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MINI REVIEW

Technologies for energy use of rice straw: a review

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Rice straw is a major field-based residue that is produced in large amounts in Asia. In fact, the total amount equaling 668 t could produce theoretically 187 gallons of bioethanol if the technology were available (Kim and Dale 2004). However, an increasing proportion of this rice straw undergoes field burning. This waste of energy seems inapt, given the high fuel prices and the great demand for reducing greenhouse gas emissions as well as air pollution. As climate change is extensively recognized as a threat to development, there is growing interest in alternative uses of field-based residues for energy applications. In contrast to the use of food crops (such as maize), the use of agricultural residues as biofuel offers a potential pathway of renewable energy that avoids risks for food security.

There are primarily two types of residues from rice cultivation that have potential in terms of energy—straw and husk. Although the technology of using rice husk is well established in many Asian countries, rice straw is, as of now, rarely used as a source of renewable energy. One of the principal reasons for the preferred use of husk is its easy procurement—that is, it is available at the rice mill. In the case of rice straw, however, its collection is laborious and its availability is limited to harvest time. The logistics of collection could be improved through baling, but the necessary equipment is expensive and buying it is uneconomical for most rice farmers. Thus, technologies for energy use of straw must be especially efficient to compensate for the high costs involved in straw collection.

This review aims to give an overview of the available technologies for energy applications of rice straw, their development status, and the problems encountered in their use. It also provides an overview of rice straw quality as this property has an influence on technology efficiencies.

Rice straw quality

The chemical composition of feedstock has a major influence on the efficiency of bioenergy generation. Table 1 lists the chemical properties of rice straw, rice husk, and wheat straw to highlight the particular differences in feedstock. The low feedstock quality of rice straw is primarily determined by a high ash content (10–17%) as compared with wheat straw (around 3%) and also high silica content in ash (SiO_2 is 75% in rice and 55% in wheat) (Zevenhoven 2000). On the other hand, rice straw as feedstock has the advantage of having a relatively low total alkali content (Na_2O and K_2O typically comprise <15% of total ash), whereas wheat straw can typically have >25% alkali content in ash (Baxter et al 1996).

However, straw quality varies substantially within seasons as well as within regions. If straw is exposed to precipitation in the field, alkali and alkaline compounds are leached, improving the feedstock quality. In turn, moisture content should be <10% for combustion technology, which is the most mature technology at this point (see below). Rice husk also has poor feedstock quality, which is mainly caused by the very high silica content (Table 1), but its advantage is the uniformity in size. Thus, the preferred use of this material for bioenergy is related to both quality and availability.

Table 1. Proximate composition and selected major elements of ash in rice straw, rice husk, and wheat straw.

	Rice straw	Rice husk	Wheat straw
Proximate analysis (% dry fuel)			
Fixed carbon	15.86	16.22	17.71
Volatile matter	65.47	63.52	75.27
Ash	18.67	20.26	7.02
Total	100.00	100.00	100.00
Elemental composition of ash (%)			
SiO_2	74.67	91.42	55.32
CaO	3.01	3.21	6.14
MgO	1.75	<0.01	1.06
Na_2O	0.96	0.21	1.71
K_2O	12.30	3.71	25.60

Source: Jenkins et al (1998).

Energy technologies

The transportation of biomass is one of the key cost factors for its use as a source of renewable energy. Decentralized energy systems provide an opportunity to use biomass to meet local energy requirements—that is, heat and electricity. In contrast to straw, the use of rice husk for energy has been realized faster. One important factor is that rice mills can use the husk to serve their internal energy requirement. As an alternative, rice millers could sell the husk to a power-plant operator. The propagation of rice husk use for energy was accelerated by energy providers, who deal with a relatively small number of rice millers for supplying husk, which is an easier task than dealing with thousands of farmers supplying rice straw. As a new trend, electricity is now often produced by the millers themselves and then sold to a power grid. This setup has to be seen as the most promising option in terms of logistics and transportation energy saved.

Transportation costs of straw are a major constraint to its use as an energy source. As a rule of thumb, transportation distances beyond a 25–50-km radius (depending on local infrastructure) are uneconomical. For long distances, straw could be compressed as bales or briquettes in the field, rendering transport to the site of use a viable option. Nevertheless, the logistics of a supply chain is more complicated in the case of straw.

Although five different energy conversion technologies seem to be applicable for rice straw in principle (Fig. 1), only combustion technology is currently commercialized and the other technologies are at different stages of development.

As a general rule for energy use, each step in the chain consumes a certain amount of energy and thus reduces the net energy of the end product.

The following sections describe the principal features of the possible energy conversion technologies, experiences, and technical difficulties in the use of rice straw.

Thermal combustion

Rice straw can either be used alone or mixed with other biomass materials (the latter is called co-firing or co-combustion) in direct combustion. In this technology, combustion boilers are used in combination with steam turbines to produce electricity and heat. The energy content of rice straw is around 14 MJ kg^{-1} at a moisture content of 10% (EEF 2007). In thermal combustion, air is injected into the combustion chamber to ensure that the biomass is completely burned in the combustion chamber.

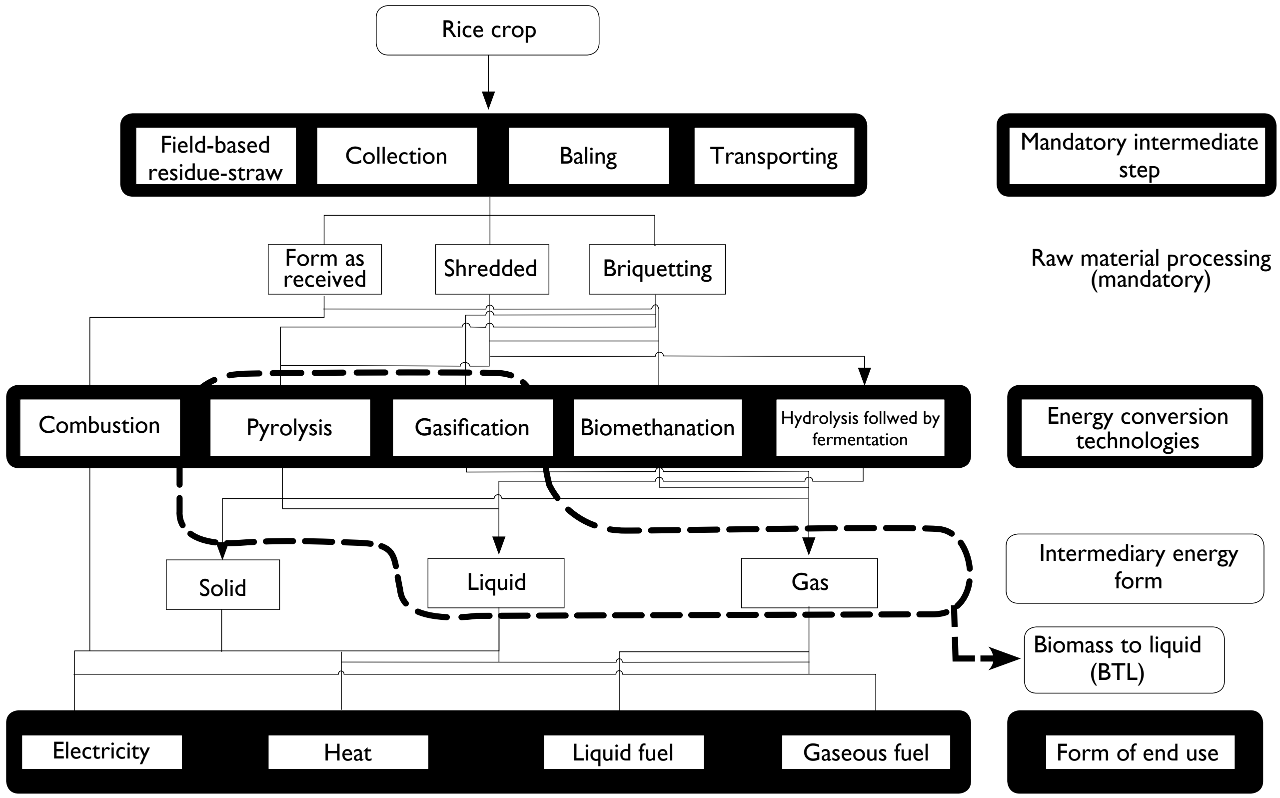

Fig. 1. Energy conversion technologies for rice straw.

Fluidized bed technology is one of the direct combustion techniques in which solid fuel is burned in suspension by forced air supply into the combustion chamber to achieve complete combustion. A proper air-to-fuel ratio is maintained and, in the absence of a sufficient air supply, boiler operation encounters various problems.

In straw combustion at high temperatures, potassium is transformed and combines with other alkali earth materials such as calcium. This in turn reacts with silicates, leading to the formation of tightly sintered structures on the grates and at the furnace wall. Alkali earths are also important in the formation of slags and deposits. This means that fuels with lower alkali content are less problematic when fired in a boiler (Jenkins et al 1998). The by-products are fly ash and bottom ash, which have an economic value and could be used in cement and/or brick manufacturing, construction of roads and embankments, etc.

Experiences with existing facilities in India, China, and Europe are described in detail in Annex 1. The following is a summary of the technical difficulties and measures adapted to overcome these constraints.

1. The alkali content of straw (both wheat and rice) is high and these compounds have the typical characteristic of melting at comparatively low temperatures and forming alkali deposits (Miles et al 1995). The measure adapted is to increase the melting point of ash through the addition of limestone. This indirectly reduces sulfur (especially SO_2) emissions as well.
2. The high alkali content of straw at high temperature results in increased corrosion and fouling problems in the superheater (Barnes 1999). Although this problem cannot be avoided completely, its adverse effects can be mitigated through controlled boiler temperature and special coating on the superheater surface. In addition, as mentioned earlier, alkali and alkaline compounds are leached when straw is exposed to precipitation in the field. This improves feedstock quality by increasing the melting temperature of ash (Jenkins et al 1998).
3. The silica content of rice straw ash is around 75%, which has a low meting point. In addition to feeding limestone onto the furnace bed, controlling the temperatures inside the boiler is essential to prevent the melting of silicon dioxide (SiO_2).

The quality of by-product may not be good if straw is co-fired in coal power plants—that is, the ash may not be suitable for cement manufacturing.

Carbonization

Carbonization is one of the thermal conversion techniques wherein charcoal (process output) is produced by heating the carbonaceous fuel under restricted air flow. But this process releases environmentally harmful emissions. A good-quality charcoal could be obtained in a kiln when its temperature is maintained around 450–500 °C. In the best case, the charcoal can have a carbon content of more than 70%, a volatile element content of 25% or lower, and ash could be around 5% (Wereko-Brobby and Hagen 1996).

Carbonization could be an alternative to open-field burning in locations where straw transport is not economical and the point of use is more than 50 km away. When rice straw undergoes carbonization, the product is char, often called biochar. This may have a lower carbon percentage when the rice straw has high ash content (10–17%). Biochar can then be incorporated into the soil to act as a soil conditioner by improving the structure and fertility of the soil as well as a carbon sink because the carbon is stabilized in the char (Lehmann 2007b). But, before doing so, the carbon emission balance needs to be estimated for the carbonization process and open-field burning to ensure how much carbon is stabilized through carbonization.

There are experiences with sugarcane trash at the field level. This is also a low-density material and, after carbonization, the powdery char is mixed with a suitable binder and shaped with the help of a mold into briquettes. The briquettes are then dried under the sun before being used as fuel (ARTI 2007). The possibility of using rice straw in a similar way cannot be ruled out as it is also a major field-based residue.

Pyrolysis

This technology is one of the thermo-chemical conversion methods by which carbonaceous fuel can be readily converted into gas, liquid, char, or a combination of these three. Pyrolysis is the process in which biomass is heated in the absence of air to around 500 °C. The rate of change in process temperature and process duration guides the composition of gas and char that could be varied. The slow pyrolysis enhances char production, which is a transfer to the stable form of carbon, and the higher concentration of lignin increases carbon recovery (Lehmann 2007a). In this regard, rice straw is a potential feedstock as its lignin content is 22.3% (hemicellulose—35.7%, cellulose—32.0%, and extractive matter—10%) (Worasuwannarak et al 2007). Fast pyrolysis is practiced to enhance liquid production (i.e., bio-oil). The by-products of the pyrolysis process (liquid and gas) are used to meet the energy requirements of the process or eventually to produce surplus energy. From that perspective, even char could be used as a fuel. The pyrolysis process needs an external heating source—it could be the gases evolved during the process itself. Use of the gases that evolved during pyrolysis improves the energy balance as well as the carbon balance, but this analysis has never been reported recently for the feedstock under consideration. This technology is still in an R&D phase.

Experimental results show that pyrolysis temperature and atmosphere have an influence on bio-oil yield and composition, for which particle size has a minor influence on product yields (Putun et al 2004). The optimal conditions for maximizing bio-oil yield are a maximum temperature of 550 °C with a heating rate of 5 °C min^{-1} and particle size between 0.850 mm and 8.425 mm. Use of an inert gas as sweeping gas atmosphere increases bio-oil yield significantly, whereas the yield of char and gas reduces it (Calvo et al 2004). Worasuwannarak et al (2007) observed a difference in gas formation during pyrolysis of different types of biomass and this was attributed to the composition of hemicellulose, cellulose, and lignin. The large amount of water production during pyrolysis of rice straw was thought to be caused by its high hemicellulose content (Worasuwannarak et al 2007).

A different approach was followed by Antonietti (2006) in the production of biochar. Biomass and water were placed in a pressure container and a catalyst was added. This mixture is heated up to 180 °C in the absence of air. After 12 h, the mixture was allowed to cool. The output is a black powder consisting of coal nanospheres (Antonietti 2006). It is too early to comment on this technology as it is currently in the R&D stage. In addition, there has to be an analysis of the energy and carbon balance for this process.

Many data are not available with regard to preprocessing required for rice straw pyrolysis. However, being a low-density material, rice straw needs briquetting if the product of pyrolysis is char.

Gasification
Gasification is a thermo-chemical conversion method, in which solid biomass is directly converted into gas. It requires high temperatures (about 700 °C) with a controlled amount of air or oxygen to a gaseous mixture, which is called synthesis gas or syngas. Rice straw could be used directly in a gasifier along with other biomass materials to produce syngas. Syngas could be used in an internal combustion (IC) engine to produce electricity or in a combined heat and power (CHP) plant to produce electricity as well as heat. Although the experiments so far were performed with wheat straw (which has low ash content), a similar behavior is expected in the case of rice straw. In Thailand, rice husk is being used successfully in a fluidized bed gasifier and after gas cleanup is fed to the IC engines. However, problems persist due to tar content in the cleaned syngas.

To overcome the technical difficulties in the energy use of wheat straw, the Technical University of Denmark (DTU), along with other partners, identified a new method to gasify straw in a low-temperature circulating fluidized bed (LT-CFB) gasifier and the produced gas is fed into direct combustion boilers (DEA 2003, Stoholm et al 1999). Another technique tested in the 1990s at DTU used a 50-kW system combined with an initial step of straw pyrolysis. The char and volatile pyrolysis products passed to the top of a gasifier for combustion. This technique tremendously reduced the tar content of syngas (nearly tar-free gas) (Henriksen and Christensen 1994). This new gasification technique could provide an opportunity for the efficient use of difficult biomass materials such as rice straw.

To summarize the technology experiences with wheat straw in Europe, problems similar to those seen in combustion are likewise observed in gasification, especially the formation of alkali deposits and ash melting. Measures to overcome the technical hurdle could be either softened and melted ashes can be handled or the maximum temperature in the gasifier can be kept below the softening point of ash (Henriksen and Christensen 1994).

In addition, other approaches exist combining gasification and production of liquid fuels using, for example, Fisher-Tropsch synthesis. This process is called biomass to liquid (BtL).

Biomethanation
This is a bio-conversion technique wherein rice straw could be used alone or mixed with municipal/industrial solid waste or liquid waste (biodegradable) and fed into bioreactors. When mixed with other biodegradable material, the straw acts as a buffer to control pH as well as degradation of cellulose material, which leads to the production of biogas. Biogas could be used directly in IC engines or CHP systems to produce electricity and heat. Since 2003-04, the Sardar Patel Renewable Energy Research Institute (SPRERI) has been conducting research on a 100 kg d^{-1} rice straw-based biomethanation system in both mesophilic and thermophilic digestion. Biogas yield is higher in thermophilic digestion than in mesophilic digestion, around 340 L kg^{-1} of total solids (SPRERI 2006). The biogas yield achieved in mesophilic digestion is around 233 L kg^{-1} of dry matter added (biogas calorific value is 6–6.5 kWh m^{-3}) at a C-N ratio of 30:1 with maximum volatile solid degradation of around 56% (Bardiya and Gaur 1997).

A consistent feed of biomass is expected in the digester every day to maintain steady microbial activity. In addition, pH and temperature need to be controlled for effective microbial activity. As rice straw is usually a dry resource and would contain only limited digestible substances (very high C-N ratio, could vary up to 75% [Zhu 2007]), it alone is a bad substrate.

As the technology is in the R&D stage, data pertaining to possible commercial capacity and its economics are not available.

Hydrolysis followed by fermentation
In California, several companies work on the biological conversion of rice straw (lignocellulosic material) to ethanol. The Colusa Biomass Energy Corporation (CBEC) is one such company working toward an integrated bio-refinery concept, which could produce approximately 143,000 L of ethanol daily. This process is now patented. The rice straw is hydrolyzed first using enzymes (some would adopt acid or base); it is then fermented to produce ethanol (CBEC 2007).

In this process, good yields of ethanol are known to be produced (303–379 L t^{-1} of rice straw). The ash and silica are co-products for which commercial markets are being evaluated (Schuetzle 2006). As per Karimi et al (2006), 1 kg of rice straw will contain 390 g of cellulose. This amount of cellulose is theoretically enough to produce 220 g or 283 mL of ethanol. However, considering the practically achievable best yield as 74%, it could produce 208 mL of ethanol from a cellulose content of 1 kg of rice straw (Karimi et al 2006). Honda, a leading car manufacturer, envisions that the future generation of cars would run on leaves and rice straw (MarketWatch 2006). Many research institutions and organizations are working on this technology across the world (Schuetzle 2006, Anonymous, no date).

Still, the challenge is for cost-effective pretreatment of rice straw. This pretreatment requires shredding, steam explosion, and enzyme treatment of rice straw. Nevertheless, much information is not known in the public domain as most of the processes developed are patented.

Summary of energy technologies for rice straw

The results of the evaluation of technologies are summarized in Table 2, with different parameters indicated. The main findings are as follows:

- Combustion technology is well established and power plants in the range of 5–12 MW are possible in decentralized locations where the density of rice straw produced is high. Although there are system capacities up to 24 MW, fuel security would be an issue.
- In very remote locations where transporting rice straw over longer distances is quite challenging, farmers could adopt a technique that is easier to be practiced in the field. In this regard, carbonization seems a viable solution. However, a carbon emission balance analysis needs to be done in comparison with open-field burning of rice straw and other possible options, if there are any.
- Although gasification of rice husk is proven, the problems associated with the tar content in syngas and ash melting are unavoidable. Hence, a combination of pyrolysis, followed by gasification, seems to work better for rice straw. However, further research on the use of rice straw in pyrolysis and gasification is needed.
- Because of the low energy density of biomethanation technology as well as the low bulk density of rice straw, thermophilic digestion has an advantage over mesophilic digestion. However, this technology is still in the R&D phase.
- Although the demand for liquid fuel is high and extensive research is now under way in the conversion of lignocellulosic material to liquid fuel, the challenge is still achieving cost-effective pretreatment of rice straw for ethanol production.

