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Integrated crop management of chickpea in environments of Bangladesh prone to Botrytis grey mould

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ABSTRACT

Botrytis grey mould (BGM) is the major constraint to chickpea production in Bangladesh and is considered primarily responsible for that country's recent drastic decrease in chickpea production. There is no substantial host plant resistance to BGM in current chickpea cultivars, but component studies have developed various agronomic options to manage the disease. These include reduced seed rate, delayed sowing and thinning of plants to ensure an open canopy, and need-based foliar application of fungicide. These components were combined with other agronomic requirements for the target region, such as application of phosphate fertilizer, pest management measures against chickpea pod borer, and fungicidal seed treatment against collar rot. The resultant integrated crop management (ICM) package was compared with normal farmer practice (FP) for chickpea cultivation in farmer-managed, operational scale plots at 100 locations across five districts in western Bangladesh in the 2002–2003 and 2003–2004 seasons. Grain yields in ICM plots were generally 15–50% higher than in FP in both seasons. Conduct of these on-farm evaluations in two additional districts in 2004–2005 gave similar results. In 2004–2005, 505 farmer-managed demonstrations were conducted in the five original districts, giving a 5–104% yield advantage (district means) of ICM over FP. In 2005–2006, 642 demonstrations were conducted across the eight districts giving district-wise yield advantages of 27–70%. Effective implementation of BGM management practices by participating farmers demonstrated that remunerative and reliable chickpea yields could be obtained in this BGM-prone environment. The ICM strategy evolved has relevance to other chickpea growing regions prone to BGM in South Asia, Australia and the Americas. Studies are now required on the adoption of components of the ICM package, and the underlying reasons, to identify any adoption constraints and thus guide further promotion of chickpea cultivation.

1. Introduction

Chickpea (*Cicer arietinum* L.) is the most widely cultivated cool season food legume globally, with annual area sown fluctuating between 9.3 and 12 million ha over the previous decade (FAOSTAT, 2007). Mean global yield of chickpea (0.7–0.8 t ha^{-1}) remains well below potential yields for most growing environments (>2.5 t ha^{-1}) with foliar diseases being a major yield reducer. Botrytis grey mould (BGM, *Botrytis cinerea* Pers. ex. Fr.) is the second most important foliar disease after ascochyta blight (*Ascochyta rabiei* (Pass.) Lab.) and is prevalent in South Asia (northern and eastern India, Pakistan, Nepal, Bangladesh, Myanmar), Australia and the Americas (Haware, 1998). The area sown to chickpea in Bangladesh has reduced from >100,000 ha in the 1980s to around 15,000 ha in recent years (FAOSTAT, 2007). This reduction is primarily attributed to the yield instability caused by BGM (Rahman et al., 2000; Bakr et al., 2002). Environmental conditions in Bangladesh during the late vegetative and reproductive period for chickpea (February to mid-March) are particularly conducive to BGM development. Day temperatures are in the range of 20–30 °C; 22–25 °C is optimum for BGM development

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(Haware, 1998). Further, high residual soil moisture and the usually prolific growth of chickpea creates conditions within the canopy sufficiently humid (>95%) to proliferate BGM (Haware, 1998).

Other important constraints contributing to the reduction in chickpea cultivation in Bangladesh are root diseases (e.g. wilt caused by *Fusarium oxysporum* f. sp *ciceris* and collar rot caused by *Sclerotium rolfsii*), pod borer (*Helicoverpa armigera* Hübner), phosphorus (P) deficiency, increased irrigation capability which marginalizes land available for chickpea, and inadequate seed systems for dissemination of improved chickpea cultivars (Rahman et al., 2000). Nevertheless, chickpea remains an important staple food of Bangladesh and ever-increasing imports of the grain are required to meet demand; 101,090 t of chickpea grain was imported into Bangladesh in 2005 (FAOSTAT, 2007).

Component research has identified alleviatory measures against the major biophysical constraints to chickpea in Bangladesh. For example, although only low levels of host plant resistance to BGM have been found (Haware, 1998), small plots trials have shown that BGM can be alleviated through maintaining an open crop canopy and judicious application of foliar fungicides (Pande et al., 1998; Pande et al., 2002; Pande et al., 2006; Saxena and Johansen, 1997). Host plant resistance is effective in minimizing *Fusarium* wilt in chickpea although collar rot has proven more difficult to control (Haware, 1998). Effective control of chickpea pod borer in Bangladesh has been achieved by various insecticides in small plot studies (e.g., Mia, 1998) and integrated pest management (IPM) strategies in farmers' fields (Harris et al., 2008). Based on extensive field trials over space and time, 20 kg ha^{-1} P is recommended to overcome P deficiency in chickpea in its traditional growing areas in Bangladesh (Karim et al., 1989).

