Larger rice mills have more disposal problems with hulls compared to smaller village-type rice mills. Some rice mills operate for only a few months of the year, whereas others operate all year round. In most rice mills, rice hulls are separated from husked rice via aspiration, as rice hulls are lighter than husked rice. Sometimes, hulls are ground prior to piling or storage. Grinding makes it easier to transport hulls, reduces the space needed for storage and lowers transportation costs.

Rice hull as animal feed

Rice hull may be used as an ingredient in ruminant feeds; commercial feeds may contain 5 to 10 percent of ground rice hulls. Chemical, physical and biological treatments have been used to prepare rice hulls for feed:

- Physical processes include explosion-puffing at high pressure.
- Chemical treatments include alkaline solutions to increase digestibility of the dry matter.
- Biological treatment uses microorganisms and fermentation processes to grow single cell protein to increase protein and reduce fibre.

Of all cereal by-products, the rice hull has the lowest percentage of total digestible nutrients; adding a source of nitrogen can enhance hulls as feed. There are limitations to the use of rice hull as feed, including: low digestibility, peculiar size, low bulk density, high ash/silica content and abrasive characteristics (IRRI, 2006). The silica content of ash is 90 to 97 percent (Juliano, 1997).

Rice hull in agriculture uses

Rice yields can be improved with regular use of fertilizer by addition of rice husk ash. Rice hull can also serve to increase moisture retention or as a weed growth inhibitor in the soil. When the rice hull is burned, the remaining ash can be used as a mix for fertilizer or to neutralize acid soils, as is the tradition in some Asian countries and other countries where rice hull is used as a domestic fuel.

Finely-ground rice hulls are a component of commercial mixed fertilizers. The rice hull prevents caking of other fertilizer components. Worms can be used in rice hull decomposition, as rice hulls can be difficult to compost.

Rice hull can also be used as substrate for seed germination, in crop growing and even in chicken hatchery to make nests for incubating eggs.

Rice hull as fuel for direct combustion and gasification

Rice husks are much more economical than rice straw for direct combustion. It is used for domestic fuel consumption and can be used to make briquettes as it improves the combustion characteristics and ease of handling. In the modern rice-milling industry, rice hulls are used as a fuel source for grain drying and parboiling. In Thailand, rice is dried in high-temperature fluidized bed dryers, and drying heat is provided by cyclonic rice hull furnaces. In Bangladesh, rice hulls are the preferred fuel for parboiling, and rice hulls are widely used for grain drying in the larger rice mills of northern India.

The gasification of rice hulls to produce combustible gas can have several objectives: direct combustion in boilers or furnaces, combustion in internal combustion engines, or production of cooking gas. Gas produced in gasifiers for use in boilers and furnaces is a technically and economically proven technology, and provides more efficient energy conversion than direct combustion of rice hulls. A limited number of small-scale rice hull gasifiers (5-20 kW) are in use in northern India (IRRI, 2006).

Other industrial uses

Other industrial uses of rice hull add higher value than agricultural uses to the products. Products that can be developed from full utilization of the rice hull include: concrete blocks, tiles and moulding, fireboard, ceramics, road-building material, sugars, ethanol, furfural and cement (Del Rosario, 1997). Rice hull ash (RHA) (35 percent) mixed with Portland cement produces compressive strength cement (DTI, 2006). Prices for RHA on the world market are approximately US\$200 per tonne of ash (equivalent to US\$40 per tonne of rice hulls, or US\$8 per tonne of rough rice). Using RHA in the cement industry is also under consideration (IRRI, 2006).

CONSTRAINTS IN DEVELOPING THE RICE INDUSTRY

The paddy rice milling process and utilization of the main derived products and by-products represents a good alternative to rice farmers and partnerships in developing

countries for the promotion and development of the small and medium rice industry to:

- add value and increase profitability;
- create employment opportunities; and
- make rice cost effective and in harmony with the environment.

However, it is important to first analyse in detail the technical and socio-economic aspects of the rice industry in question.

Different types of industry can be derived from paddy rice milling, operating in various areas:

- milled rice;
- rice processed products derived from milled rice;
- utilization of by-products; and
- paddy rice services industry (drying, parboiling, de-husking etc.).