Conclusions

It is possible to use rice straw for energy applications, although technical difficulties exist in using rice straw for direct combustion technology. Nevertheless, these could be overcome through additional measures. Still, the challenge is in the sourcing of rice straw required for continued plant operation—that is, logistical aspects. Thus, co-combustion has a better opportunity for the use of rice straw. The biomethanation technology is still in the R&D phase and economic aspects are not yet known. The lasting application of rice straw use for energy could never be successful unless logistics are worked out well. Otherwise, theoretical estimates on energy production would remain a dream.

The pragmatic approach would be to develop application-specific technology solutions, such as, if a surplus quantity of rice straw exists in a given area within a 25–50-km radius, direct combustion, provided the rice straw is baled in the field before transport. There are successful examples in a few Asian countries where baling of rice straw is practiced to transport rice straw for other applications. Or, a technology such as carbonization could be implemented at a small scale. There is a need for thorough research to evaluate whether applying biochar or charcoal onto the soil is more beneficial than using it as energy sources. As biochar or charcoal would have an energy content of about 30 MJ kg^{-1}, further analysis of the energy and carbon balance is required. From combustion technology, it is apparent that there are additional operation (collection and transportation) and maintenance (addition of lime, running at lower efficiency) costs involved. Hence, governments should provide continuous support, through policies for successful demonstration and financial incentives to cover the risks, when rice straw is used for energy applications.

By having these measures in place, governments could convince farmers not to burn rice straw and enforce environmental regulations on open-field residue burning.

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Table 2. Summary of technologies.

Parameter	Technologies				
	Thermal combustion	Pyrolysis (fast and slow)	Gasification	Biomethanation	Hydrolysis followed by fermentation
Form of energy output	Electricity	Bio-oil or and/or heat	Syngas charcoal	Biogas	Ethanol
Mode of operation	Centralized	Decentralized and decentralized	Decentralized	Decentralized	Centralized
Applications	Large and commercialized, connected to electricity grid	Small-scale production of charcoal	Energy needs of a small Indus-try or a few hundred houses	Energy needs of less than 100 houses	Replacement of fossil fuel such as petrol and diesel for automobile
Stage of develop-ment	Commercial-ized	R&D	R&D	Being practiced at a small scale	Beginning phase; R&D
Capacity of out-put range of ex-isting systems	Up to 10 MW	Few liters of liquid or kg of solid fuel	Up to 1 MW	Few kW range	Tons or liters of liquid
Processing of rice straw as feedstock	Baling	For charcoal-briquetting; for bio-oil–pulverizing or grinding	Should be briquetted	As received	Basic preparation—perhaps shredding
Overall effi-ciency of the system	Around 20%	Not yet known	Around 20–25%	Not yet known	Not yet known
Straw consump-tion	1.4 kg kWh^{-1}	Not yet known	1.1–1.5 kg kWh^{-1}	Few kg at a cer-tain rate on a daily basis	Not yet known
Operation and maintenance cost	Competing with current price	Moderate	Moderate to high	Competing with current price	Very high
Levelized cost a (€cents/kWhel)—2010	11–13 (SE–cogen.)	Moderate	Moderate	8 (biowaste–IC engine 500 kW)	Very high
Jobs created * (persons/TWh_{el})	370–390	Not yet known	Not yet known	522	Not yet known
Net savings in terms of GHGeq	Very high	Moderate	Above moderate	Low	Very high

[a]Fritsche UR. 2005. Öko-Institut (Institute for Applied Ecology), Darmstadt Office, applicable wherever values are mentioned.

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Annex 1. Experiences with existing facilities

Development status and lessons from existing facilities in India

A 10-MW power plant, which used rice straw as fuel, was constructed at Jalkheri village in Punjab State by the Punjab State Electricity Board (PSEB) in 1992. This was the first plant of its kind using "fluidized bed" technology (the boiler was supplied by Bharat Heavy Electricals Limited) for firing rice straw. Rice straw bales were dropped into the fluidized bed combustion chamber, which weighs around 15–18 kg, and this created difficulties in fluidization in the boiler. Rice straw ash has a very low melting point, and this requires maintaining the boiler temperature below the ash melting temperature. The ash, composed of sodium, potassium, magnesium, and silica, has created innumerable problems such as ash melting, slagging, superheater choking, and clinker formation. The inconsistency in boiler temperature was due to the moisture in the bales. Initially, the plant was operated for only 15 d continuously and then it was shut down.

Later, some of these problems were overcome through the addition of limestone into a free board, just above the boiler bed level (Muthukrishnan et al 1995), as well as by sheltering the fuel required for a few days of operation. Despite this, the plant could not be operated on a sustained basis because of fuel insecurity. The plant was shut down for 8 years before it was brought back into operation in 2002. Again, during this period, fuel security was a major issue on top of problems with the conveyor system. In 2004, investment was made to set up a new feeding system capable of feeding various biomass fuels.

The experience drawn from this plant indicates that rice straw alone could be used in the combustion (5–12 MW range), but it has many operational problems. The Ministry of New and Renewable Energy, Government of India, has given the go signal for the implementation of rice straw–based power plants. Nine plants (12 MW each) in Punjab and eight (12 MW each) in Haryana totaled 204 MWel (Anonymous 2006). The first plant at Ghannur, Punjab, is expected to be operational by October 2008, which could use other biomass fuels as well. But the primary focus is the use of rice straw.

Development status in China

Six power projects are being implemented in Jiangsu Province, China. One project has started operation, supplying electricity to the East China Power Grid (JGRBG 2007).

The Zhongjieneng Suqian (2 × 12 MW) biomass power project located in the southeastern part of Suqian City, northwest of Jiangsu Province, has been operational since March 2007. This plant uses wheat and rice residues generated in the vicinity of Suqian City. The total amount of biomass residue generated in this region is around 1,690,000 t annually within the 25-km radial distance from the plant site. A maximum of 195,000 t of biomass will be used in the power plant. The Zhongjieneng Jurong (2 × 12 MW) biomass power project is located near Daijia village, Huayang town, Jurong City in southern Jiangsu. These two plants are equipped with a circulating fluidized bed (CFB) boiler. They are designed to handle various types of biomass resources. At least 50–60% of the biomass expected to be used in these plants is rice straw.

The Jiangsu Rudong Biomass Power Generation Project (25 MW) is now under way in Rudong County, Jiangsu Province. This plant will source the available straw (mainly rice straw, wheat straw, and maize straw) within a 50-km radius of the power plant site and the maximum straw consumption is approximately 150,000 t per year (about 60% of this is rice straw). The project is expected to be operational in March 2008. The straw-fired power plant consists of one 110 t h^{-1} high-temperature, high-pressure, straw-fired boiler (the boiler was supplied by Wuxi Huaguang Boiler Co., Ltd.) and one 25-MW generator unit. Other projects are under way at three locations: Sheyang (25 MW), Donghai (2 × 12 MW), and Huaian (2 × 15 MW) (JGRBG 2007).

All these projects are in Jiangsu and care has been taken toward fuel security and collection and transportation to the project site or closest collection point. Safety standards have been tightened at storage sites as straw could catch fire easily. It is assumed that collection and transportation charges will increase every year because of increasing labor and transport costs.

Lessons from existing facilities in Europe with wheat straw

Denmark has played a pioneering role in the co-combustion of biomass (especially wheat straw) since the 1970s. Denmark has 75 straw-fired plants and about 11 of these are combined heat and power (CHP) plants (IEA/OECD 2002) wherein wheat straw alone is used or co-combusted. As the name implies, a CHP plant generates heat as well as electricity. As of 2000, Denmark, Sweden, and the United Kingdom were the only countries using straw in total primary energy consumption (Alakangas and Vesterinen 2003). However, several countries in Europe are using straw for decentralized heating applications.

In Denmark, the companies MidtKraft and ELSAMPROJEKT have worked on the co-combustion of coal and wheat straw in CFB boilers since 1988 with pilot combustion tests. The technical difficulties are similar to those observed in the Indian plants. Additional problems were derived from seasonal differences in the composition of straw due to its exposure to precipitation (Rasmussen and Clausen 1994). However, over a decade of extensive research, the average efficiency of a straw-fired steam turbine plant has been raised from 20–25% to 25–32% in small plants, whereas the more advanced and larger power plants can now reach efficiencies of 42–50% (DEA 2003). One example of a district heating system in Denmark is the Sydlangeland district heating plant, which was built in 1993. This system produces approximately 30,000 MWh of heat a year and is equipped with two boilers—a 5-MW straw-fired boiler and a 6-MW oil-fired boiler.

Occurrence and distribution of the invasive rice black bugs *Scotinophara* spp. (Hemiptera: Pentatomidae) in the Philippines

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Rice (*Oryza sativa* L.) is the staple diet of almost two-thirds of the world's human population and food to 1,400 species of rice-feeding invertebrates (Walker 1962, Barrion and Litsinger 1987). Of the rice-feeding invertebrates, 25 species are putative major and minor pests of rice in tropical Asia. Among the putative pests, the highly cryptic and invasive rice black bugs (RBB) of the genus *Scotinophara* Stål, 1867 (Pentatomidae: Podopinae) are emerging insect pests in irrigated and rainfed wetland rice fields in the Philippines. Upland rice is also prone to RBB infestation as observed recently in Landang, Datu, and Montawal in Maguindanao Province in April 2006 (AT Barrion, pers. obs.). Damage caused by the sap-feeding RBB is similar to that caused by rice stem borers—i.e., deadheart and whitehead are observed in the vegetative and reproductive growth stage, respectively (Barrion and Litsinger 1987). As a cryptic organism, limited information was known about RBB in the past (Gabriel 1975); previous damage attributed to stem borer may have been due to RBB. These pentatomid bugs are also potential vectors of plant diseases as damaged plants become stunted and leaf-feeding sites turn yellowish to dark brown, resembling a blast lesion (Lim 1975).

Based on labeled specimens loaned from different museums locally and abroad, RBB have been in the Philippines since the early 1900s. *Scotinophara serrata* was the first RBB reported in Palawan Island, Philippines (Banks 1909), followed by the collection of *S. tarsalis* (Vollenhoven) in Los Baños, Laguna. About four decades ago, six additional unidentified specimens belonging to three species [= to *S. serrata*, *S. latiuscula* Breddin, and *Scotinophara cinerea* (Le Guillou)] were collected in the vicinity of Manila in 1948 by an agricultural entomologist of the Bureau of Plant Industry. By 1983, six species had already been recorded in the Philippines (Miyamoto et al 1983). All but *S. coarctata* (Fabricius) and *S. latiuscula* Breddin damaged rice plants in the Philippines (Barrion and Litsinger 1987).

Scotinophara coarctata, the most destructive and highly invasive species based on recorded outbreaks and migration patterns in Palawan Island, was reported to have invaded the islands of Mindanao, Negros, Panay, Bohol, Siquijor, Leyte, and Samar between 1992 and 2003 (PhilRice 2006). In November and December 2005, RBB were found in Sorsogon Province located at the southern tip of Luzon Island, particularly in the municipalities of Bulan, Matnog, and Gubat. Several outbreaks were reported thereafter and, by August 2006, RBB were all over in the nearby provinces of Bicol Region, except in Camarines Norte. At almost the same time, in July 2006, the RBB scared agriculture officers of Nueva Ecija and Bulacan, two major rice-producing provinces in Central Luzon, Philippines, as RBB were seen here for the first time. Farmers again used insecticides to kill the pest. In all instances, the highly invasive and cryptic pest was referred to as *S. coarctata*.

Because of the confused state of taxonomy of the RBB cryptic species complex, we have doubted earlier reports that only *S. coarctata* is the invasive pest species. To shed light on the problem, we hypothesized that RBB *S. coarctata* migrated from Palawan Island and established founding populations in the islands of Mindanao, Negros, Panay, Bohol, Leyte, and Luzon. Migration was believed to have been facilitated by the attraction of RBB to the strong 1,000-watt light bulbs used by fishermen in their boats. Upon docking in the respective ports, primarily to sell a fish catch, RBB were left at the dock sites. These black bugs either died at the new sites for lack of food or survived by moving into irrigated and rainfed rice areas that were commonly located 300–500 m away from the sea shores.

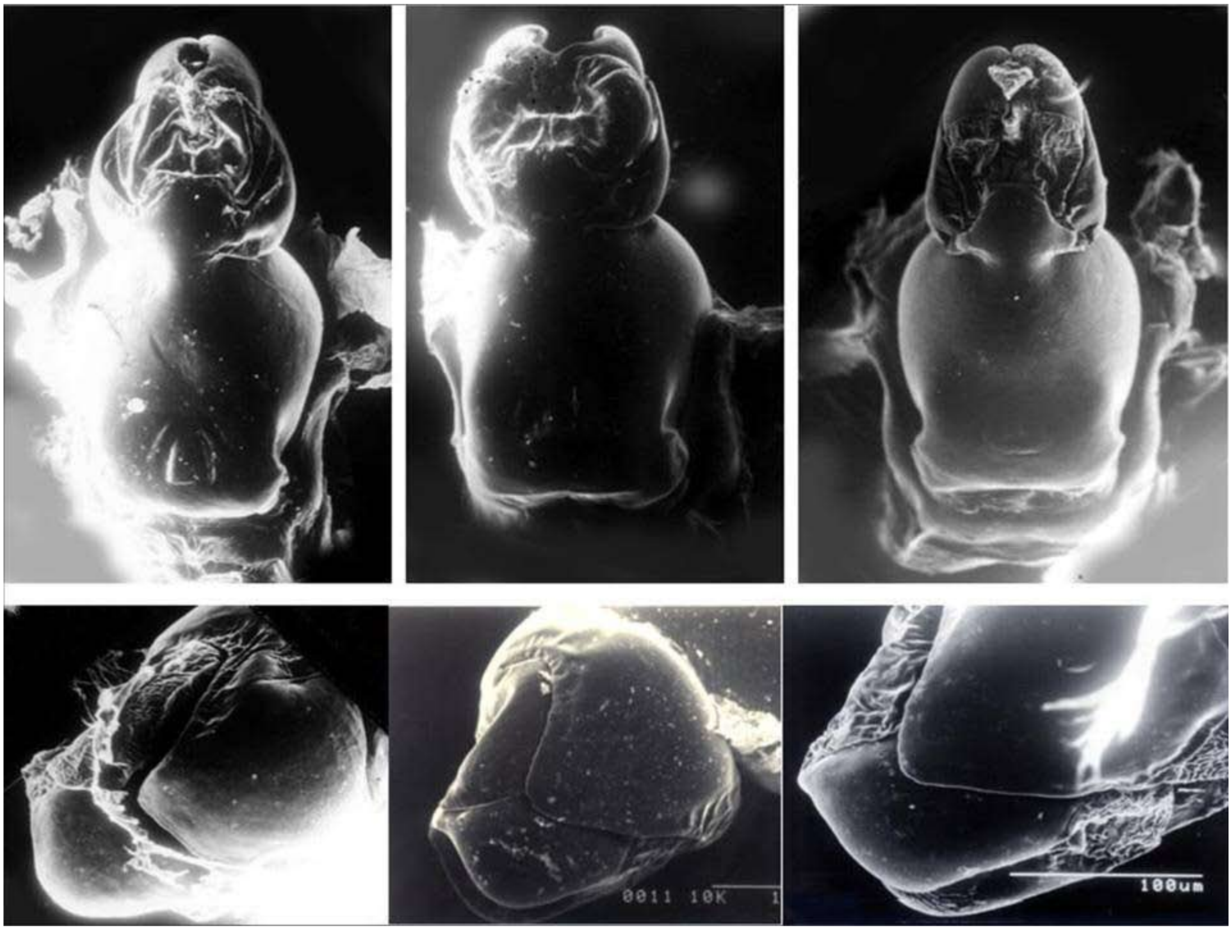

Fig. 1. Dorsal (top row) and lateral (bottom row) views of aedeagus of RBB from Palawan, Iloilo, and Sorsogon (left to right).

To validate our hypothesis, we collected RBB from six big islands representing 20 provinces in 2006 and borrowed Philippine RBB specimens from local and international museums representing 13 additional provinces within the same year (Table 1). All collected and loaned materials were taxonomically treated and compared with *S. coarctata* from Palawan previously identified by Professor S. Miyamoto from Japan. In conjunction with the hypothesis that RBB migrated through fishing vessels, we interviewed 22 fishermen with more than 10 years of fishing experience and inspected their vessels for remnants of RBB. These fishermen were regularly plying the sea routes from Palawan to Zamboanga City (n=12), Palawan-Negros Island (n=6), and Palawan-Panay Island (n=4). A 10-point structured questionnaire was developed to elicit from the fishermen what they knew about RBB movement through their boats (Table 2).

We also monitored farmers' irrigated rice fields between 55 and 95 days after transplanting. We also checked the stubbles left after harvest to determine the population density of RBB. The sample size used was 25 randomly selected hills per field in each of the irrigated rice fields and stubbles. The number of RBB (egg masses, number of eggs per egg mass, nymphs and nymphal stages, and adults) was counted and recorded. The data gathered will be used to advise farmers on how to manage RBB effectively.

Our findings showed that *S. coarctata* (Fabricius) was present only in Palawan Island and has not yet been found in other islands, contrary to earlier reports of bug invasion in irrigated rice fields in Mindanao, Negros, Panay, Leyte, Bohol, and Luzon. Based on more than 2,500 specimens examined, the Philippines has 24 species of RBB belonging to four groups: *tarsalis* (one species), *serrata* (two species), *lurida* (five species), and *coarctata* (16 species). Different species were present in these six islands, most of which, however, belong to the *coarctata* group (Table 1). *S. serrata*, *S. latiuscula*, and all members of the *coarctata* group were collected from rice fields. The rest were collected from light traps.

Population density of RBB based on a sample size of 25 hills

Table 1. Incidence of rice black bugs in the Philippines with notes on their date of occurrence, distribution, and population density in the field.

