African Journal of Agricultural Research Vol. 7(26), pp. 3819-3827, 10 July, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR12.541
ISSN 1991-637X

Full Length Research Paper

Increase in rice yield through the use of quality seeds in Bangladesh

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Accepted 21 February, 2012

A farmer participatory research was conducted to determine the yield advantage of cleaned seeds over farmer-saved seeds in seven sites in Bangladesh in five cropping (three Boro and two transplant Aman) seasons. In each site, 30 participating farmers transplanted seedlings from cleaned seeds and their saved seeds of the same variety in adjacent plots in their fields. The results show a significantly higher grain yield in the cleaned seed than the farmer-saved seeds of 10.1% in Boro season and 11.3% in transplant (T) Aman season. The highest advantage in yield of cleaned seeds over farmer-saved seeds of 12.2% was observed in Barisal in Boro season, and 15.5% in Habiganj in T. Aman season. In the Boro season, significantly lower mean incidences of weeds below canopy, rice hispa, whiteheads, brown planthopper and bakanae were observed for cleaned seeds than for farmer-saved seeds. In the T. Aman season, significantly lower mean incidences of deadheart, whiteheads, gall midge, green leafhopper, other defoliators, sheath blight, sheath rot, and kernel smut were observed for cleaned seeds than for farmer-saved seeds. This indicates that using cleaned rice seeds increased grain yield, enhanced crop growth and also reduced damage from weeds, insect pests and diseases.

Key words: Rice, seed health, quality, yield, farmer participatory research.

INTRODUCTION

Rice is grown on 10.27 million ha in Bangladesh producing 94% of the total food grain requirement, but there is still a need to increase production to feed the growing population with rapid increase of 1.8% per year (Sattar, 2000). The rice yield gap due to biotic and socio-economic constraints in Bangladesh is about 0.9 and 1.3 tons ha^{-1} for the Boro (winter) and the Transplant (T) Aman (monsoon) seasons, respectively. To meet the dietary needs and fulfill the yield gap, an additional production of 0.3 million tons and 7.5 million tons of rice every year is needed. The use of poor quality rice seed for planting is a major contributory factor to this yield gap (Hossain, 2004).

In Bangladesh, 80% of the rice is planted from farmer's own harvest procurement, 10% through imports, while only 10% certified seeds is available from the Bangladesh Agricultural Development Corporation, non-government organizations (NGOs) and private seed companies (Hossain, 2004). Due to poor and inappropriate storage infrastructure incurred at farmer's field, there are reduced rice seed quality due to low purity, low germination rate and high moisture content (Huda, 1992; Mia and Nahar, 2000) and carrier of seed-borne pathogens (Islam et al., 1994; Mia and Nahar, 2000). Inadequate technical knowledge constrains the good storage of farmer's harvested seeds to be used for planting and causes lower yield (Karim, 1999). Poor quality of rice seeds often results from infection by pathogens (fungi, bacteria and nematode) (Mew and

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Gonzales, 2002; Mew and Misra, 1994), weeds and rice mixtures (Delouche, 1988) and insect pests (both storage and field pests) (Peng and Morallo-Rejesus, 1988). Using poor quality rice seeds for planting reduces the productivity of modern cultivars in attaining its genetic potential (Mew et al., 2004). For instance, the use of high-quality IR64 foundation seeds showed a significant increase of 7 to 20% in grain yield over low-quality IR64 farmer-saved seeds in a farmer participatory research in Central Luzon, Philippines (Diaz et al., 1998).

In this study, we assessed the quality of farmer–saved rice seeds and estimated the yield gains by using clean seeds for planting with a view to enhancing farmers' awareness on the importance of seed health in rice production. Information addressing the benefits of using good seeds was disseminated to farmers and this stimulated the curiosity of farmers on crop management using quality seeds.