There has been little evidence of adoption by farmers of any of these single component alleviatory measures for chickpea in BGM-prone areas of Bangladesh, nor of improved varieties due to limited availability of seed. Indeed implementation of a single alleviatory measure is unlikely to be effective if other constraints are also operative. Thus, it is necessary to formulate integrated crop management (ICM) packages whereby alleviatory measures to the major yield limitations are combined in a form that can be implemented by the resource-poor farmers that could potentially benefit from the cultivation of chickpea. This necessarily requires a participatory approach, involving researchers, extension personnel and farmers, to encourage ownership and thus hasten adoption of improved technologies. It is also necessary for prospective farmers to themselves evaluate ICM packages in operational scale plots on land that they normally cultivate. This approach had been followed since 1998 in farmers' fields in Nepal, where BGM is also the main constraint to chickpea (Pande et al., 2005). It was decided to extend the approach to the traditional, BGM-prone chickpea growing areas of central-western Bangladesh from 2002. A project was implemented with the objective of facilitating farmer evaluation of effectiveness of ICM packages in increasing chickpea yields. Then, if ICM packages were found promising, it was also intended to scale up the technology dissemination process across the target region. These are considered as necessary steps in the research-to-adoption continuum, following the component technology development phase but preceding the technology adoption phase.

2. Materials and methods

2.1. Chickpea cultivation practices

During the 2002–2003 and 2003–2004 chickpea growing seasons, the project targeted five districts in western Bangladesh – Jessore, Jhenaidah, Magura, Faridpur and Rajbari (Fig. 1) – which were traditional chickpea cultivation areas in the country (Rahman et al., 2000). In the 2004–2005 and 2005–2006 seasons, three additional adjacent districts were included in the programme – Kushtia, Chuadanga and Pabna (Fig. 1). The soils of these districts are mostly silty loams formed on recent Gangetic alluvium (Brammer, 1996). The cropping patterns followed by the smallholder farmers of the region are predominantly based on rainy season rice (June–November) with mostly irrigated rice, wheat or vegetables in the post-rainy season; however, there are upland areas where irrigation is not readily accessible and rainfed pulses and oilseeds are grown.

Usual farmer practice (FP) for chickpea cultivation in the target region is to give pre-sowing tillage usually by bullock-drawn plough or power tiller after harvest of rainy season rice during November, hand broadcast seed of a "local" variety (often mixed with seed of mustard, linseed or wheat), cover the seed by another ploughing and levelling, grow entirely rainfed, hand weed as required, and use no fertilizer or pesticide. The chickpea ICM package formulated for on-farm evaluation was initially based on earlier studies on BGM management (Pande et al., 2002) and subsequently modified according to findings in on-farm trials conducted during this project period in Bangladesh. It superimposed the following practices on the normal farmer practice:

- use of a chickpea variety less susceptible to BGM (mainly BARI chola 5, but ICCL 87322 in some cases);
- delayed sowing, to late November or early December to prevent excessive vegetative growth;
- from 2003–2004, reduction of the seed rate, from 50 to 37.5 kg ha^{-1}, to prevent excessive plant population density,
- thinning of the crop if required, to maintain an open canopy;
- need-based foliar application of fungicide (usually Bavistin® @ 1 kg ha^{-1}) to control BGM;
- integrated management of chickpea pod borer (scouting for eggs and young larvae, placing of perches to encourage predator birds and need-based insecticide spray, according to Harris et al., 2008);
- application of triple superphosphate (TSP, @ 20 kg P ha^{-1}); and
- from 2004–2005, seed treatment with the fungicide Vitavax-200® to minimize collar rot.

2.2. On-farm trials

Various on-farm trials were conducted, in randomized complete block design, to evaluate candidate components of the ICM package. The effects of seed priming (soaking of seed overnight prior to sowing to promote early growth vigour – Musa et al., 2001), intercropping of chickpea with wheat and linseed to reduce pest and disease incidence, and seed treatment with Bavistin® to control seed-borne BGM were examined. In 2002–2003, the effects of priming and intercropping were tested in 400 m^2 plots in five dispersed replications each at three locations and in 2003–2004 intercropping and seed treatment were tested in 267 m^2 plots in five dispersed replications each at two locations. No statistically significant advantages of these treatments over the ICM control were obtained and so they were not included in the ICM package, and are not further discussed here; details of these on-farm trials are reported in CLIMA (2006).