Site (island/province)	Date of collection (Mo/year)	Source of specimens[a]	Fields examined (no.)	RBB 25 hills^{-1} (no.)		RBB hill^{-1} (no.) (R + S)	*Scotinophara* species identified
				Rice	Stubbles		
LUZON							
Albay	Feb 2006	FC	82	64	580	0.30	Species A
Camarines Sur	Apr 1965	LM					*S. tarsalis*
	Jul 1973	LM					Species B
	Nov 2006	FC	60	0	514	0.34	Species A
Sorsogon	Feb 2006	FC	102	186	1,014	0.50	Species A
Laguna	Apr b 1909,						
	Oct 1976	LM					*S. tarsalis*
	Oct 1948, Jul 1953-54,						
	Jun and Sep 1956,						
	Jun 1959, Nov 1981-82	LM					*S. latiuscula*
	Oct 1971, May 1972	LM					Species C
							Species D
Manila	Aug 1948	LM					*S. cinerea*
							S. latiuscula
							S. serrata
Nueva Ecija	Jul 2006	LT	20	0	0	0	*S. latiuscula*
Nueva Vizcaya	Apr 1972	LM					Species B
Tarlac	Apr 1972	LM					Species B
Pangasinan	Jun 1953	LM					*S. latiuscula*
Ilocos Sur	May 1972	LM					Species D
Kalinga	Apr 1972	LM					Species D
Mt. Province	Jun 1951, May 1964	LM					Species E
PALAWAN							
Palawan	Aprb 1909	LM					*S. serrata*
	Feb 1982, Mar 1985	LM					*S. coarctata*
PANAY							
Capiz	Jun 1951	LM					*S. latiuscula*
Iloilo	May 2006	FC					Species F
Roxas	May 1951	LM					*S. latiuscula*
NEGROS							
Negros Occidental	Nov 1998,	LM,					Species G
	Aug 2006	FC	16	0	0	0	
LEYTE							
Leyte	Apr 1952	LM					*S. serrata*
MINDANAO							
Agusan del Sur	Nov 1959,	LM,					*S. tarsalis*
	Apr 2006	FC	50	26	348	0.38	Species H
Agusan del Norte	Sep 2006,	FC	1				*S. tarsalis*
	Apr 2006	FC,	28	0	24	0.03	Species H
Davao del Sur	Aprb 1909	LM					*S. tarsalis*
Lanao del Norte	Jan 2007	FC	6	568	34	5.05	Species M
Maguindanao	Apr 2006	FC	18	0	64	0.14	Species K and L
North Cotabato	Nov 1997						
	Apr 2006	LM					Species N
		FC	34	0	340	040	Species O
South Cotabato	Apr 2006	FC	28	5	176	0.26	Species P and Q
Sultan Kudarat	Apr 2006	FC	16	0	28	0.10	Species Q
Surigao	Aprb 1909		LM				
S.tarsalis							
Surigao del Norte	Apr 2006	FC	10	0	21	0.10	Species R
Surigao del Sur	Apr 2006	FC	10	12	86	0.40	Species R
Zamboanga del Norte	Nov 1959	LM					S .tarsalis
	Oct 1959	LM					Species S
	Nov-Dec 2006	LM					Species M
Zamboanga del Sur	Jan 2007	FC	15	106	944	2.8	Species M

[a]FC = field collected; LM = loaned materials; LT = light trap. [b]Not sure of exact month.

Table 2. A 10-point structured questionnaire used in the fishermen's interview.[a]

Question	Response (%)		
	Palawan-Negros (n=6)	Palawan-Panay (n=4)	Palawan-Zamboanga City (n=12)
1. Kind of job			
1.1 Fisherman	50	100	75
1.2 Farmer	50		16.7
1.3 Construction worker			8.3
2. Fishing experience			
2.1 10-15 years	16.7	25	16.7
2.2 16-20 years	16.7	25	16.7
2.3 > 21 years	66.6	50	66.6
3. Do they know the insects?	Yes [100]	Yes [100]	Yes [100]
3.1 Are insects good or bad?	Bad [100]	Yes [75]: bad [25]	Bad [100]
3.1.1 Nuisance	Yes [100]	Yes [100]	Yes [75]: Ni [25]
3.1.2 Bite	Yes [33]: Ni [67]	Yes [100]	Yes[100]
3.1.3 Damage crops	Ni	Ni [100]	Yes[25]: Ni [75]
3.2 Have seen mosquitoes?	Yes [100]	Yes [100]	Yes [100]
3.3 Have seen flies?	No [100]	Yes [100]	Yes [100]
3.4 Have seen ants?	Yes [100]	Yes [100]	Yes [100]
3.5 Have seen termites?	Yes [100]	Yes [75]: No [25]	Yes [100]
3.6 Have seen beetles?	No [100]	Yes[50]:Ni [50]	Yes [100]
3.7 Have seen RBB?	Yes [100]	Yes [25]: No [75]	Yes [8]: No [92]
4. Have seen RBB?	No [67]: Ni [33]	Ni [100]	No [100]
4.1. Smell	Pungent	Ni [100]	Ni [83]: Bad [17]
4.2 Size	Small	Small and slender [25]; Ni [75]	Small [8]: Ni [92]
4.3. Color	Blue [67]: black[33]	*	Blue [33.3]: Brown [16.7] Red [16.7] Ni [33.3]
5. Have experienced 3.1–3.6 swarms to light of fishing vessels?	All have experienced termite swarms.	All have experienced swarms of winged ants and green mosquitoes.	All have experienced swarms of brown-winged ants and mosqui toes.
6. Among 3.1–3.6, which of them swarm to lights?	Termites	Termites and green mosquitoes	Termites and mosquitoes
7. What do they do if there are insect swarms?	No action	No action	Put mask on their face
8. Upon docking, do fishermen clean the vessels?	All clean their vessels	All clean their vessels	All clean their vessels
9. Do they report incidence(s) of swarm to DA, BPI, QO for possible control?	All do not care	All do not care	All do not care
10. How far from the nearest land area do swarms get in?			
10.1 6–10 km			
10.2 > 11 km	Yes [100]	Yes [100]	Yes [50]: Ni [50]
		Yes [100]	Yes [100]

[a]Ni = no idea; * = no response.

per field was very low. Across all fields, the range was 0–5.02 bugs per hill (Table 1). Moreover, there is no reason for alarm as majority of the RBB were in the old and newly harvested and abandoned stubbles. A do-nothing approach at this time is recommended, which is safer and more economical than the farmers' practice of spraying hazardous insecticides to control RBB. The best practice, however, is to cut the stubbles at ground level to remove the bugs' breeding habitats or to flood the field if water is available. This practice is necessary to remove the RBB's potential breeding grounds—the abandoned decaying stubbles capable of producing thousands of second-generation populations that swarm to light traps during full moon.

Fishermen interviews revealed that they have knowledge about some species of insects, particularly ants and mosquitoes, as they are always exposed to insect bites. The fishermen have commonly experienced swarms of winged termites (order Isoptera) and chironomids (order Diptera) attracted to lights on their boats, but not RBB, even at distances more than 10 km away from the shore. Similarly, fishermen mistakenly called chironomid flies green mosquitoes. Our findings from the interview showed that RBB may not have been transported by fishing vessels at all. Otherwise, a fisherman could have recognized the RBB that are attracted to street lights by the thousands in the villages. More so, the taxonomic investigation could have indicated the presence of *S. coarctata* in the other islands.

The taxonomic investigation supported the results of fishermen interviews—that RBB have not been transported by fishing vessels at present. *S. coarctata* appears to be endemic in Palawan and other species exist in other islands. The discovery of 24 taxa of *Scotinophara* in the Philippines only reflects its diversity of occurrence and distribution in the different islands. To date, only two species of *Scotinophara* (*coarctata* and *latiuscula*) were found to be feeding on the rice plant.

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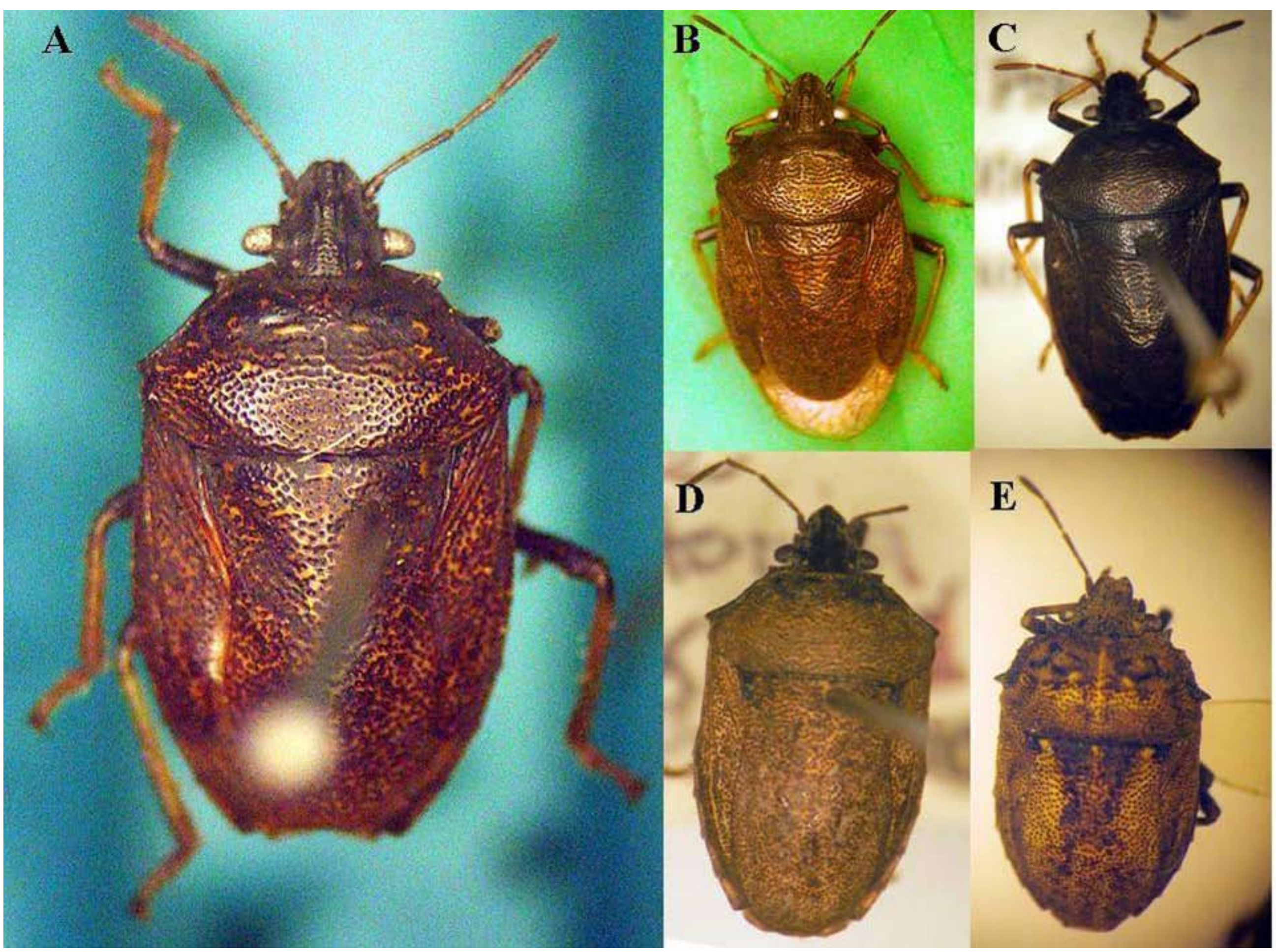

Fig. 2. General appearance of RBB species from Palawan (A), Iloilo (B), Sorsogon (C), and Laguna (D and E).

us access to their RBB museum collections. We thank the International Rice Research Institute, Philippines, and BIOTECH, University of the Philippines Los Baños, for allowing ATB the use of their equipment and other facilities.

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Rice domestication decreases tolerance for yellow stem borer *Scirpophaga incertulas*

Y.H. Chen and A. Romena

The yellow stem borer *Scirpophaga incertulas* (Lepidoptera: Pyralidae) is an important pest of irrigated rice in Asia because it attacks all stages of the crop (Bandong and Litsinger 2005). Yield loss due to *S. incertulas* has been estimated to range from 5% to 10% (Elazegui et al 1993, Pathak and Khan 1994, Islam and Karim 1997), but it can be as high as 20% in certain regions and on particular varieties (Catling et al 1987, Islam 1990). Larval tunneling during the vegetative stage results in "deadhearts," while feeding during the reproductive stage results in "whiteheads" or dried and unfilled panicles. Whiteheads, not deadhearts, are the major cause of yield loss (Catling et al 1987, Viajante and Heinrichs 1987, Taylor 1988, Bandong and Litsinger 2005). *Scirpophaga incertulas* is difficult to control because larval tunneling reduces the number of pest management options. Standard plant resistance screening measures at IRRI have focused on plant tolerance, which is a plant's ability to withstand pest damage while supporting the same levels of pest abundance that would damage a susceptible plant. Despite extensive screening for stem borer resistance, no accessions have been found with tolerance during the reproductive stage (Heinrichs 1988), the period when larval damage most severely affects yield (Bandong and Litsinger 2005).

Wild relatives of agricultural crops are a promising source of resistance because of their long coevolutionary history with insect herbivores and because they retain traits that were lost during the domestication process (Chen and Welter 2005). *Oryza sativa* is clearly less genetically diverse than its wild progenitor *O. rufipogon* (Dally and Second 1990, Sano and Sano 1990, Sun et al 2001). There is also some evidence that *O. rufipogon* is more tolerant of stem borers. In a common garden study, *S. incertulas* densities were lower in plots of *O. rufipogon* than in cultivated rice (Y. Chen, unpubl. data). *Oryza* spp. have been found to be tolerant of stem borers during the vegetative stage (Zaheruddeen and Prakasa Rao 1983, Romena and Heinrichs 1989, Romena et al 1989, Padhi and Sen 2002), so there may be tolerance during the reproductive stage.

The standard screening test for *S. incertulas* tolerance does not differentiate between the vegetative and reproductive stage (Heinrichs et al 1985). Athough standard screening tests are adequate for estimating deadhearts during the vegetative phase, the considerable phenological variation among accessions during the reproductive phase can inflate the screening error. Tiller phenology strongly influences larval feeding location and the likelihood of whitehead or deadheart damage. Stem borer larvae are more likely to attack booting reproductive tillers than vegetative tillers, but ripening tillers are no longer vulnerable to damage (Chen and Romena 2006). Therefore, tolerance scores are inflated if larvae are introduced onto plants too early or too late. Traits associated with tolerance such as stem toughness and silica content are not effective during the reproductive stage because the larvae crawl in between the panicle leaf sheaths to reach the panicle (Chen and Romena 2006). Therefore, plant phenology should be closely monitored when screening for stem borer tolerance during the reproductive stage.

In this study, we use a new screening technique to assess tolerance during the reproductive stage. Although it is considerably more labor intensive, it strongly improves data quality. We use these new methods to (1) determine whether crop domestication has reduced tolerance for *S. incertulas*, (2) determine whether there is variation in tolerance for *S. incertulas* during the reproductive stage, and (3) identify tolerant accessions.

Twenty-one wild accessions and 16 accessions of cultivated rice seeds were requested from the Genetic Resources Center at IRRI (Table 1). Some of the test accessions were chosen because they were previously reported to be tolerant during the reproductive stage (Khan et al 1991). The rice was planted in September because a short daylength was needed to stimulate reproduction of the wild rice. The seeds were sown directly in a seedbox with fine soil. At 15 d, seedlings were transplanted into a concrete bed in a screenhouse at IRRI, Los Baños, Philippines. Groups of 10 plants from each accession were grown 40 cm apart in a randomized block design. We did not detect a significant block effect, so each accession could be considered to be replicated over 30 plants. Fertilizer was applied at 60 kg N ha^{-1} 1 wk after transplanting. We rescreened nine accessions of wild rice in 2 consecutive years to assess the reliability of our screening process.

At 45 d after seeding, we started monitoring the plants for panicle development, especially the early-maturing and photoperiod-sensitive varieties. When the panicle was about 1 mm in length, we estimated that it would take 23–25 d until heading because it takes about 30 d from the start of panicle initiation to heading (Yoshida 1981). Plants were infested with larvae when at least 60% of the tillers were booting. Moths were collected every few days for 2 wk after panicle initiation to ensure that larval infestation was timed properly. Using a fine camel-hair brush, we placed three first-instar larvae on each tiller of the booting plants. An alternative method would be to introduce a fixed cohort on each plant, and then count the total number of damaged tillers (K.L. Heong, pers. commun.). This would be in line with the definition of plant tolerance, which is to compare damage between plants carrying the same herbivore load. However, because the number of tillers varies widely between cultivated and wild rice accessions, we standardized the number of larvae per stem, resulting in a higher herbivore load on the wild plants. This should be considered when evaluating damage across accessions. All plants were harvested 15 d after infestation and stored at 10 °C until they were dissected.

During dissection, we counted the number of tillers and classified the phenological stage of each tiller (tillering, panicle initiation, booting, heading, flowering, milking, hard dough, and ripening) according to Yoshida (1981). Based on our estimation of the amount of time required for tiller maturation, tillers that were in the heading, milking, ripening, and hard dough stages had been exposed to larvae in the susceptible stages (panicle initiation, booting, and flowering). This allowed us to determine the number of tillers exposed during the window of susceptibility. Each tiller was examined for feeding damage and damage was classified into the following categories: partially sterile panicles, highly sterile panicles, deadheart, and whitehead. Sterile panicles and whiteheads were grouped jointly as damaged tillers.

There was considerable variation in plant phenology, particularly for the wild rice accessions (Table 1). We calculated several indices to account for this variation: total number of tillers, proportion of reproductive tillers, proportion of damaged tillers over total tillers, proportion of damaged tillers over ripening tillers, proportion of whiteheads over total tillers, and proportion of whiteheads over ripening tillers. These different statistics were calculated to demonstrate the biases of the more conventional index of whitehead number/total tillers. The proportion of damaged and whitehead tillers over ripening tillers was the most appropriate measure for estimating damage during the window of susceptibility. For cultivated accessions, sterile tillers were exclusively due to larval feeding, whereas sterile tillers on wild plants were mostly due to incomplete pollination. As a consequence, the number of damaged (sterile and whitehead) tillers was overestimated for wild rice but accurate for cultivated rice.

We used an ANOVA test to determine whether the number of tillers differed between cultivated and wild accessions, and whether the damaged tillers/ripening tillers and whiteheads/ripening tillers differed between species and among accessions. We also tested whether damaged tillers/total tillers and whiteheads/total tillers differed among accessions and between wild and cultivated accessions. To identify tolerant accessions, we set the upper tolerance to 30% damage or 30% whiteheads to reproductive tillers. For each accession, we also used a linear regression to test the relationship between tiller number and tiller damage. The linear regression is a useful way to describe damage risk with increasing number of tillers, while treating each accession as a population of plants. Certainly, there could be considerable among-plant variation within each wild accession. Highly susceptible tillers should have a 1:1 relationship between the number of tillers and the number of damaged tillers. All statistical tests were performed in JMP 5 (SAS Institute 2003).

The accessions showed considerable variation in number of tillers and proportion of ripening tillers (Table 1). Crop domestication has reduced the number of tillers by close to 40%. Although the average wild accession had

Table 1. Plant growth and tolerance for stem borer herbivory. From left, columns indicate (av ± SE) tillers per plant, proportion of reproductive tillers, total damaged tillers, total whiteheads, proportion of damaged tillers to total tillers, proportion of damaged tillers to reproductive tillers, proportion of whiteheads to total tillers, and proportion of whiteheads to reproductive tillers. Both sterile panicles and whiteheads were classified as damaged tillers. Bold numbers indicate accessions with less than 30% damage, indicating tolerance for *S. incertulas*.