A wide range of processed rice products and by-products can be obtained for human consumption as well as for industrial use. There is potential for further development, but improvement is required in terms of preparation, packaging and machinery usage. A wide range of tasks need to be performed, which means that such industries can create employment opportunities for all family members.

Experience in some Asian countries indicates that home industry (1-4 workers) and small industry (15-19 workers) at rural and village level are vital to the national economy, despite the phenomenal growth of the large-scale sector. Some governments encourage and support the promotion of small-scale industries through deliberate policies, for example: capital subsidies, preferential tax treatment and reservation of exclusive manufacture in the small-scale sector. In India, employment generated from small and medium enterprises is 80 percent of the total amount for manufacturing industries; in Japan and the Republic of Korea, it is 78 and 69 percent, respectively (Tamil Nadu, 2004).

In the small industry sector of developing countries, studies have indicated that organized businesses may have advantages over unorganized ones.

Constraints faced by small industries include (AGNET, 2006):

- insufficient supply of good quality raw material;
- lack of research activity at factory level;
- low level of technology;
- lack of adequate market strategies;

- inconsistent quality due to lack of facilities for quality control;
- lack of small-scale industry associations;
- lack of food standards and regulations;
- low quality packaging;
- low level of education of entrepreneurs;
- lack of finance (a common problem);
- lack of skills in small business management; and
- poor policies and incentives to promote the agro-industry sector.

CONCLUSIONS

- Rice product and by-product use in the development of small and medium industries represents an attractive technical and socio-economic challenge to stakeholders in developing countries associated with rice production, processing, research and trading.
- SMEs for rice products and by-products represent an opportunity for diversifying the food and non-food industry, including rice service industries (drying, parboiling etc.), and offer great potential for increasing income and employment opportunities.
- Rice by-products which are likely to be economically feasible include: rice hull as a fuel source, rice bran as a source of oil and broken grains as a source of flour.

RECOMMENDATIONS

- Support should be provided for the development of rice SMEs, especially in developing countries, in order to implement and improve production efficiency, quality control and safety conditions.
- Given that many products exist with the potential to be industrialized, a preliminary feasibility study should be carried out to facilitate implementation.
- In several countries, SMEs make a more significant contribution to employment generation than do large businesses; governments must, therefore, promote them and help overcome constraints through policies and strategies, including: transfer of innovative technologies and regulations; financial subsidy or assistance where possible; preferential tax treatment; and the development of adequate infrastructure.
- Transfer of technologies and financial programmes are required in order to improve the rural and village rice industry in developing countries.