MATERIALS AND METHODS

Experimental site

The farmer participatory experiment was conducted in seven districts of Bangladesh representing distinct agro-ecological zones. These are Barisal (Ganges Tidal floodplain, coastal non-saline submergence-prone), Bogra (Barind tract, irrigated double cropped rice system), Chuadanga (High Ganges floodplain, drought-prone medium land), Gazipur (Brahmaputra-Jamuna floodplain, favorable upland), Habiganj (Surma-Kusiyara floodplain, flood-prone lowland), Rajshahi (Barind tract, drought-prone highland), and Rangpur (Tista Meander floodplain, favorable floodplain) (FAO, 2004). In each district, 30 farmers' fields were used in the experiment. The 30 fields were fixed from season to season although some fields, being too far or becoming flooded, were replaced. The study was carried out in five cropping seasons, three of Boro and two of T. Aman season. Boro or winter rice is grown from January to June under irrigated conditions, while the Transplanted Aman (T. Aman) or monsoon rice is grown from July to December mostly under rain-fed conditions as described (Rashid, 1994).

Seed cleaning

In the first cropping season, a farmers' training workshop on seed cleaning was held. Each participating farmer brought seed samples of own harvest, and cleaned 1 kg of each by manual seed sorting. Farmers were trained in identifying different poor seed conditions and contaminants. Prior to sowing, the seed components were removed by floating method.

Crop establishment and management

Seedlings of transplanted rice were raised in a seedbed side by side from farmer-saved seeds. All other crop management practices such as fertilizer application and pest management were kept uniform and similar for both of seed sources used. In the subsequent seasons, seeds to be used for next season's planting were taken from the cleaned seed plot where the field seed health selection process was done as a supplement to seed cleaning. In the field seed health selection process, an area of uniform crop stand in the cleaned seed plot was selected and marked with flags. Roguing of weeds and varietal mixtures was conducted at maximum tillering stage, booting stage and one week before harvesting in the selected area. In addition, infected panicles were also rogued out at one week before harvesting.

Data collection

Two sets of data were collected from the cleaned seed and farmer seed plots in the selected parcel - that is the general information describing the field and on crop growth, pests and grain yield. One diagonal line pattern of sampling was done using 10 hills per plot. Data on general information consisting of planting dates, previous crop, fallow period, rice variety, fertilizer application, crop growth and development stage, disease and insect pests incidence were done using the method describe by Elazegui et al. (1990) and Savary et al. (1997).

Weed infestation was assessed as percent ground area covered by the weeds above and below the rice canopy. Weeds were observed from three 1 m^2 sampling areas in the first to third visit and from one sampling area (whole plot) in the fourth visit. Grain yield was harvested by farmers from a 6 m^2 crop area in the cleaned and farmer seed plots in each farmer's field. The researchers supervised the harvesting by farmers. Grain yield was adjusted at 14% moisture content.

Data management and analysis

Some of the pest data were integrated over time to obtain indices indicating damage mechanisms (Savary et al., 1997). Diseases like brown spot and narrow brown spot, and leaf injuries due to whorl maggot, leaf folder and other leaf feeders observed throughout the crop development stages were integrated over time by determining the area under disease or injury progress curve. On the other hand, diseases like sheath blight and sheath rot, stem borer injuries, deadheart and whitehead, which are observed at definite development stages of the crop were represented using its maximum incidence.

Data on grain yield, crop growth parameters, weeds, insects and disease incidences were analyzed separately for the Boro and T. Aman seasons using PROC MIXED in SAS (Anonymous,1998).. Data that are not normally distributed were transformed using appropriate transformations. The treatments of cleaned and farmer-saved seeds and their interaction with the seven sites representing distinct agro-ecological zones were considered as fixed effects. Years and farmers' fields nested within sites and years were considered as random effects. Pair wise comparison of means between cleaned and farmer seed treatments were done using *t*-tests with PDIFF option.