Variety/accession	Tillers per plant (no.)	Proportion of reproductive tillers	Total damaged tillers (no.)	Total whiteheads (no.)	Proportion of damaged tillers to total tillers	Proportion of damaged tillers to reproductive tillers	Proportion of whiteheads to total tillers	Proportion whiteheads to reproductive tillers
Azmil 85	14.87 ± 0.92	0.97 ± 0.01	12.93 ± 0.92	3.88 ± 0.77	0.89 ± 0.03	0.91 ± 0.03	0.2 ± 0.03	0.2 ± 0.03
BMT53 R 3536	31.3 ± 1.48	0.84 ± 0.02	25.17 ± 1.35	19.47 ± 1.29	0.80 ± 0.02	0.96 ± 0.01	0.61 ± 0.02	0.74 ± 0.03
Ballocok	20.23 ± 0.66	0.88 ± 0.03	11.17 ± 1.00	3.68 ± 0.46	0.55 ± 0.05	0.63 ± 0.05	0.17 ± 0.02	0.21 ± 0.03
CI 1240	21.07 ± 1.11	0.88 ± 0.03	18.23 ± 1.31	11.57 ± 1.16	0.84 ± 0.03	0.95 ± 0.02	0.54 ± 0.04	0.62 ± 0.04
CI 27-4	19.57 ± 1.4	0.88 ± 0.02	16.47 ± 1.76	8.00 ± 0.98	0.78 ± 0.05	0.88 ± 0.04	0.39 ± 0.03	0.46 ± 0.04
CI 5339	52.5 ± 2.89	0.84 ± 0.03	38.53 ± 2.81	11.00 ± 1.02	0.72 ± 0.03	0.86 ± 0.02	0.21 ± 0.02	0.26 ± 0.02
Chianan 2	15.37 ± 0.8	0.95 ± 0.02	12.91 ± 0.88	10.77 ± 0.6	0.9 ± 0.02	0.94 ± 0.02	0.72 ± 0.03	0.76 ± 0.03
China 97-35-2	31 ± 1.44	0.96 ± 0.01	25.73 ± 1.69	7.14 ± 1.09	0.81 ± 0.03	0.85 ± 0.03	0.21 ± 0.03	0.22 ± 0.03
Debrax	7.83 ± 0.55	0.72 ± 0.05	5.66 ± 0.50	3.42 ± 0.35	0.68 ± 0.05	0.96 ± 0.02	0.37 ± 0.04	0.55 ± 0.06
Inilang-ilang	9.57 ± 0.85	0.95 ± 0.02	8.5 ± 0.94	4.18 ± 0.53	0.86 ± 0.04	0.91 ± 0.03	0.39 ± 0.04	0.42 ± 0.05
K Askam 36-14	10.78 ± 0.81	0.62 ± 0.04	4.15 ± 0.48	3.88 ± 0.43	0.37 ± 0.04	0.61 ± 0.05	0.35 ± 0.03	0.58 ± 0.05
Rexoro	13.87 ± 0.66	0.93 ± 0.02	11.97 ± 0.60	5.14 ± 0.58	0.87 ± 0.02	0.94 ± 0.04	0.35 ± 0.04	0.38 ± 0.04
Su-yai 20	25.5 ± 1.19	0.61 ± 0.02	7.82 ± 0.83	5.46 ± 0.67	0.28 ± 0.03	0.45 ± 0.05	0.19 ± 0.02	0.32 ± 0.03
Szu-miao	32.21 ± 1.81	0.86 ± 0.02	16.1 ± 1.23	7.83 ± 0.8	0.50 ± 0.03	0.59 ± 0.03	0.24 ± 0.02	0.29 ± 0.02
TKM6	32.03 ± 1.54	0.85 ± 0.02	19.9 ± 1.00	7.79 ± 0.82	0.63 ± 0.02	0.74 ± 0.02	0.22 ± 0.02	0.26 ± 0.03
Taitung 16	17.57 ± 1.22	0.74 ± 0.04	11.67 ± 1.21	8.72 ± 1.07	0.63 ± 0.03	0.87 ± 0.02	0.45 ± 0.04	0.62 ± 0.05
100926 *O. rufipogon*	28.33 ± 2.13	0.41 ± 0.05	9.43 ± 1.19	6.96 ± 0.72	0.32 ± 0.05	0.74 ± 0.05	0.21 ± 0.03	0.54 ± 0.06
103814 *O. nivara/ O. rufipogon*	18.7 ± 1.7	0.44 ± 0.06	10.74 ± 1.62	6.36 ± 1.11	0.43 ± 0.07	0.91 ± 0.06	0.23 ± 0.04	0.57 ± 0.07
103419 *O. nivara*	19.67 ± 1.32	0.68 ± 0.04	11.7 ± 1.04	7.17 ± 0.63	0.62 ± 0.04	0.90 ± 0.04	0.39 ± 0.03	0.59 ± 0.04
103823 *O. rufipogon*	19.85 ± 2.96	0.41 ± 0.07	10.73 ± 2.17	6.87 ± 1.61	0.38 ± 0.07	0.91 ± 0.05	0.24 ± 0.05	0.63 ± 0.07
103830 *O. nivara*	25.53 ± 0.88	0.78 ± 0.03	16.47 ± 1.07	5.97 ± 0.63	0.64 ± 0.04	0.82 ± 0.03	0.22 ± 0.02	**0.3 ± 0.04**
103837 *O. nivara*	27.43 ± 1.29	0.86 ± 0.03	21.07 ± 1.47	7.07 ± 0.95	0.74 ± 0.04	0.87 ± 0.02	0.22 ± 0.03	**0.25 ± 0.03**
103838 *O. nivara*	12.37 ± 0.76	0.76 ± 0.03	7.97 ± 0.71	2.52 ± 0.37	0.65 ± 0.04	0.86 ± 0.04	0.15 ± 0.02	**0.21 ± 0.03**
103840 *O. nivara*	27.23 ± 1.32	0.94 ± 0.01	25.2 ± 1.34	9.57 ± 0.9	0.93 ± 0.02	0.98 ± 0.02	0.35 ± 0.03	0.37 ± 0.03
103841 *O. nivara*	23.9 ± 1.06	0.89 ± 0.02	18.7 ± 1.03	6.47 ± 0.65	0.78 ± 0.03	0.88 ± 0.02	0.26 ± 0.02	**0.3 ± 0.03**
103842 *O. nivara*	16.87 ± 0.74	0.93 ± 0.02	14.3 ± 0.77	3.63 ± 0.49	0.85 ± 0.03	0.92 ± 0.02	0.17 ± 0.02	0.18 ± 0.03
103844 *O. rufipogon*	21.53 ± 1.43	0.54 ± 0.06	10.07 ± 1.42	4.17 ± 0.53	0.50 ± 0.06	0.92 ± 0.04	0.22 ± 0.03	0.53 ± 0.07
103849 *O. rufipogon*	23.6 ± 1.76	0.87 ± 0.03	18.67 ± 1.55	6 ± 1.31	0.79 ± 0.04	0.91 ± 0.03	0.23 ± 0.04	0.29 ± 0.05
104056 *O. rufipogon/ O. nivara*	26.8 ± 1.74	0.61 ± 0.05	14 ± 1.60	7.83 ± 1.49	0.50 ± 0.05	0.82 ± 0.05	0.22 ± 0.04	0.34 ± 0.05
103814 *O. nivara/ O. rufipogon*	37.27 ± 3.33	0.53 ± 0.06	6.76 ± 1.43	6.76 ± 1.43	0.15 ± 0.03	0.31 ± 0.06	0.15 ± 0.03	0.31 ± 0.06
103830 *O. nivara*	30.67 ± 1.88	0.97 ± 0.01	10.5 ± 0.70	10.5 ± 0.7	0.36 ± 0.02	0.36 ± 0.02	0.36 ± 0.02	0.36 ± 0.02
103837 *O. nivara*	26.83 ± 2.43	0.98 ± 0.01	5.96 ± 0.72	5.96 ± 0.72	0.18 ± 0.03	**0.19 ± 0.03**	0.18 ± 0.03	**0.19 ± 0.03**
103838 *O. nivara*	27.43 ± 3.18	0.60 ± 0.05	7.25 ± 1.49	7.25 ± 1.49	0.22 ± 0.03	0.42 ± 0.05	0.22 ± 0.03	0.42 ± 0.05
103839 *O. nivara*	34.17 ± 3.24	0.91 ± 0.02	7.69 ± 0.88	7.69 ± 0.88	0.23 ± 0.03	**0.25 ± 0.03**	0.23 ± 0.03	**0.25 ± 0.03**
103840 *O. nivara*	25.93 ± 1.43	0.92 ± 0.01	9.37 ± 0.69	9.37 ± 0.69	0.38 ± 0.02	0.41 ± 0.03	0.38 ± 0.02	0.41 ± 0.03
103841 *O. nivara*	29.4 ± 1.87	0.92 ± 0.02	6.27 ± 0.64	6.27 ± 0.64	0.22 ± 0.02	**0.24 ± 0.02**	0.22 ± 0.02	**0.24 ± 0.02**
103842 *O. nivara/ O. sativa*	23.43 ± 1.37	0.99 ± 0.01	4.73 ± 0.54	4.73 ± 0.54	0.2 ± 0.02	**0.21 ± 0.02**	0.2 ± 0.02	**0.21 ± 0.02**
104612 *O. nivara*	30.47 ± 2.4	0.70 ± 0.04	9.9 ± 1.08	9.9 ± 1.08	0.33 ± 0.03	0.48 ± 0.04	0.33 ± 0.03	0.48 ± 0.04
105409 *O. nivara*	32.83 ± 3.22	0.61 ± 0.04	10.37 ± 1.37	10.37 ± 1.37	0.32 ± 0.03	0.55 ± 0.04	0.32 ± 0.03	0.55 ± 0.04
105710 *O. nivara*	24.9 ± 1.34	0.86 ± 0.03	9.93 ± 0.77	9.93 ± 0.77	0.41 ± 0.03	0.48 ± 0.04	0.41 ± 0.03	0.48 ± 0.04
106041 *O. nivara*	51.43 ± 3.83	0.79 ± 0.02	13.57 ± 1.22	13.57 ± 1.22	0.27 ± 0.02	0.34 ± 0.02	0.27 ± 0.02	0.34 ± 0.02
100926 *O. rufipogon*	27.97 ± 1.55	0.49 ± 0.05	8.39 ± 0.93	8.39 ± 0.93	0.27 ± 0.03	0.62 ± 0.05	0.27 ± 0.03	0.62 ± 0.05
103844 *O. rufipogon*	35.68 ± 3.56	0.36 ± 0.05	2.08 ± 0.56	2.08 ± 0.56	0.03 ± 0.01	0.09 ± 0.02	0.03 ± 0.01	0.09 ± 0.02
105349 *O. rufipogon*	38.93 ± 2.31	0.91 ± 0.02	16.53 ± 1.45	16.53 ± 1.45	0.41 ± 0.03	0.45 ± 0.03	0.41 ± 0.03	0.45 ± 0.03
105554 *O. rufipogon*	33.07 ± 1.75	0.96 ± 0.01	11.83 ± 1.05	11.83 ± 1.05	0.35 ± 0.02	0.37 ± 0.02	0.35 ± 0.02	0.37 ± 0.02
106039 *O. rufipogon*	36.3 ± 3.11	0.61 ± 0.06	8.96 ± 1.22	8.96 ± 1.22	0.22 ± 0.03	0.4 ± 0.05	0.22 ± 0.03	0.4 ± 0.05

25.05 ± 0.44 tillers, cultivated accessions averaged 15.95 ± 0.32 tillers ($F_{1,\ 1344}$ = 200.35, P < 0.0001). Cultivated accessions had a higher proportion of ripening tillers (0.85 ± 0.01) than wild accessions (0.74 ± 0.01; $F_{1,\ 1344}$ = 200.35, P < 0.0001). Given this difference in phenology between species, the proportion of damaged/ripening tillers was a better index for comparing tolerance among accessions and between species.

Rice domestication appears to have lowered plant tolerance for *S. incertulas*. Despite receiving fewer larvae during the screening process, cultivated rice accessions had a higher proportion of damaged/ripening tillers (0.82 ± 0.01) than wild rice accessions (0.58 ± 0.01; $F_{1,\ 1324}$ = 191.23, P < 0.001). Cultivated accessions also had a higher proportion of whiteheads/ripening tillers (0.43 ± 0.01) than wild accessions (0.37 ± 0.01; $F_{1,\ 1324}$ = 13.62, P < 0.01). Given that estimates of sterility were likely overestimated for wild rice accessions, it was more appropriate to compare the proportion of damaged/ripening tillers for cultivated accessions (0.82 ± 0.01) to whiteheads/ripening tillers for wild accessions (0.37 ± 0.01). In any case, wild accessions exhibited more tolerance for larval damage.

There was significant variation in damaged/ripening tillers among accessions (Table 2; $F_{45,\ 1280}$ = 58.82, P < 0.0001). Almost all cultivated accessions had more than 60% of the ripening tillers damaged (Table 1). Only two accessions showed signs of moderate tolerance. Su-yai 20 and Szu-miao had slightly lower levels of damage, with 45% and 59% of the ripening tillers damaged. In contrast, the level of damage on wild rice was much lower. Accessions 103842 and 103837 had the lowest proportion of whiteheads/ripening tillers, with 18% and 19% of the ripening tillers damaged. Using 30% whitehead damage to ripening tillers as the upper limit, 10 wild accessions showed signs of tolerance for *S. incertulas* (Table 1).

For the subset of wild accessions that was rescreened, we found that the proportion of whiteheads/reproductive tillers was similar between screening trials. On the other hand, there was some variability in the proportion of damaged/reproductive tillers because lower pollination in 2006 led to more sterile panicles (Table 1). For Acc. 103844, screening was not timed accurately with the phenology, leading to a larger difference between screening trials in the proportion of whiteheads/reproductive tillers. Both times it was screened, it had less than 50% reproductive tillers. The other possible cause for the difference between years is that random sampling of a small subset of a diverse population could lead to a different average score. Therefore, it is recommended that screening be repeated several times before selecting a parent for breeding purposes.

Table 1 also demonstrates the importance of linking larval damage with plant phenology. We presented both damage and whiteheads in terms of actual numbers and the proportion of damage. Both sets of information can be used to identify accessions that perform better than others. For instance, Acc. 103844 had very few whiteheads, but this was due to a low proportion of ripening tillers. Similarly, the cultivated accession K Askam 36-14 had relatively low damage to its reproductive tillers (34%), but it also had a lower proportion of reproductive tillers. Although this accession appeared to be tolerant in this study, it should be rescreened during the booting stage. Therefore, accounting for plant phenology will improve the precision of screening for tolerance for *S. incertulas*.

We found that almost all accessions showed a positive relationship between number of tillers and number of whiteheads or damaged tillers (Table 2). The only accession that did not show a positive relationship was wild rice Acc. 103844, but this was likely due to the low proportion of reproductive tillers during the screening period (Table 1). The positive relationship between total tillers and damaged tillers was much higher for cultivated accessions than for wild accessions, indicating that cultivated tillers were more likely to be damaged. Using the linear regressions estimated for each accession, we predicted the average number of damaged tillers for a plant with 20 tillers. The average wild accession would have 5.01 ± 0.09 damaged tillers, whereas the average cultivated plant would have 13.30 ± 0.25 damaged tillers. Table 2 shows the damage predictions for a plant with 20 tillers using the linear regression generated for each accession. Several wild accessions (Acc. 103849, 104056, 103830, 103837, 103841, and 103842) predicted a particularly low number of whitehead tillers (Table 2). These accessions also showed lower damage in Table 1.

By developing a more reliable screening technique that accounts for plant phenology, we have identified several wild rice donors that are tolerant of *S. incertulas* during the reproductive stage. These accessions could be used to enhance the tolerance of cultivated rice. Our key recom-

Table 2. Accession information and the linear regression predicting the relationship between total tillers and tiller damage. For cultivated accessions, the equations predict tiller damage (sterile and whitehead panicles). For wild accessions, the equations predict the number of whiteheads. The equations were then used to predict the number of affected tillers for a hypothetical plant with 20 tillers. The remaining columns refer to wild or cultivated species, the IRRI International Genetic Resources Center (IRGC) accession number, variety or species name, and geographic region where it was first collected.

Species	IRGC no.	Variety/species name	Origin	Damage prediction	Predicted damage for 20 tillers
Cultivated	89	Chianan 2	Taiwan	Damaged = 0.11 + 0.89 total tillers	17.91
Cultivated	99	Taitung 16	Taiwan	Damaged = –4.62 + 0.92 total tillers	13.78
Cultivated	143	Rexoro	USA	Damaged = 0.98 + 0.79 total tillers	16.78
Cultivated	237	TKM6	India	Damaged = 5.42 + 0.44 total tillers	14.22
Cultivated	289	Azmil 85	Philippines	Damaged = 2.41 + 0.71 total tillers	16.61
Cultivated	558	Ballocok	Philippines	Damaged = –0.09 + 0.56 total tillers	11.11
Cultivated	690	Inilang-ilang	Philippines	Damaged = –1.69 + 1.07 total tillers	19.71
Cultivated	958	CI 5339	China	Damaged = –7.38 + 0.87 total tillers	10.02
Cultivated	1099	K Askam 36-14	China	Damaged = 2.29 + 0.15 total tillers	5.29
Cultivated	1601	China 97-35-2	China	Damaged = –6.49 + 1.04 total tillers	14.31
Cultivated	1796	Debrax	USA	Damaged = –0.31 + 0.72 total tillers	14.09
Cultivated	1863	BMT53 R 3536	USA	Damaged = –0.92 + 0.81 total tillers	15.28
Cultivated	3465	CI 27-4	Sri Lanka	Damaged = –6.59 + 1.18 total tillers	17.01
Cultivated	3466	CI 1240	Sri Lanka	Damaged = –4.58 + 1.08 total tillers	17.02
Cultivated	3483	CI 5339	China	Damaged = –7.38 + 0.8 total tillers	8.62
Cultivated	7299	Su-yai 20	China	Damaged = –1.69 + 0.34 total tillers	5.11
Cultivated	7300	Szu-miao	China	Damaged = –0.93 + 0.51 total tillers	9.27
Wild	103419	*O. nivara*	Sri Lanka	WH = 3.92 + 0.16 total tillers	7.12
Wild	103823	*O. rufipogon*	China	WH = 0.94 + 0.21 total tillers	5.14
Wild	103849	*O. rufipogon*	India	WH = –8.03 + 0.59 total tillers	3.77
Wild	104056	*O. rufipogon/O. nivara*	China	WH = –3.55 + 0.36 total tillers	3.65
Wild	104612	*O. nivara*	Sri Lanka	WH = –0.08 + 0.32 total tillers	6.48
Wild	105349	*O. rufipogon*	India	WH = –1.39 + 0.46 total tillers	7.81
Wild	105409	*O. nivara*	Sri Lanka	WH = 0.36 + 0.30 total tillers	6.36
Wild	105554	*O. rufipogon*	India	WH = –3.51 + 0.46 total tillers	5.69
Wild	105710	*O. nivara*	India	WH = 5.03 + 0.20 total tillers	9.03
Wild	106039	*O. rufipogon*	India	WH = 0.52 + 0.21 total tillers	4.72
Wild	106041	*O. nivara*	India	WH = 1.99 + 0.23 total tillers	6.59
Wild	100926	*O. rufipogon*	Myanmar	WH= 2.89 + 0.10 total tillers	4.89
Wild	100926	*O. rufipogon*	Myanmar	WH = –0.48 + 0.30 total tillers	5.52
Wild	103814	*O. nivara/O. rufipogon*	China	WH = –2.76 + 0.36 total tillers	4.44
Wild	103814	*O. nivara/O. rufipogon*	China	WH = –0.40 + 0.16 total tillers	2.8
Wild	103830	*O. nivara*	Bangladesh	WH = –0.23 + 0.23 total tillers	4.37
Wild	103830	*O. nivara*	Bangladesh	WH = 5.49 + 0.16 total tillers	8.69
Wild	103837	*O. nivara*	Bangladesh	WH = –8.34 + 0.53 total tillers	2.26
Wild	103837	*O. nivara*	Bangladesh	WH = 0.15 + 0.17 total tillers	3.55
Wild	103838	*O. nivara*	Bangladesh	WH = –8.34 + 0.22 total tillers	–3.94
Wild	103838	*O. nivara*	Bangladesh	WH = –2.33 + 0.33 total tillers	4.27
Wild	103839	*O. nivara*	Bangladesh	WH = –2.72 + 0.14 total tillers	5.52
Wild	103840	*O. nivara*	Bangladesh	WH = –0.21 + 0.36 total tillers	6.99
Wild	103840	*O. nivara*	Bangladesh	WH = 0.90 + 0.33 total tillers	7.5
Wild	103841	*O. nivara*	Bangladesh	WH = –3.02 + 0.40 total tillers	4.98
Wild	103841	*O. nivara*	Bangladesh	WH = 0.19 + 0.21 total tillers	4.39
Wild	103842	*O. nivara/O. sativa*	Bangladesh	WH = –0.78 + 0.22 total tillers	3.62
Wild	103842	*O. nivara/O. sativa*	Bangladesh	WH = 0.42 + 0.18 total tillers	4.02
Wild	103844	*O. rufipogon*	Bangladesh	NS	NS
Wild	103844	*O. rufipogon*	Bangladesh	NS	NS

mendations for modifying the screening technique are to (1) record tiller phenology of each plant during the damage assessment, (2) count the number of ripening and total tillers on each plant, (3) determine the proportion of damaged tillers/ripening tillers and whiteheads/ripening tillers, and (4) assess the relationship between the total number of tillers and the number of damaged tillers for each accession. A linear regression is appropriate because it accounts for considerable variation that can be found among plants within a particular accession. It can also be used as a predictive tool, as we have done here.