REFERENCES

- AGNET.** 2006. Available at www.agnet.org/library/article/eb409.html.
- Bean, M.M. & Nishita, K.D.** 1985. Rice flours for baking. In B.O. Juliano, ed. *Rice chemistry and technology*, 2nd ed., p. 539-556. St Paul, MN, USA, Am. Assoc. Cereal Chem.
- Calloway, D.H.** 1995. *Human nutrition: Food and micronutrient relationship*. Agricultural Strategies for Micronutrient Working Paper 1. Washington, DC, International Food Policy Research Institute.
- Chang, P.Y.** 1988. The utilization of rice in Taiwan, Republic of China. *Food Fert. Technol. Cent. Asian Pac. Reg. Ext. Bull.*, 273: 1-9.
- Chen, L. & Houston, D.F.** 1970. Solubilization and recovery of protein from defatted rice bran. *Cereal Chem.*, 47(1): 72-79.
- Cheng, W.P. & Chang, Y.C.** 1984. Production of high fructose, rice syrup and high protein rice flour from broken rice. *J. Sci. Food Agric.*, 35: 1128-1135.
- Crampton, E.W. & Harris, L.E.** 1969. *Applied animal nutrition* (2nd ed.), San Francisco, W.H. Freeman & Co. (Cited in Barber and Benedito de Barber, 1977)
- Damardjati, D.S.** 1995. *Food processing in Indonesia: The development of small-scale industries* (available at www.agnet.org/library/abstract/eb410.html).
- Del Rosario, R.R.** 1997. *Rice by products in Asia*. FAO-RAP Publication No. 39.
- DTI (Department of Trade and Industry).** 2006. Available at www.dti.gov.uk/renewables/publications/pdfs/exp129.pdf.
- Eggum, B.O., Juliano, B.O., Villareal, C.P. & Perez, C.M.** 1984. Effect of treatment on composition and protein and energy utilization of rice and mung bean in rats. *Qual. Plant. Plant Foods Hum. Nutr.*, 34: 261-272.
- FAO.** 2004. Available at www.fao.org/rice2004/en/f-sheet/factsheet3.pdf.
- FAOSTAT.** 2006. FAO Statistical Database (available at www.fao.org/faostat/).
- Griffin, V.K. & Brook, J.R.** 1989. Production of size distribution of rice maltodextrins hydrolyzed from milled rice flour using heat stable alpha-amylase. *J. Food Sci.*, 54: 190-193.
- Hadiwigeno, S.** 1997. Foreword. In *Rice product in Asia*, p. i. FAO-RAP Publication. No. 38, Bangkok, Thailand.
- Houston, D.F. & Mohammad, A.** 1966. Air classification sieving of rice bran and polish. *Rice J.*, 69(8): 20-22, 44.
- Hudson, C.A., Chui, M.M., & Knuckles, B.E.** 1992. Development and characteristics of high fibre muffin with oat bran, rice bran or barely fibre fractions.
- Ilag, L.L. & Juliano, B.O.** 1982. Colonization and aflatoxin formation by aspergillus spp on brown rice differing in endosperm properties. *J. Sci. Food Agric.*, 33: 97-102.
- IRRI.** 2006. Available at www.knowledgebank.irri.org.
- Iwasaki, T.** 1987. Measures for the enhancement of rice consumption and diversification of rice utilization. Paper presented at the International Seminar on the Diversification of Rice Utilization, Bangkok, 12-17 Oct. 3 pp.
- Juliano, B.O.** 1997. *Rice products in Asia*. FAO-RAP Publication No. 38.
- Juliano, B.O.** 1996. Grain quality problems in Asia. In B.R. Champ, E. Higley & G.I. Johnson, eds. *Grain drying in Asia*, p. 15-22. Proc. International Conference, FAO Bangkok, Thailand, 17-20 Oct. 1995, Australian Centre for International Agricultural Research. Canberra, Australia, ACIAR Proc. 71.
- Juliano, B.O. (ed.).** 1985. *Rice: Chemistry and technology* (2nd ed.). St Paul, MN, American Association of Cereal Chemist.
- Juliano, B.O.** 1984. Rice starch: production, properties, and uses. In R.L. Whistler, J.N. BeMiller & E.F. Paschall, eds. *Starch: chemistry and technology* (2nd ed.), p. 507-528. Orlando, FL, USA, Academic Press.
- Juliano, B.O. & Sakurai, J.** 1985. Miscellaneous rice products. In B.O. Juliano, ed. *Rice chemistry and technology* (2nd ed.), p. 569-618. St Paul, MN, American Association of Cereal Chemist.
- Juliano, B.O. & Perez, C.M.** 1993. Critical moisture content for fissures in rough rice. *Cereal Chem.*, 70: 613-615.
- Kennedy, G., Burlingame, B. & Nguyen, N.** 2002. Nutritional contribution of rice: impact of biotechnology and biodiversity in rice consuming countries. *Proc. 20th Session of the International Rice Conference*, Thailand, Bangkok.
- Kiryama, S. & Morita, T.** 1992. Preparation of highly purified rice protein and its tumor preventive effect. *Hissu Aminosan Kenkyo*, 136: 43-447 (Japan).
- Kohlwey, D.F.** 1992. The quest for the whole grain in rice milling. *Cereal Foods World*, 37: 633-639.
- Kunze, O.R.** 1985. Effect of environment and variety on milling qualities of rice. In *Rice grain quality and marketing*, p. 37-47, Proc. International Rice Research Conference, IRRI, 1-5 June 1985. Manila, Philippines, IRRI.
- Lai, M.N., Chang, W.T.H. & Luh, B.S.** 1980. Rice vinegar fermentation. In B.S. Luh, ed. *Rice: production and utilization*, p. 690-711. Westport, CT, AVI Publishing Co.
- Nishimura, K., Kida, K., Nakagawa, M., Yahata, K. & Sonoda, Y.** 1993. Production of spirit from crushed rice by non-cooking fermentation using a benchscale plant. *Process Biochem.*, 28(3):147-153.