RESULTS

Grain yield

The farmer participatory research showed that the cleaned (quality) rice seed treatment produced a significantly higher mean grain yield than the farmer's seed in the Boro and T. Aman seasons averaged across sites and years (Table 1). The advantage in mean grain yield of cleaned seeds over farmer seeds ranged from 8 to 12% and 7 to 15% in the Boro and T. Aman seasons, respectively. The yield advantage in grain yield across

Table 1. Mean grain yield (t/ha) between cleaned and farmer-saved seed in a farmer participatory research in the Boro and T. Aman seasons in seven sites in Bangladesh.

Season	Site	Cleaned seed	Farmer seed	Difference
Boro[a]	Barisal	5.35	4.7	0.65***[c]
	Bogra	5.81	5.16	0.65***
	Chuadanga	5.52	4.98	0.54***
	Gazipur	5.30	4.85	0.45***
	Rangpur	5.62	5.14	0.48***
	Habiganj	4.55	4.12	0.43*
	Rajshaji	6.82	6.11	0.71***
	Mean	5.57	5.01	0.56***
T. Aman[b]	Barisal	4.76	4.43	0.33*
	Bogra	3.97	3.65	0.32*
	Chuadanga	3.96	3.48	0.48**
	Gazipur	4.45	3.82	0.63**
	Rangpur	4.02	3.54	0.48**
	Habiganj	4.39	3.71	0.68**
	Rajshaji	4.03	3.63	0.40*
	Mean	4.23	3.75	0.47***

[a]Mean of three seasons; [b]mean of two seasons; [c]* - significant at *P*=0.05; ** - significant at *P*=0.01; *** - significant at *P*=0.001 (Based on *t*-tests).

Table 2. Mean crop growth parameters between cleaned and farmer-saved seed in a farmer participatory research in the Boro and T. Aman seasons in seven sites in Bangladesh.

Season	Variable	Cleaned seed	Farmer seed	Difference
T. Aman[a]	Uniformity (%)	86.84	82.35	4.49***[b]
	Number of leaves (AUC)[c]	4473.73	4214.28	259.45***
	Number of tillers	16.31	15.54	0.77***
	Number of panicles	12.71	11.62	1.09**
	Plant height (AUC)[d]	7965.49	7874.92	90.57[ns]
Boro[e]	Uniformity (%)	87.74	85.52	2.22[ns]
	Number of leaves (AUC)[c]	5231.71	5034.12	197.59[ns]
	Number of tillers	18.30	17.80	0.50[ns]
	Number of panicles	15.54	14.87	0.67[ns]
	Plant height (AUC)[d]	6742.42	6641.05	101.37[ns]

[a]Mean of seven sites in two seasons; [b]** significant at *P*=0.01; *** significant at *P* = 0.001; ns – not significant at *P* = 0.05 (based on *t*-tests); [c]AUC – area under the curve (% dsu^{-1} (crop development stage unit)); [d]AUC – area under the curve (cm dsu^{-1} (crop development stage unit)); [e]mean of seven sites in three seasons.

years and sites of cleaned seeds was 10.1 and 11.3%, in the Boro and T. Aman seasons, respectively. Meanwhile, the highest advantage in yield of cleaned seeds over farmer seeds was observed in Barisal, a tidal non-saline submergence-prone environment, in the Boro season with 12.2%, and in Habiganj, a flood-prone environment, in the T. Aman season with 15.5%. Higher yields were obtained in Boro than in T. Aman seasons in all sites across years.

Crop stand and weeds

Significant differences in mean crop stand variables between cleaned and farmer seed treatments were observed in the T. Aman season, but not in the Boro season (Table 2). The cleaned seed treatment had 5.2% higher uniformity than the farmer seed treatment in the T. Aman season. In addition, cleaned seeds had 5.8, 4.7 and 8.6% more leaves, tillers, and panicles respectively

Table 3. Crop morphological variables and weed incidence between cleaned and farmer-saved seed in a farmer participatory research in the Boro and T. Aman seasons in seven sites in Bangladesh.