Rice domestication has decreased tillering and reduced plant phenological variation (Cai and Morishima 2002). The simplification of plant architecture during domestication and breeding has been linked with a reduction in tolerance for herbivory in other crops (Welter and Steggall 1993). The greater frequency of tolerance in wild accessions provides strong evidence that domestication and selective breeding have reduced the tolerance of rice for *S. incertulas*. The decrease in tiller production increases the relative impact that each *S. incertulas* larva can have on total plant reproductive fitness. Also, the uniformity of flowering further increases the impact of *S. incertulas* on cultivated rice because all of the tillers are in the window of susceptibility at the same time (Chen and Romena 2006). Given that *O. sativa* panicles are larger than *O. rufipogon* panicles (IRRI GRC, unpubl. data), each damaged tiller has a greater impact on plant fitness in cultivated rice. Rice domestication has clearly reduced plant tolerance for stem borer herbivory, but identifying tolerant accessions opens up new opportunities to study the morphological and biochemical basis of rice tolerance for *S. incertulas* damage during the reproductive stage. These accessions can also be used to begin the long process of breeding for stem borer resistance in rice.

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A new phenotypic screen to map quantitative trait loci associated with rice tolerance for planthoppers

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There has been a long history of attempts to design screening tests to measure plant resistance to insects since the time Painter (1951) classified plant resistance into three mechanisms: nonpreference (antixenosis), antibiosis, and tolerance. As the most important insect pests of rice (*Oryza sativa* L.), brown planthopper *Nilaparvata lugens* (Stål) and whitebacked planthopper *Sogatella furcifera* (Horvath) demanded the attention of entomologists and breeders to develop easy and reliable screening techniques to screen a large number of germplasm and breeding materials to develop cultivars with improved resistance to planthoppers (Heinrichs et al 1985). Tolerance is the most important component of resistance for breeding, but it has not been well used as the phenomenon of tolerance has not been fully understood, there is a lack of suitable techniques to identify and incorporate tolerance into an improved genetic background, and details of the genetics of tolerance have not been determined (Velusamy and Heinrichs 1986).

Panda and Heinrichs (1983) described some tolerance tests: functional plant loss index, tolerance index, antibiosis index, and plant dry weight loss per milligram of insect dry weight produced for BPH. Although various tests have been developed, the availability of tests that measure the nature of resistance precisely without the influence of another factor is still a concern and requires continuous exploration (Reese et al 1994).

Plant resistance to planthoppers in rice has been a much studied subject since 1969 when varietal resistance was established for the first time at the International Rice Research Institute (Pathak et al 1969). However, studies on genetics of resistance have always relied on a standard seedbox screening test, which can be effective only for qualitative resistance. Current research has indicated that plant resistance to planthoppers is a quantitative trait, demanding insights into the complexities of signaling and interactions among host and pest genomes. This situation underscores the need for addressing the gap in our understanding of resistance phenotype at the molecular, cell, and whole-plant levels. Our work is one such attempt to design a screening test that can be a more sensitive phenotypic screen for genetic analysis of tolerance for planthoppers in rice.

We hypothesized that days-to-wilt, measured as the number of days after infestation required to kill the plants, can be a sensitive phenotypic screen to identify tolerance in rice for BPH. We evaluated a subset of 94 doubled-haploid (DH) lines produced from a cross between IR64 and Azucena (Guiderdoni et al 1992), along with the parents, for days-to-wilt after planthopper infestation. A brief description of the screening procedure is given as follows.

Days-to-wilt was measured at two plant age levels: 30 and 60 d after sowing (DW30 DAS and DW60 DAS, respectively) with an insect load of 50 first- and second-instar nymphs per plant. For DW30, 15-d-old seedlings were transplanted in 15-cm-diameter clay pots and placed inside a cylindrical mylar sheet cage (13 × 75 cm). For DW60, seedlings were transplanted in 30-cm-diameter clay pots and put in a 25 × 90-cm mylar cage. The nymphs were released on the plants and allowed to feed. The day the plant wilted completely was recorded.

After BPH infestation, 30-d-old IR64 plants survived up to 12.7 d; the Azucena plants survived only up to 5.3 d. The 60-d-old IR64 plants survived up to 17.7 d, whereas the Azucena plants survived up to 11.3 d. Days-to-wilt of 30-d-old DH plants ranged from 6.3 to 13 d; those of 60-d-old DH plants ranged from 8.7 to 19.7 d.

Similarly, 30-d-old plants of IR64 survived up to 88 d after WBPH infestation, whereas the Azucena plants survived only up to 18.5 d. When 60-d-old plants were infested, the WBPH could not kill the IR64 plants, even beyond 90 d after infestation, but the Azucena plants wilted quickly (28 d). Days-to-wilt of 30-d-old DH lines ranged from 9 to 87.5 d, whereas those of 60-d-old plants ranged from 16 to 90 d (Table

1). The experiment was terminated 90 d after insect infestation. Therefore, 90 d was considered as the days-to-wilt of plants that survived beyond 90 d after infestation. The frequency distribution of phenotypic values of DH lines for days-to-wilt after BPH and WBPH infestation clearly indicated the quantitative nature of resistance (Fig. 1). We did a QTL analysis to test the sensitivity of days-to-wilt with respect to the genetic mechanism behind tolerance for planthoppers using 175 marker data of an IR64/Azucena DH population through Mapmaker/QTL (Lander et al 1987). Putative BPH resistance QTLs were detected on chromosomes 6 and 7, with LOD scores of 2.5 and 3.1, when 30- and 60-d-old plants were infested with BPH nymphs, respectively (Soundararajan et al 2004). Similarly, days-to-wilt after WBPH infestation also indicated the presence of possible QTLs on chromosomes 1 and 6 (Table 2, Fig. 2). These QTLs were detected with threshold values of 1.6 and 1.8 for 30- and 60-d-old plants, respectively. The low number of replications might have affected the significance levels of these QTLs. Furthermore, the detected QTLs were specific to plant age 30 and 60 d old, supporting the observation that plant age influences resistance level. Genetic analysis at the appropriate growth stage is necessary. Based on these results, we propose that days-to-wilt after insect infestation could be a sensitive phenotypic screen to detect QTLs associated with resistance to planthoppers.

Table 1. Phenotypic values of parents and DH lines of IR64/Azucena cross for resistance to planthoppers.

Trait	Parents[a]		DH lines		
	IR64	Azucena	Mean	SD	Range
Days-to-wilt (30 DAS) after BPH infestation	12.7	5.3	9	1.3	6.3–13.0
Days-to-wilt (60 DAS) after BPH infestation	17.7	11.3	14	2.2	8.7–19.7
Days-to-wilt (30 DAS) after WBPH infestation[b]	88.0	18.5	28.9	18.8	9–>90
Days-to-wilt (60 DAS) after WBPH infestation	>90	28.0	48.5	23.5	14–>90

[a]Mean of two replicates. [b]Days from infestation to complete wilting of plant; >90, not wilted on 90th day after infestation.

Table 2. Putative QTLs identified for various traits associated with resistance to planthoppers in IR64/Azucena DH populations of rice.

Trait[a]	Marker interval	Chromosome	LOD	Variance (%)	Additive[b]
Days-to-wilt after BPH infestation (30 DAS)	Pgi2–pRD10B	6	2.5	14.3	–0.5
Days-to-wilt after BPH infestation (60 DAS)	RG773–CDO59	7	3.1	17.6	1.1
Days-to-wilt after WBPH infestation (30 DAS)	W1–RG173	1	1.6	11.6	–7.9
Days-to-wilt after WBPH infestation (60 DAS)	RG172–Cat-1	6	1.8	8.8	–7.8

[a]Putative BPH resistance QTLs are presented here on the basis of the findings of Soundararajan et al (2004). [b]Effect of Azucena allele.

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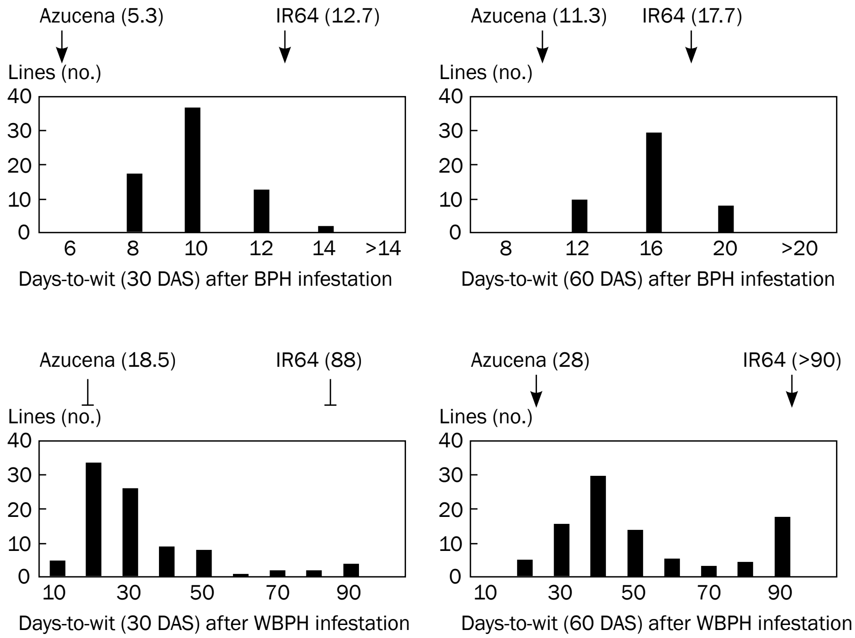

Fig. 1. Frequency distribution of DH lines of IR64/Azucena cross for days-to-wilt after planthopper infestation.

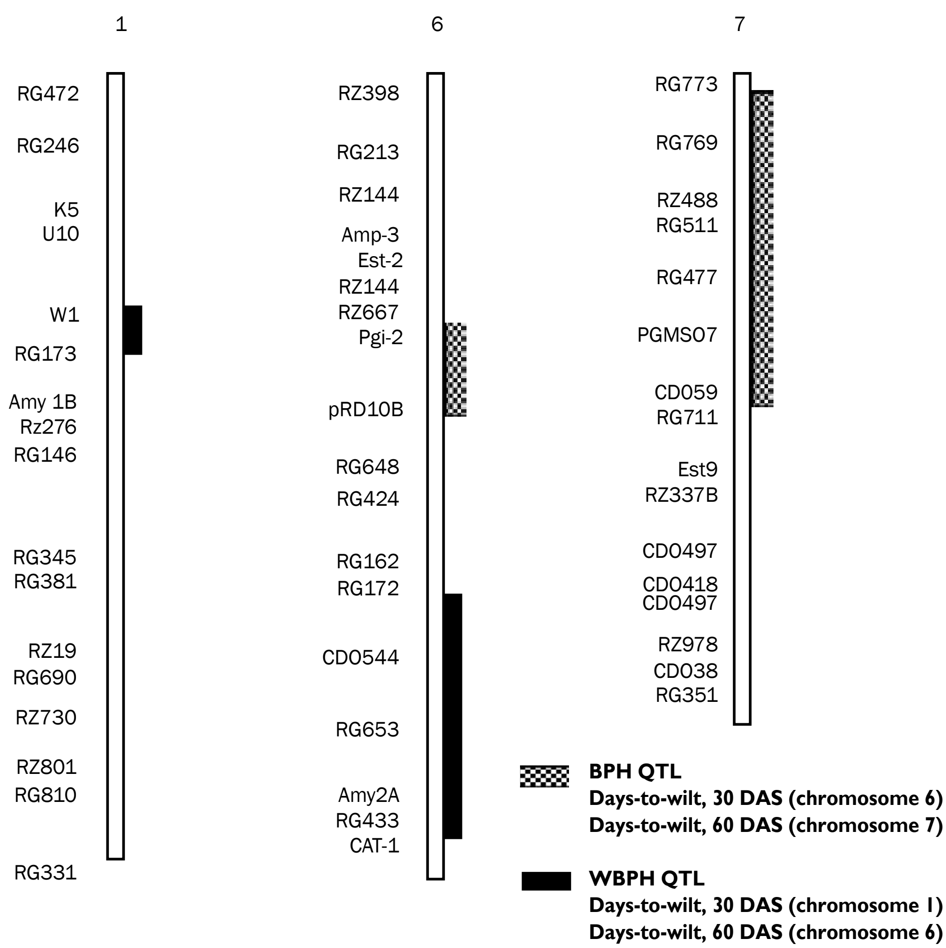

Fig. 2. Linkage map showing chromosomal locations of putative QTLs detected for tolerance for planthoppers.

Application of herbicide lethality in hybrid rice

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With improved seed production technology and parental outcrossing traits, hybrid rice seed production yield has increased from hundreds of kilograms per hectare to a national average of 2.5 t ha^{-1} during the last three decades in China. However, current seed production protocols are based on a technology established 30 years ago—female and male parents are separately transplanted in different rows at a certain ratio and are harvested separately. The complexity of seed production has become a limiting factor for wide-scale adoption of hybrid rice as more labor is consumed and purity control and mechanical operations are difficult.

In 1984, Norin 8M, a mutant from japonica rice variety Norin 8, was found to be lethally susceptible to bentazone (3-isopropyl-1H-benzo-2,1,3-thiadiazine-4(3H)-ketone -2,2-dioxide), which is an ingredient of herbicides such as "basagran," "bentazone," and others that are used widely in rice fields for weed control. The discovery of bentazone lethality, which was genetically controlled by a pair of recessive genes, opened the path for an innovative system of hybrid rice seed production. The key approach is to integrate the lethality trait into restorer lines, which have the same days to flowering as the cytoplasmic male sterile (CMS) lines, so that seeds of both female and male parents can be blended, planted, or transplanted together. After pollination, the herbicide bentazone is sprayed in the field to eliminate the male plants, leaving CMS plants bearing hybrid seeds that can be bulk-harvested. This technology simplifies the operation of seed production, employs less labor, and is adaptable to mechanical seed production on a large scale, besides increasing hybrid seed yield and purity. After 21 seasons in 10 years of breeding, we successfully developed many CMS restorer lines with bentazone lethality and with different maturities to synchronize planting of various CMS lines. Heterotic hybrids were developed using these restorer lines and were applied to commercial production.

The donor parent of the lethality trait was a mutant line contributed by Dr. G. Takeda), Norin 8M, which is lethally susceptible to bentazone. A typical japonica variety, it was used to cross with many indica restorer lines to develop restorer lines with an indica genetic background having bentazone lethality. It has the same days to flowering as that of the CMS female parent. Pedigree and backcross breeding were used. The herbicide dose study was first carried out to select the best herbicide rate that would let plants show obvious but limited damage from the chemical and would let them survive until seed harvest. The herbicide used, made by Jiansu Lulilai Co. Ltd., China, was bentazone 25% aqua. (The normal dosage recommended by the manufacturer for rice is 3,000–6,000 mL ha^{-1}.) Experiments showed that, at heading stage, application of 600 mL ha^{-1} of bentazone showed no damage to plants; with 900 mL ha^{-1}, plants had minor damage but recovered within 10 d after herbicide spraying. However, with 1,200–1,800 mL ha^{-1}, the plants showed obvious damage 7 d after spraying and the panicles died after 10 d. At a dose of 2,700–3,600 mL ha^{-1}, obvious damage was observed in the plants by the 4th day after spraying and the whole plant died 10 d after spraying.

In the course of breeding, 900 mL bentazone ha^{-1} was applied to screen plants with susceptibility at the panicle initiation stage in every breeding generation from F_2. Selection on the basis of phenotype was started on the 7th day after herbicide treatment. Herbicide susceptibility, along with other agronomic traits, was selected following the same selection criteria used in a general restorer line breeding program. The trait days to flowering was specifically noted because of the required flowering synchronization with female parents. Different CMS lines were planted along with R lines to provide a reference of days to flowering. The selected R lines were harvested as single plants, advanced to the next generation, and then testcrossed with various CMS lines to make hybrids for evaluation of restoration ability, combining ability, and yield (heterosis). Table 1 shows the characteristics of the selected R lines used in the herbicide dosage study.

The selected hybrid varieties with high yield potential and acceptable quality were advanced to provincial or national yield trials and tested for commercial hybrid seed production. Many restorer lines with bentazone lethality in various indica genetic backgrounds and related commercial hybrids have now been developed. One of the good performers, hybrid "Green Rice # 5", has gained nationwide acceptance and is being commercialized. In a farmer's yield trial in 2004, it produced 11.45 t ha^{-1} and outyielded, by 1.52 t ha^{-1}, the best hybrid check, Shanyou 63, the most widely grown hybrid in China. It had a 15.3% yield advantage but the same maturity.