Variable	Season	Site	Cleaned seed	Farmers' seed	Difference
Uniformity (%)	Boro	Gazipur	75.33	71.47	3.86*[a]
	T. Aman	Bogra	80.24	74.42	5.82*
		Gazipur	75.33	68.77	6.56*
		Habiganj	92.00	86.47	5.53*
		Rajshaji	94.88	89.56	5.32*
Number of leaves (AUC)[b]	Boro	Habiganj	5661.30	5190.90	470.4*
	T. Aman	Chuadanga	4232.92	3919.44	313.48*
		Gazipur	3766.86	3546.87	219.99*
		Rangpur	3788.23	3534.14	254.09*
		Rajshaji	4915.64	4326.98	588.66**
Number of panicles	T. Aman	Rajshaji	11. 90	10.87	1.03*
Number of tillers	T. Aman	Chuadanga	15.02	14.18	0.84*
		Rangpur	17.96	16.91	1.05*
		Rajshaji	16.39	14.79	1.60**
Weeds below canopy (AUC)	Boro	Barisal	130.74	129.90	0.84*

[a]* Significant at $P = 0.05$; **significant at $P = 0.01$; ***significant at $P = 0.001$ (based on *t*-tests). [b]AUC, Area under the curve (% dsu (crop developmental stage unit)).

than farmer seeds averaged across years and sites in the T. Aman season. Moreover, no significant difference in plant height was found between cleaned and farmer seed treatments in both Boro and T. Aman seasons, but plants were taller in later than former. In Rajshahi, percent uniformity, the number of tillers, leaves and panicles were significantly higher for cleaned seeds than for farmer seeds in the T. Aman season (Table 3). Significant difference in mean weed incidence was observed only in the Boro season, in which 17.8% more weeds below canopy was found for farmer seeds than for cleaned seeds (Table 4).

Insect pests

Significant differences in the mean incidence of several insect pests were observed between cleaned and farmer seed treatments in the Boro and T. Aman seasons across years and sites (Table 4). Significantly higher incidences of insects, rice hispa, brown planthopper and stem borer were observed in farmer source than for cleaned seeds in the Boro season, as well as stem borer, gall midge, green leafhopper and other defoliators in the T. Aman season. The highest percent difference was observed for gall midge in the T. Aman season with farmer seeds showing 35.1% higher gall midge incidence than cleaned seeds. Differences in stem borer damage was significant in both Boro and T. Aman seasons, in which 26.6 and 29.7% higher whitehead incidence were observed for farmer seeds than for cleaned seeds, in Boro and T. Aman seasons, respectively. In addition, 28.9% higher mean deadhearts were observed for farmer seeds than for cleaned ones in the T. Aman season.

In the different sites, significantly higher insect pest incidences were observed in the farmer seed treatment than in the cleaned seed treatment (Table 5). Significantly higher stem borer damage, ranging from 31 to 41% for deadhearts and 13 to 45% for whiteheads, was observed for farmer seeds than for cleaned seeds in four sites: Barisal, Chuadanga, Gazipur and Habiganj in the Boro season. In the T. Aman season, whitehead incidence was 45 and 29% higher for farmer seeds than for cleaned seeds in Gazipur and Rajshahi, respectively. In addition, rice hispa incidence was 16 to 38% higher for farmer seeds than for cleaned in the western districts of Bogra, Chuadanga, Rajshahi and Rangpur in the Boro season. The southern districts of Barisal, Chuadanga and Gazipur and the northeastern district of Habiganj also had high incidences of insect pests that were significantly higher for farmer seeds than for cleaned seeds.

Diseases

Significant differences in mean incidence of diseases

Table 4. Insects, diseases and weeds incidences between cleaned and farmer-saved seeds in a farmer participatory research in the Boro and T. Aman seasons in seven sites in Bangladesh.

Season	Variable	Farmer seed	Cleaned seed	Difference
Boro[a]	Weeds below canopy (AUC)[b]	652.66	536.38	116.28**[c]
	Whitehead incidence (%)	4.44	3.26	1.18*
	Rice hispa (AUC)	279.59	240.83	38.76***
	Brown planthopper (%)	3.94	3.33	0.61***
	Bakanae incidence (%)	0.10	0.02	0.08*
T. Aman[d]	Deadheart incidence (%)	3.66	2.60	1.06**
	Whitehead incidence (%)	4.95	3.48	1.47***
	Gall midge incidence (%)	4.90	3.18	1.72**
	Other defoliators (AUC)	749.93	669.59	80.34**
	Green leafhopper (AUC)	287.10	249.68	37.42**
	Sheath blight severity (%)	13.90	11.63	2.27***
	Sheath rot incidence (%)	5.47	4.12	1.35***
	Kernel smut incidence (%)	0.62	0.52	0.10**

[a]Mean of seven sites in three seasons; [b]AUC – Area under the curve (% dsu^{-1} (crop development stage unit)); [c]* significant at *P* = 0.05; **significant at *P* = 0.01; ***significant at *P*=0.001 (based on *t*-tests); [d]mean of seven sites in two seasons.

Table 5. Insects incidence between cleaned and farmer seed treatments in a farmer participatory research in the Boro and T. Aman seasons in seven sites in Bangladesh.

Insect variable	Season	Site	Farmer seed	Cleaned seed	Difference
Deadheart (%)	Boro	Barisal	7.19	4.52	2.67***[a]
		Chuadanga	2.73	1.67	1.06**
		Gazipur	3.17	1.86	1.31*
		Habiganj	1.46	1.01	0.45*
	T. Aman	Gazipur	3.31	1.48	1.83*
Whitehead (%)	Boro	Barisal	6.24	4.88	1.36*
		Chuadanga	4.33	2.37	1.96**
		Gazipur	2.19	1.90	0.29*
		Habiganj	4.13	2.76	1.37**
	T. Aman	Gazipur	4.58	2.51	2.07*
		Rajshaji	7.49	5.32	2.17*
Whorl maggot (AUC)[b]	Boro	Bogra	40.46	29.80	10.66*
		Habiganj	59.32	36.27	23.05*
	T. Aman	Barisal	106.72	84.51	22.21*
Rice hispa (AUC)	Boro	Bogra	120.40	99.37	21.03***
		Chuadanga	259.36	217.48	41.88*
		Rangpur	347.57	215.41	132.16***
		Rajshaji	40.83	36.72	4.11**
Brown planthopper (AUC)	Boro	Chuadanga	4.53	3.40	1.13***
		Gazipur	8.25	6.16	2.09***

Table 5. count'd

	Boro	Barisal	73.55	28.87	44.68***
Green leafhopper (AUC)	T. Aman	Barisal	391.24	338.12	53.12*
		Bogra	252.83	199.36	53.47*
		Gazipur	114.99	76.83	38.16**
Gall midge (%)	T. Aman	Rangpur	12.72	7.26	5.46***
		Rajshaji	6.67	4.14	2.53**
Rice bug (AUC)	Boro	Habiganj	154.59	146.29	8.30***

[a]*Significant at *P* = 0.05; **significant at *P* = 0.01; ***significant at *P* = 0.001 (based on *t*-tests). [b]AUC – Area under the curve (% dsu (crop developmental stage unit)).

Table 6. Disease incidence between cleaned and farmer seed treatments in a farmer participatory research in the Boro and T. Aman seasons in seven sites in Bangladesh.

Disease variable	Season	Site	Farmer seed	Cleaned seed	Difference
Narrow brown spot (AUC)[a]	Boro	Habiganj	472.64	340.35	132.29*[b]
Bacterial leaf streak (AUC)	Boro	Rangpur	58.26	6.13	52.13*
Bakanae (%)	Boro	Gazipur	0.63	0.09	0.54***
Kernel smut (%)	T. Aman	Habiganj	3.67	2.90	0.77***
Aborted seeds (%)	T. Aman	Gazipur	6.73	5.26	1.47**
		Habiganj	6.99	5.85	1.14**
Sheath blight (%)	T. Aman	Barisal	11.57	9.98	1.59*
		Bogra	17.81	14.05	3.76*
		Gazipur	6.24	3.95	2.29*
		Habiganj	12.61	3.08	9.53**
		Rajshaji	20.30	16.85	3.45*
Sheath rot (%)	Boro	Barisal	7.64	5.27	2.37**
		Gazipur	3.79	2.67	1.12*
		Habiganj	3.99	2.36	1.63**
	T. Aman	Bogra	4.8	3.16	1.64*
		Chuadanga	5.65	3.25	2.4**
		Habiganj	5.59	4.09	1.5*
		Rajshaji	7.61	5.43	2.18*
Grain discoloration (%)	Boro	Bogra	1.76	1.28	0.48*
		Rajshaji	5.87	4.36	1.51***