In a 2004 seed production study, two systems—conventional seed production (row ratio of 1 male: 5 females, separate transplanting) and mixed transplanting (seed ratio of 1 male: 5 females, mixed transplanting)—were evaluated. Results showed that the mixed method produced 2.0 t ha^{-1} more hybrid seeds than did the conventional method, with a 42.6% yield increase (Table 2). All yield components in the mixed method had different levels of increase, but the most significant increase was in seed set rate, which was 25% higher than in the conventional method.

By using molecular marker technology, the lethality trait has been mapped in the rice genome. In future development of lines with bentazone lethality, it will be very helpful to apply market-assisted selection to speed up and increase the accuracy of the selection process.

Table 1. Lethality of R line 2E06, Hefei, 2004.

Herbicide dose (mL ha^{-1})	Fertile spikelets (%)	Plants surviving (%)
0	82.1	98.4
4,500	32.1	46.3
6,000	28.7	17.7
7,500	27.5	6.7
9,000	19.1	1.1
10,500	10.5	0.3
12,000	1.2	0.0

Table 2. Comparison of hybrid seed production methods, Hefei, 2004.

Method	Plants ha^{-1} (no. × 1,000)	Effective panicles ha^{-1} (no. × 1,000)	Total spikelets $panicle^{-1}$ (no.)	Seed set (%)	1,000-grain weight (g)	Yield (t ha^{-1})
Conventional (C)	18.5	218	192.2	47.0	22	4.7
Mixed planting (M)	20.0	260	199.4	58.9	22	6.7
Increase (M − C)	1.5	42	7.2	11.9	0	2.0
Increase (%)	8.1	19.3	3.5	25.3	0	42.6

Grain yield and yield components of rice as influenced by different crop establishment methods

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Conventional methods of rice transplanting have become expensive because of increasing cost of seed, fertilizer, water, and labor. A system of rice intensification (SRI), introduced from Madagascar (Uphoff 2006), and its improved form, integrated crop management (ICM), need to be further evaluated. During a national symposium on SRI held in November 2006 at ANGRAU, Hyderabad, India, farmers from Andhra Pradesh and Tamil Nadu claimed great savings in terms of seed, water, and labor with SRI. To validate these claims, an experiment was conducted to evaluate different crop establishment methods in the Tarai plain of Uttarakhand.

A field experiment was conducted during the wet seasons of 2005 and 2006 at Pantnagar (29° N, 79°29′ E, 243.8 m), Uttarakhand. Six and eight crop establishment methods were tested in 2005 and 2006, respectively. Only four methods were discussed here: SRI with a spacing of 25 × 25 cm, one 9-d-old seedling per hill; ICM with 20 × 20-cm spacing, two 15-d-old seedlings per hill; line sowing of sprouted seeds at 20-cm distance in puddled soil; and the conventional method of transplanting (20×10-cm spacing, two 25-d-old seedlings per hill). The soil of the experimental field is Aquic Hapludoll, silty loam in texture, and rich in organic carbon (1.15%), and it has medium phosphorus (20.3 kg ha^{-1} Olsen's P) and potash (222 kg ha^{-1}) levels.

Rainfall received during the crop period was 1,725 mm in 2005 and 802 mm in 2006. The experimental field has been under a rice-wheat rotation system since 1966. The high-yielding variety Pant Dhan 4 was used in the experiment, which had a randomized block design with five replications. In addition to inorganic nutrients (120 kg N, 26.4 kg P, and 33.2 kg K), farmyard manure at 5 t ha^{-1} was also added to the SRI and ICM plots. The SRI and ICM plots were kept moist up to the panicle initiation stage; water level was then maintained at 3–5 cm through the milk stage. The moist condition was maintained by providing irrigation during rainless periods and excess water was drained as and when needed. In SRI and ICM, weeds were controlled through a conoweeder (used 20, 45, and 55 d after transplanting). Weeds growing near the rice plants were manually removed. Grain yields were adjusted to 14% moisture.

The grain yields obtained from the different crop establishment methods did not differ significantly. The number of tillers and panicles m^{-2} recorded with direct seeding was significantly higher than that observed in SRI, ICM, and conventional transplanting, except for number of tillers produced under conventional transplanting in 2005. The SRI produced 12 panicles (2005) and 14 panicles (2006) per hill as compared with five panicles per hill in conventional transplanting. SRI tiller number was statistically on a par with ICM in both years. The number of filled grains per panicle was highest in SRI (117). SRI and ICM were found to save irrigation water by about 50% compared with conventional transplanting and line sowing of sprouted seeds in puddled soil. SRI and ICM also had 80% and 57% savings on seed rate (Table 2). However, these results need to be evaluated further.

Table 1. Grain yield and yield components as influenced by crop establishment method.

Treatment	Grain yield (t ha^{-1})		Panicles m^{-2} (no.)		Tillers m^{-2} (no.)		Filled grains panicle^{-1} (no.)	
	2005	2006	2005	2006	2005	2006	2005	2006
Conventional transplanting	6.52	6.22	227	246	363	353	101	96
System of rice intensification	5.84	6.65	187	217	266	286	104	117
Integrated crop management	5.93	6.41	222	234	278	325	100	102
Direct seeding (line sowing)	5.79	6.11	290	328	415	414	71	73
SE	0.34	0.20	17	11	24	20	4	4
LSD 0.05	ns	ns	54	33	77	60	14	11

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Table 2. Number of irrigations and seeding rate used in both 2005 and 2006 wet seasons.

Treatment	Irrigations (no.)	Seeding rate (kg ha^{-1})
Conventional transplanting	12	35
System of rice intensification	6	7
Integrated crop management	6	15
Direct seeding (line sowing)	12	50

Total RNA isolation from dry and germinating rice seeds for gene expression studies

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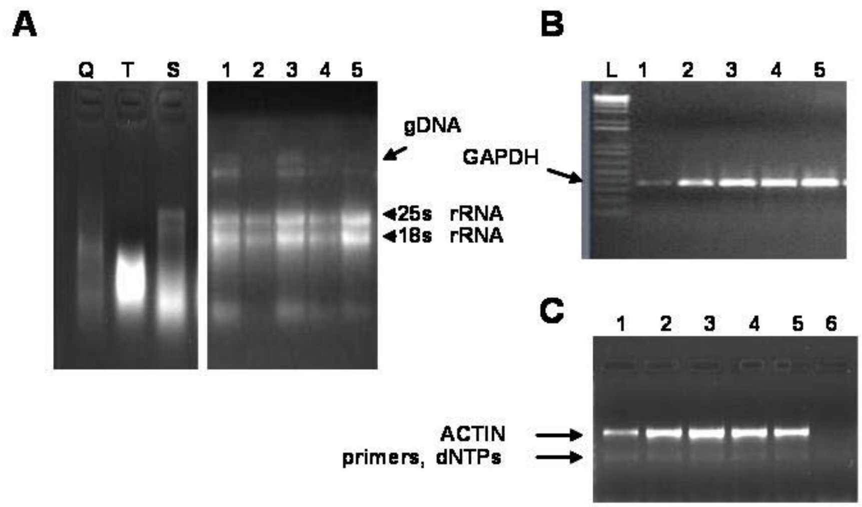
Dry seeds normally contain high levels of lipids, storage proteins, polysaccharides, and polyphenols, which decrease RNA yield and quality, factors that are highly important for gene expression analyses (Tai et al 2004). Commercially available RNA isolation kits, which contain guanidium salt solutions, were found to be ineffective in yielding high-quality RNA from dry rice seeds (Fig. 1a) as high levels of polysaccharides prevent the solubilization of RNA after alcohol precipitation (Groppe and Morse 1993). Several other RNA isolation techniques—e.g., SDS-LiCl extraction buffer, SDS-TRIzol method, and high NaCL-LiCl precipitation methods—were also tested but not one was found effective. The method described here is a modification of the procedure described by Stirn et al (1995), which proved to be more effective in yielding high-quality total RNA.

Dry and germinated rice seeds were treated with 10% sodium hypochlorite solution for 10 min, washed three times with sterile distilled water, and dissected in halves to remove most of the starchy endosperm. Around 18 to 20 half-seeds (100 mg) were freeze-dried in liquid nitrogen and ground into powder. Standard precautions for RNA preparation, including the use of DEPC-treated water, were followed. The autoclaved extraction buffer consisted of 1% sarcosyl, 100 mM Tris-HCl, 280 mM NaCl, and 10 mM EDTA at pH 8.5.

The new procedure involved the following steps: (1) an equal volume of extraction buffer was added to the ground tissue together with 10 µL β-mercaptoethanol per mL of extraction buffer to inhibit RNAse activity; (2) phenol (1:1 v/v to the extraction buffer used) was then added to the mixture and samples were vortexed well and kept on ice for 10 min; (3) after thawing, cellular debris and starch grains were pelleted at 10,000 × g for 5 min at 5 °C; (4) the supernatant was then collected into a new RNAse-free tube to which ½ volume of chloroform:isoamyl alcohol (24:1) was added; (5) the mixture was then vortexed well and centrifuged at 10,000 g for 5 min at 5 °C (this separation resulted in a clear upper phase, a whitish mid-phase that contains most of the proteins and starch complexes, and a dark lower phase with solid debris); (6) the upper phase was further extracted twice using phenol:chloroform (1:1 v/v); (7) nucleic acids were then precipitated from the upper clear phase by adding 1/10 volume of 3 M sodium acetate and two times the volume of absolute ethanol (tubes were placed



(A) RNA isolated using Qiagen RNEasy Kit (Qiagen Inc., Hilden Germany; Q); TRIzol Reagent (GIBCO, Invitrogen Inc.; T); Stirn et al (1995) RNA isolation method (S) and the new procedure described here using dry rice seeds (lane 1) and germinated rice seeds at 12 h (2), 24 h (3), 48 h (4), and 72 h (5) after the start of imbibition. The samples were separated on 1.5% nondenaturing Tris-boric-EDTA (TBE)-agarose gel and stained with ethidium bromide. Locations of genomic DNA (gDNA) and 25s and 18s rRNA are indicated. (B) Amplified products from isolated RNA using the new method, after DNAse treatment (Promega) and reverse-transcribed PCR (RT-PCR) using SuperScript One-Step RT-PCR (Invitrogen Inc.) using GAPDH forward primer: 5′-GCAGGAACCCTGAGGAGATC-3′ and reverse primer: 5′-TTCCCCCTCCAGTCCTTGCT-3′. A 1-kb DNA ladder (L) is shown to mark the expected fragment size. (C) Amplified RT-PCR products from Actin forward primer: 5′-ACGAGCTTCCTGATGGACA-3′ and reverse primer: 5′-ATGGGTCAGACTCGTCGTAC-3′. Lane 6 is the control for –RT, indicating no contaminating gDNA after DNAse treatment.

in ice to hasten precipitation or optionally put at 5 °C overnight); (8) the pellet was collected by centrifugation at 10,000 $\times$ g for 5 min at 5 °C and resuspended in 50 µL DEPC-treated water; (9) RNA precipitation was performed using 1/10 volume of 2.5 M lithium chloride plus two volumes of absolute ethanol and samples were placed at –20 °C for 30 min; (10) samples were then centrifuged at 10,000 $\times$ g for 10 min, and the RNA pellet was washed with 70% ethanol, air-dried, dissolved in a final volume of 50 µL DEPC-treated water, and stored at –20 °C. Following gel visualization and RNA quantitation using a UV spectrophotometer, samples were treated with DNAse following suppliers' standard protocols.

The above procedure was found to be effective in obtaining good quantity and quality of total RNA from rice seeds for gene expression studies as shown by the reverse-transcribed PCR (RT-PCR) products in Figures 1B and 1C. The use of 1% sarcosyl instead of SDS increased NaCl and the addition of β-mercaptoethanol as a protein denaturant and RNAse inhibitor, as modifications of Stirn et al (1995) extraction buffer solution, greatly improved quality and yield. Another important step was the use of ice during the lysis step, in contrast to other methods performed at room or higher temperatures. Although heat softens the cell walls, it also breaks most of the polysaccharides and makes the extraction mixture viscous. Double extraction using phenol: chloroform adapted from Stirn's protocol uses an additional step but ensures elimination of other interfering substances such as polysaccharides, polyphenols, and other cellular debris. The average total RNA yield from this procedure is 10 µg 100 mg^{-1} seed tissues, which is comparable with yields obtained using TRIzol reagent on leaves. Positive results were also obtained with rice leaf and root tissues besides dry and germinated rice seeds (data not shown). The new procedure could effectively substitute for commercial RNA isolation kits when using tissues with high carbohydrates such as rice seeds.

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Socioeconomics

Effects of applying all or individual management components on rice yield in rainfed uplands

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Direct-seeded upland rice is an important production system for the resource-poor farmers of eastern India. With the recent emphasis on improving the productivity of this important risk-prone ecosystem, a number of technological interventions have been suggested by researchers. Application of technology components as a package is required for achieving higher productivity in upland rice. Whenever a single component of the package is not applied, productivity decreases significantly. The contribution of each technology component to increasing rainfed upland rice productivity is not investigated thoroughly. In our study, we examined the contribution of the different components of technology to rainfed upland rice productivity.

A preliminary field experiment was conducted to study the effect of individual technology components on upland rice productivity in 2000 and significant differences were observed (data not reported). Based on this information, on-farm experiments with farmers' participation were conducted in Khorahar village (Hazaribagh, India) in upland red soil during the wet seasons of 2001 and 2002. The amount of rainfall received at the site was 570.5 mm (2001) and 800.4 mm (2002), which was about 52.25% and 73.2%, respectively, of the long-term average seasonal (Jun-Oct) rainfall in the area. The year 2001 was highly unfavorable for crop growth, with the crop experiencing three dry spells of 12, 10, and 8 d, which corresponded to the tillering, reproductive, and grain-filling stage. In 2002, there was one dry spell of 9 d at the grain-filling stage.

The technology components studied were (1) fertilization (40 kg N, 13 kg P, and 16 kg K ha^{-1}); (2) weed control (two hand weedings); and (3) insect control (gamaxine at 25 kg ha^{-1} for termites and endosulphan at 1.0 L ha^{-1} for rice bugs). The combinations were T1 (fertilizer + weeding + insect control), T2 (weeding + insect control), T3 (fertilizer + insect control), and T4 (fertilizer + weeding). All four combinations of technology components were tested with two upland varieties, Brown Gora (traditional) and Vandana (improved), in four farmers' fields treating farmers as replications.

Urea, single superphosphate, and muriate of potash were the sources of N, P, and K, respectively. Nitrogen was applied in two splits (50% 22 d after germination and 50% 40 d after germination). All P and K were applied basally at seeding. Gamaxine dust at 25 kg ha–1 was mixed in the soil before seeding and endosulphan at 1.0 L ha–1 was sprayed at the milking stage. At harvest, grain and straw yields were recorded and the corresponding effects of technology components were calculated.

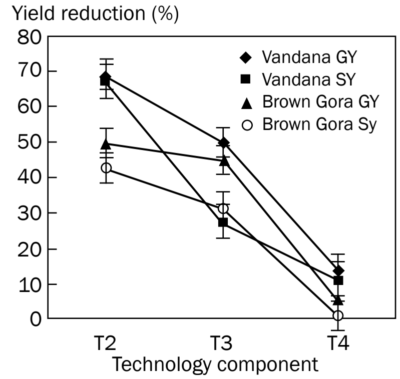
The results of the 2-year field experiment showed that the application of all components as a package gave significantly higher yield, whereas no application of fertilizer or no weeding reduced yield significantly. There was no

Variety and treatment means for grain and straw yield (t ha^{-1}) during the 2001-02 wet seasons.

Variety and treatment	2001		2002	
	Grain yield	Straw yield	Grain yield	Straw yield
Variety				
Vandana	0.59	1.40	1.15	1.86
Brown Gora	0.82	1.36	1.08	1.93
Treatment				
T1	1.06	1.88	1.49	2.34
T2	0.33	0.62	0.75	1.34
T3	0.53	1.36	0.82	1.60
T4	0.91	1.66	1.40	2.31
LSD(0.05)				
Variety	0.13	ns[a]	ns	ns
Treatment	0.19	0.20	0.29	0.40
Variety × treatment	ns	ns	ns	ns

[a]ns = not significant.

significant difference between T1 and T4, which implies that yield reduction due to omission of insect control measures (T4) was not significant as compared with the other two components (see table). Nonapplication of fertilizer substantially reduced grain and straw yields in both cultivars. There was a significant difference in grain yield among varieties in 2001, but the variety × technology component interaction was not significant in either year. Maximum yield reduction was recorded with no fertilizer application, followed by no weeding and no insect control (see figure). Average yield data for 2 years revealed that the no-fertilization component reduced grain yield by 69% and 50% and straw yield by 67% and 43% in Vandana and Brown Gora, respectively; no weeding reduced grain yield by 50% and 45% and straw yield by 28% and 32%; and no insect control reduced grain yield by 14% and 6% and straw yield by 12% and 1%. The lower grain and straw yield reduction in local variety Brown Gora was due to its early vigor, weed competitiveness, and low responsiveness to inputs. Grain yield was considerably low in 2001 as the crop suffered from moisture stress at the tillering, reproductive, and grain-filling stages. As reported by Yambao and Ingram (1988), the most severe moisture stress affecting rice yield coincides with booting to flowering /early grain filling.



Reduction in grain and straw yield due to nonapplication of technology components.

Our study revealed that, among the technology components, fertilizer application and weeding control measures need special attention to achieve and sustain higher productivity in the rainfed upland rice ecosystem. Insect pest control should be implemented as needed.

Reference

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Benefit-cost ratio in producing aromatic and nonaromatic rice genotypes in Kashmir Valley

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Kashmir is well known for the cultivation of a large number of aromatic as well as nonaromatic landraces, which occupy different agroecological niches. Most of the aromatic rice varieties are local landraces maintained by farmers since time immemorial (now preserved at various rice stations of the university). Some of these varieties possess not only good aroma but also elite morphological features, which are desirable under our valley conditions. Of the aromatic genotypes, Mushk Budgi and Kamad are in great demand and are highly priced, whereas nonaromatic rice varieties K-332 and Jhelum (SKAU-27) are commercially grown. Since a vast difference is found in the yielding abilities of these aromatic and nonaromatic varieties, there is room for improving these aromatic cultivars. A study was carried out to determine the benefit-cost ratio (BCR) of producing these varieties to better identify the factors that may need to be manipulated to further improve these varieties.

The cost of cultivation per hectare was Rs 18,334 for Mushk Budgi, Rs 18,226 for Kamad, and Rs 16,186 for the high-yielding commercial varieties Jhelum (under valley basins) and K-332 (under high-altitude conditions) (Table 1a). The variation in the cost of cultivation was due to the different cost of seed—Rs 18 kg^{-1} for Mushk Budgi and Rs 15 kg^{-1} for Kamad as against Rs 6 kg^{-1} for Jhelum and K-332. Moreover, an additional expenditure of Rs 1,540 was incurred when prophylactic measures were taken to control blast in the local cultivars. An estimation of net income and benefits and BCR showed that the high-yielding commercial varieties gave the highest net income of Rs 28,814 and Rs 16,214 under valley basin and high-altitude conditions, respectively (Table 1b). Mushk Budgi performed better than Kamad, giving a net income of Rs 24,866 and Rs 14,066 under valley basin and high-altitude conditions, respectively, as compared with Kamad's Rs 15,374 and Rs 6,074. The highest BCR (1.78) was observed in Jhelum grown under valley basin conditions, followed by Mushk Budgi's 1.36 under the same conditions. K-332, which was recommended for high-altitude conditions, gave a BCR of 1.0. Mushk Budgi, under high-altitude conditions, gave a BCR of 0.77. Kamad had the lowest BCR values—0.84 and 0.33 under valley basin and high-altitude conditions, respectively.

It was evident that the high-yielding commercial varieties gave the maximum net returns and BCR under both conditions, followed by Mushk Budgi. An improvement in the yield of Mushk Budgi, through hybridization and selection of recombinants in advanced generations possessing good qualities of this variety (e.g., kernel size, milling percentage, head rice recovery, and aroma), will result in greater remuneration for farmers. There is thus an emerging need to improve the local aromatic landraces to develop varieties with high yield and aroma.

Table 1a. Cost of cultivation of high-value local aromatic rice and high-yielding commercial varieties.

Operation/input	Number/quantity required ha^{-1}	Total cost involved (Rs ha^{-1})
Power		
Tractors	Three tillings	1,300
Puddling by bullocks	Four pairs	1,000
Material		
Cost of seed	60 kg Mushk Budgi	1,080
	Kamad	900
	Jhelum/K-332	400
Fertilizer		
Urea	145 kg	609
Diammonium phosphate	105 kg	903
Muriate of potash	37 kg	172
Weedicide (Machete)	30 kg	415
Labor		
Bunding	10 labor-day	450
FYM application	–	500
Application of inputs	2 labor-day	90
Uprooting of seedlings and transfer to transplanting site	15 labor-day	675
Transplanting	80 labor-day	3,600
Hand weeding	20 labor-day	900
Irrigation	15 labor-day	675
Harvesting	20 labor-day	900
Bundling of harvested produce	15 labor-day	675
Transporting to threshing floor	15 labor-day	675
Threshing, cleaning, and bagging	50 labor-day	2,250
Control measures against blast		
Seed treatment	200 g fungicide	140
Two sprayings	1,000 g fungicide	1,400
Mushk Budgi		18,340
Kamad		18,226
Jhelum/K-332		16,186

Table 1b. Benefit-cost ratio (BCR) in producing high-value local aromatic rice versus high-yielding commercial varieties.

Agroclimatic condition	Cultivar/ variety	Av grain/straw yield (q ha^{-1})		Gross income (Rs ha^{-1})	Total expenditure (Rs ha^{-1})	Net income (Rs ha^{-1})	BCR
		Grain	Straw				
Cultivation under Kashmir valley basin conditions (up to 1750 m)	Mushk Budgi	20	36	43,200	18,334	24,866	1.36
	Kamad	18	33	33,600	18,226	15,374	0.84
	Jhelum	50	75	45,000	16,186	28,814	1.78
Cultivation under high-altitude conditions (1750-2250 m)	Mushk Budgi	15	27	32,400	18,334	14,066	0.77
	Kamad	13	24	24,300	18,226	6,074	0.33
	Jhelum	36	54	32,400	16,186	16,214	1.00

Cost per unit of grain for calculation of net income and benefit-cost ratio.

Cultivar/variety	Cost of grain (Rs ha^{-1})	Cost of straw (Rs q^{-1})
Mushk Budgi	1,800	200
Kamad	1,500	200
Jhelum	600	200
K-332	600	200

Forestry plantations on rice bunds: farmers' perceptions and technology adoption

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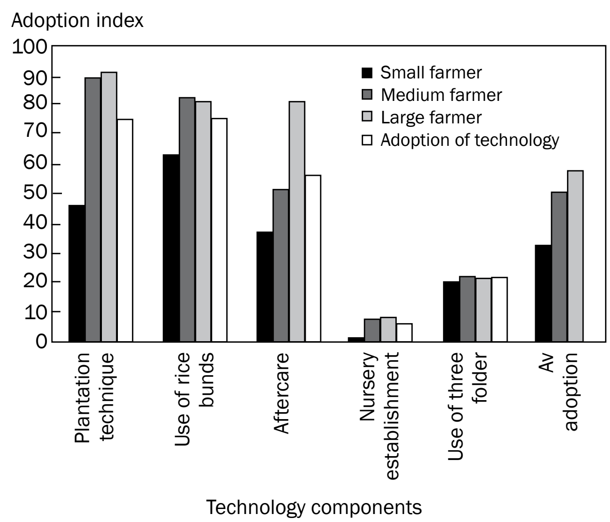
This study was conducted in Durg District, Chhattisgarh State, where about 8% of the area (0.87 million ha) is forested. The villagers collect wood products from forests for their daily needs (mainly fuel wood). This ruthless cutting of trees and shrubs to narrow the gap between supply and demand of forest products endangers biodiversity and sustainable development, thereby adversely affecting ecological restoration.

Rice, a main crop of this region, is cultivated on 0.37 million ha, mostly under rainfed conditions in Durg. About 8–10% of the rice is grown in huge bunds. Generally, the new bunds are used to grow upland crops for 1–2 years; subsequently, these bunds are left fallow. In Chhattisgarh, the trees growing naturally on bunds and boundaries form an important traditional agroforestry system, dominated by *Acacia nilotica* (Bargali et al 2004), a hardy species that provides fuel, fodder, small timber, and gum. The north and south bunds of these rice fields may be successfully used to grow suitable tree species without affecting light intensity and thereby productivity of the rice crop. The adoption of recommended tree species and management practices may give farmers more economic benefits and may reduce the pressure on government forests.

Eighty farmers were selected randomly from eight villages (10 from each) in three blocks (Durg, Dhamdha, and Gunderdehi) of Durg District. The farmers were then categorized on the basis of landholding—22 large (those who own > 4 ha), 39 medium (2–4 ha), and 19 small farmers (1–2 ha). They attended 2–7-d training activities on technology components (see figure) and were given tree saplings of their choice (>10 each farmer) at the beginning of the kharif season. After 2 years, a field survey was done and semistructured interviews were conducted. Adoption indices (AI) were calculated. Reasons for adopting/not adopting the technology were solicited. It was evident that farmers had equally adopted the plantation technique (av AI = 76.0) and planted trees on rice bunds (av AI = 76.3), followed by aftercare and management (av AI = 57) (see figure). The higher adoption of the technology components by all farmer categories reflected their need, area of interest, and awareness of technology benefits. Forestry nursery establishment was adopted by only 5.7% of the farmers probably because they were provided with saplings, which initially fulfilled their requirement. The highest



Technology adoption, by farmer category.

Species preferred by farmers for plantations.

Farmer category		
Small	Medium	Big
Bamboo (*Dandrocalamus strictus* Nees), eucalyptus (*Eucalyptus treticornis* Sm.)	Bamboo, eucalyptus, teak (*Tectona grandis* Linn.), khamar (*Gmelina arborea*)	Bamboo, eucalyptus, teak, khamar, sissoo (*Dalbergia sissoo* Roxb.)

average adoption of technologies was seen among large farmers (AI = 57.6), closely followed by medium farmers (AI = 51.2). Adoption was low among small farmers (AI = 33.6), as they had lesser landholding, limited resources, and moderate literacy.

Small landholders preferred only bamboo and *Eucalyptus* for bund and boundary plantations to meet their household requirements. Medium and large farmers preferred a number of species (see table) as they are into commercial production and they have better resources. Depommier et al (2002) articulated that the needs and strategies of small farmers usually correspond to subsistence agriculture with low inputs and, interestingly, a high level of diversification, which includes tree products and services. The multipurpose use of species partly satisfies the basic needs of poor farmers.

The data on planted saplings showed the highest mortality (71.5%) in small landholder plantations. This may be attributed to their poor socioeconomic conditions, less irrigation, limited aftercare resources, and open grazing by animals (inasmuch as the areas were not fenced). Most small farmers worked off-farm after the rice season and had no time to care for their animals. The large farmers' awareness and better management, care, and resources resulted in low mortality (28.8%) in their plantations.

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Utilization of *eui* gene from a recessive tall rice mutant 02428h in breeding

Wang Cai-lin, Zhao Ling, Zhu Zhen, and Zhang Ya-dong

To improve the panicle extrusion of photo- and thermosensitive sterile line 'Pei'ai 64S by using the elongated uppermost internode (*eui*) gene of the wide compatibility rice mutant 02428h, a new photo- and thermosensitive sterile line P8hS characterized by elongated uppermost internode was developed by transferring the *eui* gene into Pei'ai 64S through three successive backcrossings. Compared with Pei'ai 64S, P8hS was 35.6 cm higher, resulting from the elongation of the uppermost and the second internodes from the top. The panicle extrusion of Pei'ai 64S was completely improved and positive effects were found on the main agronomic characters of P8hS and its hybrids when the *eui* gene was introduced into Pei'ai 64S.

Rice Science. 2007. 14(1): 1-6
Full paper: www.ricesci.cn/pdfile/2007/E070101.pdf

Fertility expression of TGMS genes in the backgrounds of indica CMS lines, B lines, and R lines of hybrid rice

Wang Ji-feng and Lu Zuo-mei

The generation fertility of 51 F_1, 19 F_2, and 6 BC_1 of three thermosensitive genic male sterile lines (TGMS lines) Pei'ai 64S, 6311S, and 360S and the three lines of hybrid rice including seven indica cytoplasmic male sterile lines (CMS lines) and their corresponding maintainer lines (B-lines) and three indica restorer lines (R lines) were investigated to study the expression of TGMS genes in the backgrounds of the three lines of hybrid rice. Pei'ai 64S has stronger fertility restoring (*Rf*) genes for CMS lines and its TGMS trait is governed by two pairs of independent recessive genes; the TGMS trait of 6311S is governed by a single recessive gene with a weaker *Rf* gene in 6311S and the TGMS trait of 360S is governed by a single recessive gene with no *Rf* gene in 360S. The investigation on the fertility of F_1 plants between five CMS lines and four TGMS generations selected from F_2 plants of 4 CMS lines × 6311S confirmed that the expression of TGMS gene was controlled by *Rf* gene in the genetic background of cytoplasm of CMS lines but not affected by *Rf* gene in the genetic background of normal fertile cytoplasm. The potential breeding strategies of TGMS lines with cytoplasm of CMS lines and CMS lines with the nucleus of TGMS genes were discussed.

Rice Science. 2006. 13(4): 243-249
Full paper: www.ricesci.cn/pdfile/2006/E060403.pdf

Source-sink relationship in intersubspecific hybrid rice

Li Ji-hang, Xiang Xun-chao, He Li-bin, and Li Ping

Three indica restorer lines (Mianhui 725, Shuhui 527, and Shuhui 881), an American rice variety Lemont, and a javanica rice variety Xiangdali were crossed with japonica Kitaake, and five F_1 hybrids were obtained to study the photosynthetic and agronomic traits. The data on photosynthetic characteristics indicated that the net photosynthetic rate (Pn) of the five F_1 hybrids was significantly higher than that of their parents (or one of them) under high photosynthetic flux density (PFD); the overall performance of hybrids was better than their respective parents in terms of apparent quantum yield (AQY), carboxylation efficiency (CE), and CO_2 compensation point (CCP). Moreover, the photosynthetic performance of the five F_1 differed due to variation in heredity and the typical indica-japonica hybrids Mianhui 725/Kitaake and Shuhui 527/Kitaake were better than the others on this aspect. The agronomic traits revealed that the five F_1 exhibited different heterosis, with Shuhui 881/Kitaake having the largest sink, followed by Mianhui 725/Kitaake, Shuhui 527/Kitaake, Lemont/Kitaake, and Xiangdali/Kitaake. The production potential of indica-japonica hybrids was higher than that of the other two hybrids, which was consistent with the performance of Pn. However, the superior trait of indica-japonica hybrids on sink size has not been fully turned into high yield because of abnormal seed setting. Therefore, attention should be paid to proper genome coordination and appropriate genetic distance to achieve super high yield.

Rice Science. 2006. 13(4): 250-256
Full paper: www.ricesci.cn/pdfile/2006/E060404.pdf

Variation among rice cultivars in root acidification and its relation to cadmium uptake

Liu Jian-guo, Xu Hai, Cai Guo-liang, Qian Min, Wang De-ke, and Zhu Qing-sen

To understand the mechanisms of Cd uptake and accumulation in rice, soil acidification by root activities was investigated in six rice cultivars differing in Cd accumulation. The results showed a significant difference among the cultivars in terms of pH of pot water and root exudates. Soil acidification abilities varied with rice cultivars. Both pH of pot water and root exudates were lower in indica cultivars than in japonica ones. The difference in root acidification was larger in Cd-treated cultivars than in the control. Under Cd stress, the pH of pot water and root exudates correlated negatively and significantly with Cd concentrations in rice plants. It was suggested that soil acidification by root exudates, especially in Cd-contaminated soils, may be one of the mechanisms responsible for Cd uptake in rice cultivars.

Rice Science. 2006. 13(4): 278-282
Full paper: www.ricesci.cn/pdfile/2006/E060408.pdf

Effect of phosphorus deficiency on leaf photosynthesis and carbohydrate partitioning in two rice genotypes with contrasting low phosphorus susceptibility

Li Yong-fu, Luo An-cheng, Muhammad Jaffar Hassan, and Wei Xing-hua

To study the effect of phosphorus (P) deficiency on leaf photosynthesis and carbohydrate partitioning and to determine whether the characteristics of leaf photosynthesis and carbohydrate partitioning are related to low P tolerance in rice plants, a hydroponic culture experiment supplied with either sufficient P (10 mg L^{-1}) or deficient P (0.5 mg L^{-1}) was conducted by using two rice genotypes different in their responses to low P stress. Results showed that the plant growth of Zhenongda 454 (low P-tolerant genotype) was less affected by P deficiency compared with Sanyang'ai (low P-sensitive genotype). Under P-deficient conditions, photosynthetic rates of Zhenongda 454 and Sanyang'ai were decreased by 16% and 35%, respectively. Zhenongda 454 showed a higher photosynthetic rate than Sanyang'ai. Phosphorus deficiency decreased stomatal conductance in both genotypes but had no significant influence on leaf internal CO_2 concentration (Ci), suggesting that the decrease in leaf photosynthetic rate of rice plants induced by P deficiency was not due to stomatal limitation. Phosphorus deficiency increased the concentration of soluble carbohydrates and sucrose in the shoots and roots of both genotypes and also markedly increased the allocation of soluble carbohydrates and sucrose to the roots. Under deficient P supply, Zhenongda 454 had higher root-shoot soluble carbohydrate content ratio and root-shoot sucrose content ratio than Sanyang'ai. In addition, P deficiency increased the concentration of starch in roots for both genotypes, whereas it had no effect on the content of starch in the shoots or roots. Compared with genotype Sanyang'ai, the better tolerance for low-P stress of Zhenongda 454 can be explained by the fact that it maintains a higher photosynthetic rate and a greater ability to allocate carbohydrates to the roots under P deficiency.

Rice Science. 2006. 13(4): 283-290
Full paper: www.ricesci.cn/pdfile/2006/E060409.pdf

Relation of root growth of rice seedlings with nutrition and water use efficiency under different water supply conditions

Zheng Bing-song, Jiang De-an, Wu Ping, Weng Xiao-yan, Lu Qing, and Wang Ni-yan

Water deficiency is one of the primary yield-limiting factors in rice. In plants, nutrition and water use efficiency depend on root growth efficiency under different water supply conditions (WSC). Three rice genotypes—Azucena (an upland japonica), IR1552 (a lowland indica), and Jia 9522 (a lowland japonica)--were grown under different WSC with 0 cm (submerged), 40 cm, and 80 cm groundwater levels below the soil surface to investigate root parameters, water use efficiency, NPK content, net photosynthetic rate, and transpiration rate of the rice plant. The relative parameters were defined as the ratio of the parameters under submerged conditions (0 cm groundwater level below soil surface) to those under upland conditions (40 cm and 80 cm groundwater levels below soil surface). The results indicated that different genotypes showed different relative root parameters and relative nutrition content and water use efficiency under different WSC. The length and number of adventitious roots are more important

than seminal root length in water and nutrition uptake and maintaining the grain yield and increasing dry matter, but the adventitious root number could not serve as an index for screening drought-resistant genotypes. Furthermore, different drought-resistant genotypes have also been found. Azucena was resistant to drought, IR1552 was sensitive to drought, and Jia 9522 was neither sensitive nor resistant.

Rice Science. 2006. 13(4): 291-298
Full paper: www.ricesci.cn/pdfile/2006/E060410.pdf

A rapid DNA mini-prep method for large-scale rice mutant screening

Qiu Fu-lin, Wang He-he, Chen Jie, Zhuang Jie-yun, H. Leung, and Cheng Shi-hua

A high-throughput rice DNA mini-preparation method was developed. The method is suitable for large-scale mutant bank screening as well as for large mapping populations with characteristics of maintaining relatively high level of DNA purity and concentration. The extracted DNA was tested and was found suitable for regular PCR amplification (SSR) and for Targeting Induced Local Lesion in Genome (TILLING) analysis.

Rice Science. 2006. 13(4): 299-302
Full paper: www.ricesci.cn/pdfile/2006/E060411.pdf

Cloning and expression analysis of *OsNADPH1* gene from rice in drought stress response

Chen Jing, Wan Jia, Jiang Hua, Gao Xiao-ling, Wang Ping-rong, Xi Jiang, and Xu Zheng-jun

An experiment was conducted to compare the mRNA expression difference in rice leaves and roots under drought stress and normal conditions using the fluorescent differential display (FDD) method. One positive fragment was isolated by combination of the H. A. Yellow-PAGE (contained 0.1% H. A. Yellow) separation and macroarray screening methods. Compared with *Arabidopsis thaliana* NADPH oxidoreductase gene, it has 96% identity. The cDNA was 1423 bp and contained a complete open reading frame of 1048 bp encoding a protein with 345 amino acid residues. Moreover, the gene expression level was higher under drought stress than under normal conditions. The possible role of NADPH oxidoreductase gene under drought response was also discussed.

Rice Science. 2006. 13(3): 149-154
Full paper: www.ricesci.cn/pdfile/2006/E060301.pdf

Identification of QTLs for cooking and eating quality of rice grain

Sun Shi-yong, Hao Wei, and Lin Hong-xuan

The backcross inbred line (BIL) population derived from the cross between Koshihikari (good eating and cooking quality, japonica) and Kasalath (poor quality, indica) was used to analyze QTLs for amylose content (AC), gelatinization temperature (GT), gel consistency (GC), and protein content (PC). Eight main-effect QTLs including two for AC, three for GT, two for GC, and one for PC were identified. Moreover, 27 epistatic QTL pairs, including seven for AC, five for GT, four for GC, and 11 for PC were also detected, whereas for AC and GT, one main-effect QTL with a major gene was detected, respectively. Therefore, the main-effect QTL might be more responsible for the current variation than the epistatic QTL. The results indicated that the main-effect QTL is the primary genetic basis for those traits. However, for PC, the epistatic QTL explained a much greater portion of the total variation than did main-effect QTL, suggesting that epistatic loci are the primary genetic basis for such trait. In the experiment, chromosome segment substitution lines (CSSLs) were used to confirm the reliability of the main-effect QTLs detected in the BIL population. Of the eight main=effect QTLs for four traits in BIL analysis, six were confirmed and two remained unconfirmed by CSSL analysis.