[a]AUC, Area under the curve (% dsu (crop developmental stage unit)); [b]*significant at *P* = 0.05; **significant at *P* = 0.01; ***significant at *P* = 0.001 (based on *t*-tests).

between cleaned and farmer seed treatments were observed for bakanae in the Boro season, and sheath blight severity, sheath rot and kernel smut incidences in the T. Aman season (Table 6). Bakanae incidence in this experiment was low, although there is a significant difference between cleaned and farmer seed treatments. In the T. Aman season, farmer seeds had 16.3% higher sheath blight severity, 24.7% higher sheath rot, and 16.1% higher kernel smut incidences than cleaned seeds. In the different sites, significantly higher disease incidences were found in farmer seed treatment than in cleaned seed treatment (Table 6). In the T. Aman season, sheath blight severity was 13 to 75% higher for farmer seeds than for cleaned seeds in Barisal, Gazipur, Bogra, Habiganj and Rajshahi. Sheath rot incidence was 31 to 41% and 27 to 42% higher for farmer seeds than for cleaned seeds in the Boro and T. Aman seasons, respectively in several districts. In addition, grain discoloration was significantly higher for farmer seeds than for cleaned seeds in the northern districts of Bogra and Rajshaji. Among the different sites, Gazipur and Habiganj had the highest number of diseases with significantly higher incidence for farmer seeds than for cleaned seeds in both Boro and T. Aman seasons.

DISCUSSION

Seed quality analysis in the Boro and T. Aman seasons showed that farmers' seeds for planting are of low quality in seven sites representing different agro-ecological zones also previously reported (Fakir and Mia, 2004). Percentage of best seeds were very low as it ranged only from 29.14 to 60.79% and 27.56 to 52.60% in the Boro and T. Aman seasons, respectively in the 7 sites. Moisture content varied from 12.1 to 15.1% and 10.9 to 15.0% in the Boro and T. Aman seasons, respectively. The moisture content should be up to 12% only for certified seeds as fixed by the National Seed Board (Bazlur Rashid et al., 1995). The moisture content of farmer seeds was 1.8 percent higher in the Boro season than in the T. Aman season. High moisture content is unsafe for seed storage because this will cause infestation of stored grain insects and molds (Fakir and Mia, 2004). In general, the analysis of farmers' seeds showed that abnormal seedlings, dead seeds, insects, storage fungi, and white tip nematode were more common in the Boro season than in the T. Aman season. Among the different contaminants on farmers' seeds observed in all seasons and sites, insects was the most prevalent seed contaminant followed by weed seeds and varietal mixture. High prevalence of rice moth, rice weevil, red flour beetle, and lesser grain borer were observed. *Bipolaris oryzae,* a fungal pathogen, and *Aspergillus flavus,* a storage fungus, were the most predominant in both Boro and T. Aman seasons in all sites (Fakir and Mia, 2004).

Results from the farmer participatory experiments showed that an increase in rice yield is possible through the use of quality seeds. In all sites representing different agro-ecological zones, cleaned seeds had significantly higher grain yield than farmer seeds in the Boro and T. Aman seasons. The advantage in mean grain yield of cleaned over farmer seeds averaged across the 7 sites was 10.1 and 11.3%, in the Boro season and T. Aman seasons, respectively. This is equivalent to a yield advantage of 0.56 in the Boro season and 0.47 tons ha^{-1} in the T. Aman season. Similar results were observed in experiments conducted at the Seed Pathology Laboratory, Bangladesh Agricultural University showing 12 to 14% yield increase by using cleaned seeds (Doullah et al., 2000; Mathur et al., 2002) and at Gazipur district during the Boro and T. Aman 2001 seasons showing 9.7 to 12% higher yield of apparently healthy seed plots over farmers' own seed plots (Rahman et al., 2002).