Rice Science. 2006. 13(3): 161-169
Full paper: www.ricesci.cn/pdfile/2006/E060303.pdf

Variations in concentration and distribution of health-related elements affected by environmental and genotypic differences in rice grains

Ren Xue-liang, Liu Qing-long, Wu Dian-xing, and Shu Qing-yao

Research was conducted to investigate the variations in concentration and distribution of health-related elements affected by environmental and genotypic differences in rice grains. The grains of Xieqingzao B (indica) and Xiushui 110 (japonica) were divided into hull, bran, and milled rice, based on conventional rice consumption and process. Xieqingzao B was grown at four different locations; in one location, it was planted in the same field and season as Xiushui 110. In addition, another four indica and four japonica varieties were cultivated in the same field and time to analyze the elements in milled rice. The average concentrations of total P and phytic acid P were highest in the bran, followed by milled rice, and hull; Zn, K, Mg, and As concentrations were highest in bran, followed by hull, and milled rice; and Fe, Ca, and Cu concentrations were highest in the hull, and similar in bran and milled rice. The results indicated that genotype and environment significantly affected the concentrations of all the tested elements, while the distribution of the above elements in the grains was not in the same order as that of concentration. Moreover, all the elements, except 97.7% of Cu and 93.2% of Fe deposited in the hull on average, were mostly distributed either in the bran (37.3% and 57.7% for K and phytic acid P) or in milled rice (41.7%, 42.6%, 40.3%, and 49.8% for Zn, Mg, As, and total P, respectively).

Rice Science. 2006. 13(3): 170-178
Full paper: www.ricesci.cn/pdfile/2006/E060304.pdf

Photosynthetic characteristics and heterosis in transgenic hybrid rice with *maize phosphoenolpyruvate carboxylase* (*pepc*) gene

Li Ji-hang, Xiang Xun-chao, Zhou Hua-qiang, He Li-bin, Zhang Kai-zheng, and Li Ping

Three F_1 hybrids derived from sterile rice lines Gang 46A, 776A, and 2480A and improved restorer line Shuhui 881 containing *maize phosphoenolpyruvate carboxylase* (*pepc*) gene were used to analyze the effect of this gene on heterosis and photosynthetic characteristics, while the F_1 obtained by crossing Shuhui 881 with the three above mentioned sterile lines served as control. The dynamics of photosynthetic characteristics in leaves of three F_1 lines with *pepc* gene and their control was determined at initial tillering, maxium tillering, elongation, initial heading, heading, maturity stages, and at other different times after the flag leaf has fully expanded. The PEPCase activities of the three F_1 with *pepc* gene increased significantly as compared with control plants during the whole developmental stage. Moreover, net photosynthesis rate (Pn) also increased to a certain extent. The data showed that PEPCase activity was significantly correlated to Pn (correlation coefficient of 0.6081**). The photosynthetic indexes of the three F_1 with *pepc* gene were obviously superior to the respective control in apparent quantum efficiency, light compensation point, and carboxylation efficiency, while the CO_2 compensation point was lower than that of the corresponding control. The Pn of the three F_1 with *pepc* gene at light saturation point and CO_2 saturation point was also higher than that of control plants. In addition, the three F_1 with *pepc* gene had an average increase of 37.10% in grain yield per plant in comparison with control plants. The results indicated that the photosynthetic characteristics of hybrid rice containing the *pepc* gene had been improved to some extent due to the introduction of this gene.

Rice Science. 2006. 13(3): 185-192
Full paper: www.ricesci.cn/pdfile/2006/E060306.pdf

Effects of nitrogen fertilizer treatments on filling and respiratory rate of caryopsis in rice

Chen Juan, Wang Zhong, Chen Gang, and Mo Yi-wei

An experiment was conducted to study the effects of nitrogen (N) rate and application time on grain filling and respiratory trait of caryopsis in two rice varieties IR36 and Dali. The treatments consisted of no N application topdressing at both tillering and booting stages (CK), 6 g pot^{-1} of N topdressing at the tillering stage and 2 g pot^{-1} of N topdressing at the booting stage, 2 g pot^{-1} of N topdressing at the tillering stage and 6 g pot^{-1} of N topdressing at the booting stage. The results showed that proper utilization of N fertilizer can maintain higher water content, higher respiratory rate, and higher dehydrogenase activity of rice caryopsis in the late-filling phase and prolong the course for filling and maintaining higher respiratory rate and dehydrogenase activity of rice caryopsis. More N application at booting was more effective than at tillering.

Rice Science. 2006. 13(3): 199-204
Full paper: www.ricesci.cn/pdfile/2006/E060308.pdf

Effect of high temperature on sucrose content and sucrose-cleaving enzyme activity in rice grain during the filling stage

Li Tian, Liu Qi-hua, Ryu Ohsugi, Tohru Yamagishi, and Haruto Sasaki

Dynamic changes in sucrose, fructose, and glucose contents and differences in activities of sucrose synthase, vacuolar invertase, and cell wall-bound invertase in rice grain after flowering stage were studied under natural and high temperatures by using japonica rice varieties Koshihikari and Sasanishiki. In rice grains, the sucrose synthase activity was higher than that of invertase, which was significantly correlated with starch accumulation rate, indicating that sucrose synthase played an important role in sucrose degradation and starch synthesis. Under high temperature, the significant increase in grain sucrose content without any increase in fructose and glucose contents suggested that the high-temperature treatment enhanced sucrose accumulation, while diminishing sucrose degradation in rice grains. Compared with control plants, the decrease in activities of sucrose synthase, vacuolar invertase, and cell wall-bound invertase with high temperature-treated plants indicated that the deceleration of sucrose degradation was related to the decrease in activities of sucrose synthase and invertase.

Rice Science. 2006. 13(3): 205-210
Full paper: www.ricesci.cn/pdfile/2006/E060309.pdf

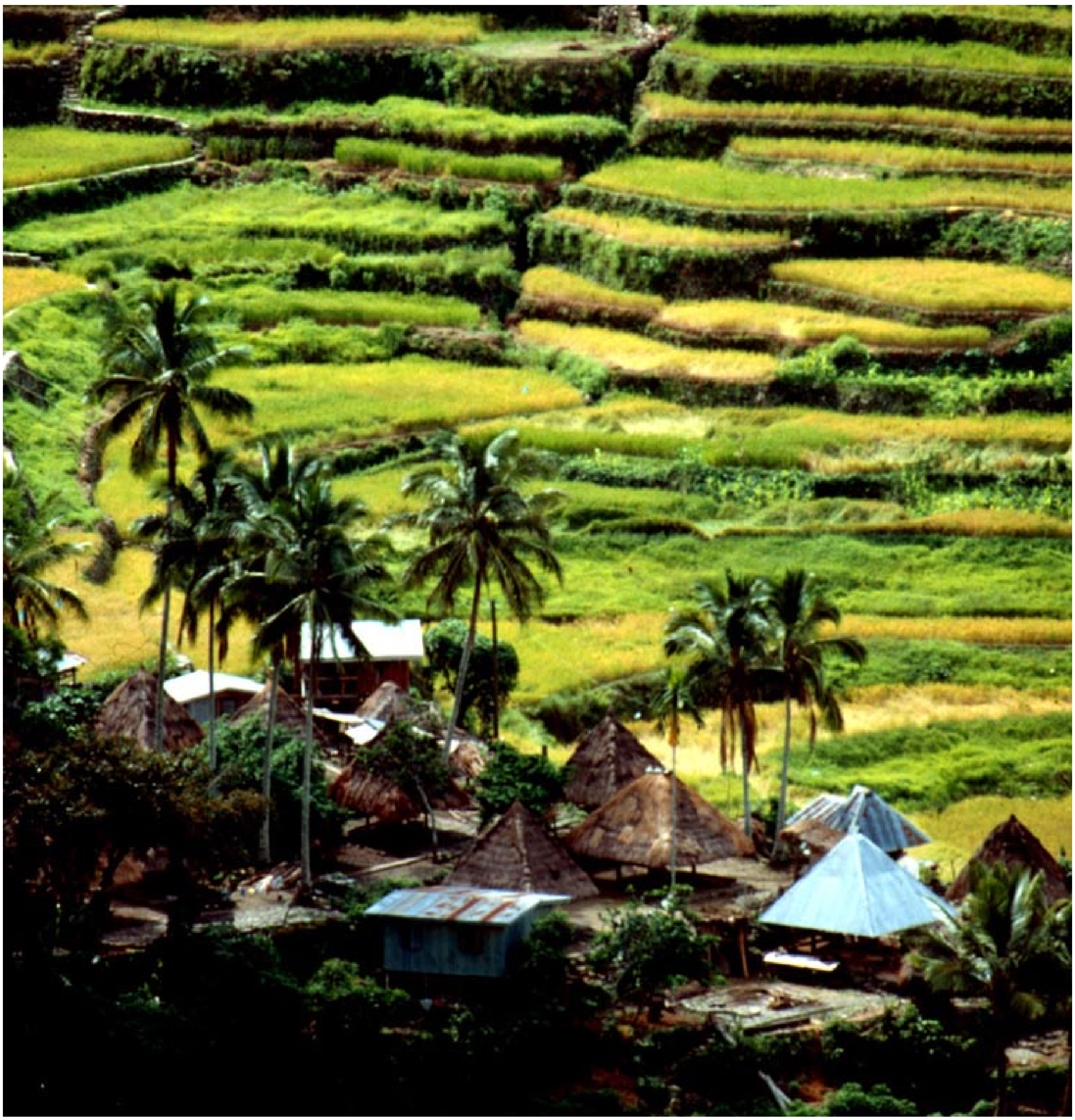
Biodiversity and dynamics of planthoppers and their natural enemies in rice fields with different nitrogen regimes

Lu Zhong-xian. S. Villareal, Yu Xiao-ping, K. L. Heong, and Hu Cui

A field experiment was conducted to study the effect of different N fertilizer rates— i.e., 200, 100, and 0 kg N ha^{-1} on paddy fields at the International Rice Research Institute, Manila, Philippines. The biodiversity of arthropods sampled by blower-vac and the dynamics of planthoppers, egg parasitoids of Homoptera trapped by rice plants with eggs of brown planthoppers (BPH) *Nilaparvata lugens*, and web spiders on rice canopy collected by sweeping net were analyzed at different rice growth stages. The most abundant arthropods were sampled at the milking stage of rice, totaling 116 species identified into 14 insect orders and 15 species of spiders in all samples. Meanwhile, the number of arthropod species significantly increased with rice growth and the diversity indices increased with the increase N rate at booting stage. On the other hand, in the dominant predators, *Pardosa pseudoannulata*, *Callitrichi formosana*, *Micraspis* sp., *Cyrtorhinus lividipennis*, *Veliidae* sp., and *Mesoveliidae* sp., only the abundance of C. *lividipennis* and *Micraspis* sp. increased significantly following the application of N at the milking stage. The egg parasitoids of planthoppers were predominated by *Anagrus flaveolus* and *Oligosita* sp. and their densities in the field without N fertilizer were markedly higher than those in fields with

100 and 200 kg N ha^{-1} at both booting and milking stages. The number and web area of dominant residential spiders *Tetragnatha* sp. and *Araneus* sp. in the rice canopy were significantly reduced with the increase in N fertilizer. The population density of planthoppers, including BPH and the whitebacked planthoppers *Sogatella furcifera* Horváth, peaked during the booting stage. However, the number of BPH in the rice field with 200 kg N ha^{-1} was considerably higher than those in the two other rice fields with 100 and 0 kg N ha^{-1} at the booting as well as the milking stage. These results indicate that the rapid growth in populations of planthoppers due to excessive N might be attributed to the combination of reduction in control capacity of the natural enemies and the strong stimulation of N to planthoppers.

Rice Science. 2006. 13(3): 218-226
Full paper: www.ricesci.cn/pdfile/2006/E060311.pdf



IRRN welcomes three types of submitted manuscripts: research notes, mini reviews, and "notes from the field." All manuscripts must have international or pan-national relevance to rice science or production, be written in English, and be an original work of the author(s), and must not have been previously published elsewhere. By submitting the manuscript, the author automatically assigns the copyright of the article to IRRI.

Research notes

Research notes submitted to IRRN should

- report on work conducted during the immediate past 3 yr or work in progress
- advance rice knowledge
- use appropriate research design and data collection methodology
- report pertinent, adequate data
- apply appropriate statistical analysis, and
- reach supportable conclusions.

Routine research. Reports of screening trials of varieties, fertilizer, cropping methods, and other routine observations using standard methodologies to establish local recommendations are not ordinarily accepted.

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Each note may include up to two tables and/or figures (graphs, illustrations, or photos). Refer to all tables and figures in the text. Group tables and figures at the end of the note, each on a separate page. Tables and figures must have clear titles that adequately explain contents.

Apply these rules, as appropriate, to all research notes:

Methodology

- Include an internationally known check or control treatment in all experiments.
- Report grain yield at 14% moisture content.
- Quantify survey data, such as in fection percentage, degree of severity, and sampling base.
- When evaluating susceptibility, resistance, and tolerance, report the actual quantification of damage due to stress, which was used to assess level or incidence. Specify the measurements used.
- Provide the genetic background for new varieties or breeding lines.
- Specify the rice production sys tems as irrigated, rainfed lowland, upland, and flood-prone (deepwater and tidal wetlands).
- Indicate the type of rice culture (transplanted, wet seeded, dryseeded).

Terminology

- If local terms for seasons are used, define them by characteristic weather (dry season, wet season, monsoon) and by months.
- Use standard, internationally recognized terms to describe rice plant parts, growth stages, and management practices. Do not use local names.
- Provide scientific names for diseases, insects, weeds, and crop plants. Do not use local names alone.
- Do not use local monetary units. Express all economic data in terms of the US$, and include the exchange rate used.
- Use generic names, not trade names, for all chemicals.
- Use the International System of Units for all measurements. For example, express yield data in metric tons per hectare (t ha^{-1}) for field studies. Do not use local units of measure.
- When using acronyms or abbreviations, write the name in full on first mention, followed by the acronym or abbreviation in parentheses. Use the abbreviation thereafter.
- Define any nonstandard abbreviation or symbol used in tables or figures in a footnote, caption, or legend.

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Notes from the field should address important new observations or trends in rice-growing areas, such as pest outbreaks or new pest introductions, or the adoption or spread of new crop management practices. These observations, while not the result of experiments, must be carefully described and documented. Notes should be approximately 250 words in length. Refer to the guidelines for research notes for other aspects of writing and content.

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2008·09·11-15 CHANGSHA·CHINA

5th International Hybrid Rice Symposium

Sustaining Development for Hybrid Rice

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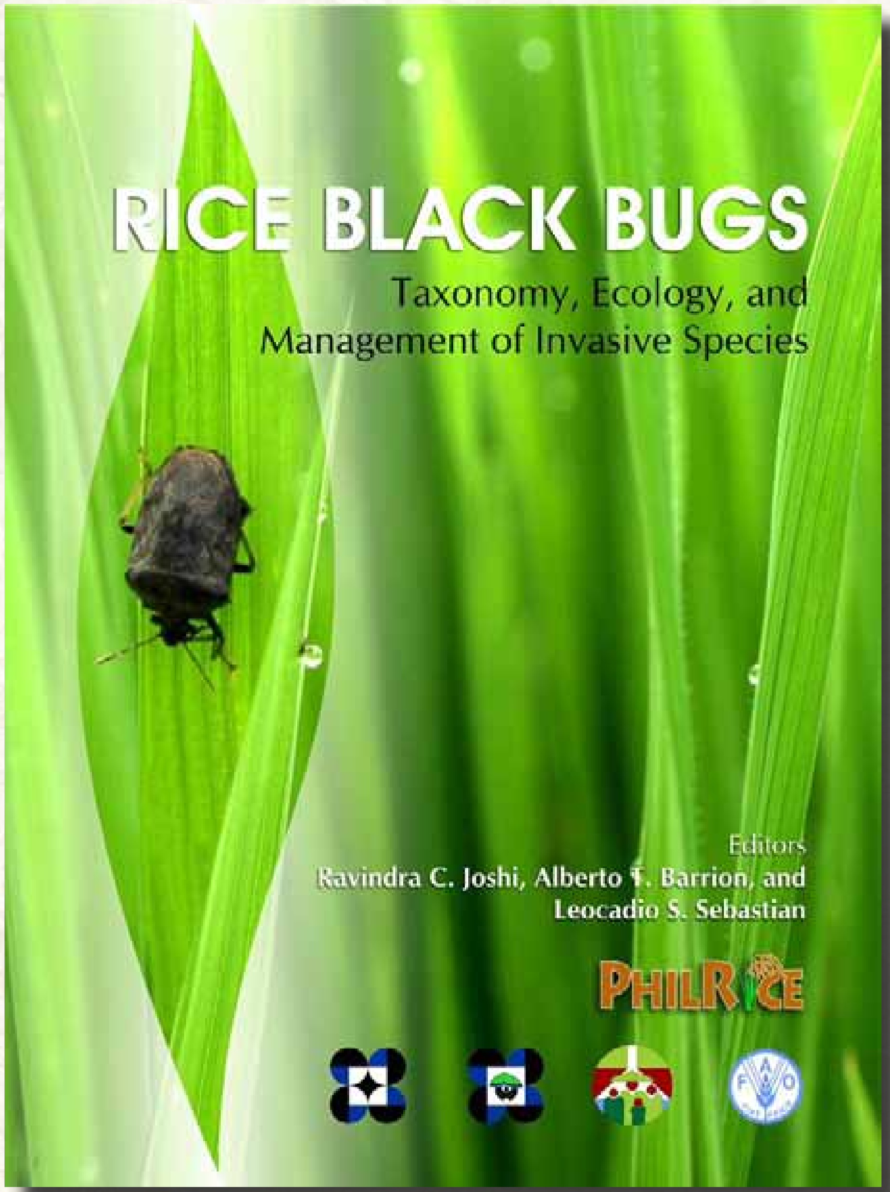
Rice black bugs: taxonomy, ecology, and management of invasive species Edited by R.C. Joshi, A.T. Barrion, and L.S. Sebastian; published by PhilRice; 800 pages; Philippines P2,500, developed countries $102, developing countries $52.

This book includes ecologically sound management approaches to rice black bug (RBB) outbreaks, country reports of RBB invasions, and clarifications of confusing RBB taxonomy. This reference manual reinterprets old problems and introduces new ecological techniques for RBB management. The book comes with a searchable DVD containing more than 300 articles on RBB from experts around the world, dating from as far back as 1864 up to 2006. Orders: email prri@philrice.gov.ph or visit http://tinyurl.com/2su32m.



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