The 'yield environment' or level of yield in a particular location due to biophysical and socio-economic factors has an effect on the yield gain from using quality seeds. This was observed in Central Luzon, Philippines where a higher rice yield was obtained by using high quality IR64 seeds than farmer-saved IR64 seeds in Guimba, a low-yield environment (20% yield advantage) as compared to Gabaldon, a high-yield environment (7% yield advantage) (Diaz et al., 1998). In this study, the yield advantage of cleaned seeds over farmer seeds was higher in the T. Aman season than in the Boro season because lower yields were observed in the T. Aman season as compared to the Boro season in all sites. In addition, the highest yield advantage from using cleaned seeds is observed in low yielding and unfavorable environments. In the Boro season, the highest yield gain of 12% from using cleaned seeds was in Barisal, which is prone to coastal salinity especially in the Boro season (Enamul Hoque, 1999). In the T. Aman season, the highest yield advantage of 15% from using cleaned seeds was observed in Habiganj, a flood-prone area. Flooding during the vegetative stage is the top technical constraint in rice production in the rain-fed Aman season (Dey et al., 1996).

Using quality seeds for planting had a favorable effect on rice growth because significant differences in crop growth parameters were observed between cleaned and farmer seed treatments in the T. Aman season. Plants in cleaned seed plots were more uniform, and had more leaves, tillers, and panicles than plants in the farmer seed plots. However, no significant difference in crop growth parameters between cleaned and farmer seeds were observed in the Boro season because the plants in both cleaned and farmer seed treatments grew vigorously due to favorable environmental conditions such as irrigation and long sunshine duration (Rashid, 1994). Nevertheless, the significantly lower mean weeds below the canopy in cleaned seed plots than in farmer seed plots in the Boro season can be due to higher plant vigor leading to better weed competition. In a farmer participatory experiment comparing high quality and farmer-saved seeds in the Philippines, the need for hand weeding was reduced by as much as 2 to 3 times in the high quality seed plots due to high seedling vigor (Mew et al., 2004). In the T. Aman season, all crop growth parameters except plant height averaged across sites and years were significantly higher for cleaned seeds than for farmer seeds. This observation was evident in Rajshahi, a drought-prone environment. More vigorous plant growth occurred in the cleaned seed plots than in the farmer seed plots in the low-yielding rain-fed T. Aman season, in which the top two abiotic constraints in rice production include drought in the reproductive stage in some areas such as in Rajshahi (Dey et al., 1996) and widespread flooding at seedling and vegetative stages. In the T. Aman or monsoon season, 38% of the total cropped area in Bangladesh is flood-prone (Enamul Hoque, 1999).

The use of cleaned seeds for planting led to lower pressure from diseases during crop growth and development. Significantly lower mean bakanae incidence in the Boro season, and mean sheath blight severity, sheath rot and kernel smut incidence in the T. Aman season were observed in the cleaned seed treatment than in the farmer seed treatment. Bakanae is an important disease causing 21 to 34% loss in yield in the Boro season (Miah, 1988), but its incidence in this study was low. Sheath blight and sheath rot caused 19 and 19 to 46% yield loss, respectively, in the T. Aman season (Miah, 1988). Bakanae, sheath blight, sheath rot and kernel smut are all seed-borne diseases (Reddy and Sathyanarayana, 2001), and these diseases may have contributed to the yield loss in the farmer seed treatment. Lower disease incidence in the cleaned seed treatment can be due to the reduction in seed-borne inoculum by removing poor quality seeds and seed contaminants (Mew, 2004; Mew et al., 2004).

Furthermore, the use of cleaned seeds for planting led to lower pressure from insects during crop growth and development. In the Boro season, insect pests that have significantly lower incidence for cleaned seeds than for farmer seeds included stem borer, rice hispa, and brown planthopper. In addition, significantly lower rice hispa incidence was observed for cleaned seeds than for farmer seeds in Bogra, Chuadanga, Rajshahi and Rangpur sites in the Boro season. Significantly higher stem borer damage, deadheart and whitehead incidences, were observed for farmer seeds than for cleaned seeds in the southern districts of Gazipur, Barisal, and Chuadanga and northeastern district of Habiganj in both Boro and T. Aman seasons. Stem borers attack the boro crop during the flowering and booting stages in the Boro season and the vegetative and flowering stages in the T. Aman season. Stem borers are more common in the southern and southeastern districts, in which heavy infestations occur (Catling and Alam, 1977). Heavy stem borer infestations can be favored by the wet environment caused by high rainfall (Mochida et al., 1987), which is abundant usually above 1900 and 2800 mm per year, in the south-central and northeastern districts, respectively (Monowar Hossain, 1998). In rain-fed farmers' fields in India, stem borer infestation is favored by the wet environment as shown by an increase in stem borer incidence as the water level increased from shallow to deepwater (Gupta et al., 1990).

The highest number of incidences of several diseases with significantly higher incidence in the farmer seed treatment than in the cleaned seed treatment was observed in Gazipur and Habiganj districts in both Boro and T. Aman seasons. However, the other districts such as Bogra and Rajshahi had significantly higher incidence of several diseases for farmer seeds than for cleaned seeds. High rainfall in Gazipur (1900 to 2300 mm per year) and Habiganj (2800 to 3500 mm per year) (Monowar Hossain, 1998) favors the occurrence of diseases. From April to October, heavy rainfall, high relative humidity and favorable temperature range occur and coincide with severe sheath blight incidence especially in late-sown boro and early-sown aman rice crops (Shahjahan et al., 1987). Sheath blight is observed in all rice ecosystems (Mew, 1991); and thus, significantly higher sheath blight incidence for farmer seeds than for cleaned seeds was also observed in the other sites (Bogra, Barisal and Rajshahi) in the T. Aman season. Sheath rot incidence was significantly higher for farmer seeds than for cleaned seeds in several sites in both Boro and T. Aman seasons. Sheath rot is severe in rice crops infested with stem borers as wounding or injury facilitates infection (Ou, 1985).

This study demonstrated to farmers that proper cleaning of rice seeds for planting could increase their yield through enhanced awareness and knowledge on seed health management in rice production. Seed health management is an important means to reduce pest damage and weed infestation, minimize the use of harmful agro-chemicals, and maximize the genetic yield potential of these modern rice cultivars (Mew et al., 2004). By removing poor quality seeds and seed contaminants, seed-borne inoculum is minimized and the risk of introducing seed-borne pathogens that can manifest in the field and constrain production is reduced (Mew, 2004; Mew et al., 2004). A survey in 2004 showed that due to the improvement of the quality of seeds, 69% of the participant farmers reported a substantial reduction in pest pressure in their fields. Furthermore, non-participant farmers in the Seed Health Improvement Project (SHIP) spent 38% more costs on pesticides and used 31% more seeds per hectare than participant farmers. The participant farmers also incurred 300 to 400 Tk less costs per unit of land than non-participant farmers; thus, food security was enhanced for participant farmers in the SHIP (Bayes et al., 2004). A widespread dissemination of this seed cleaning practice to farmers throughout the country could be done through agricultural extension and media coverage. It is estimated that at least 10% yield gain through the use of quality seeds would translate to US $360 million a year if the seed cleaning practice is widely adapted by Bangladeshi farmers (Hossain et al., 2004).

ACKNOWLEDGEMENT

The authors are deeply indebted and gratefulness to the authority of IRRI-PETRRA-DFID for providing a fund to conduct the research work at farm level.

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