To identify means of managing collar rot, on-farm trials were conducted in fields previously known to be infested by collar rot, in three districts in 2004–2005 and 2005–2006. In 2004–2005, treatments comprised: (1) seed treatment with Vitavax-200®; (2) clearing of rice stubble from the plot; (3) delayed sowing; (4) soil incorporation of poultry litter; (5) soil incorporation of mustard oil

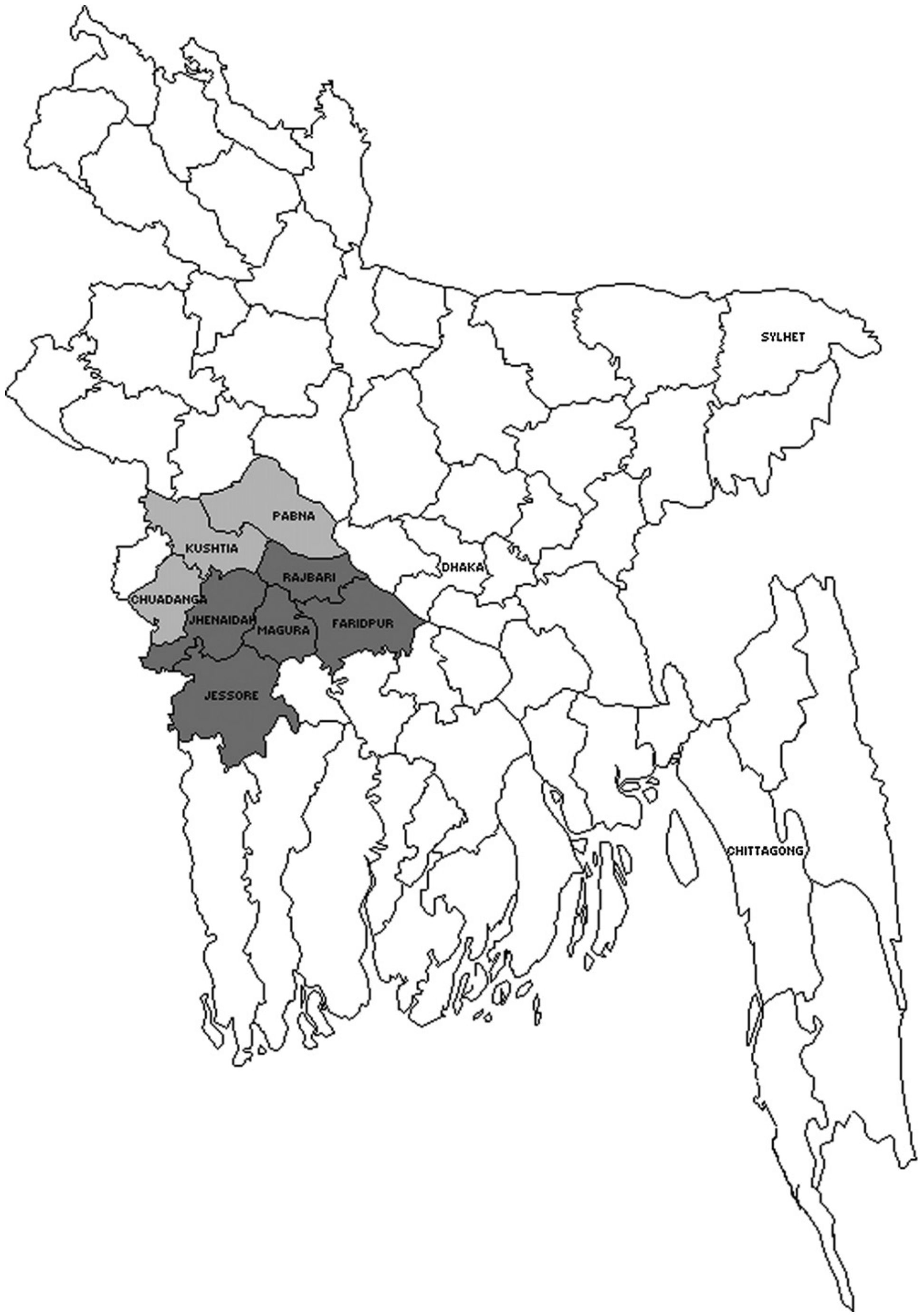

Fig. 1. Bangladesh district map indicating the five project target districts from 2002–2003 season (dark shading) and the additional three districts from 2004–2005 season (light shading).

cake; and (6) a control (ICM without Vitavax-200®). In 2005–2006, treatments comprised: (1) seed treatment with Vitavax-200®; (2) seed treatment with mustard oil; (3) seed inoculation with antifungal microoganisms (Biopharma®); (4) seed treatment with the fungicide Rovral®; (5) soil incorporation of poultry litter; and (6) a control (ICM without Vitavax-200®). Plot size was 225 m^2 and there were three dispersed replications at each location in 2004–2005 and four in 2005–2006; the chickpea variety used was BARI chola 5.

With the objective of obtaining farmer preferences for varieties and traits of chickpea, chickpea Mother Trials (Johansen et al., 2008) were conducted with 11 entries in 2004–2005 and 13 entries in 2005–2006. Six dispersed replications were sown in Rajbari, Jessore and Jhenaidah Districts in 2004–2005, but the three replications in Rajbari were abandoned due to plot damage, and one replication each was sown in Faridpur, Jessore and Jhenaidah Districts in 2005–2006. Plot size was 25 m^2 and ICM practice recommended for the particular season was followed.

2.3. On-farm evaluations

From the 2002–2003 season, on-farm evaluations (OFE) compared the ICM package with prevailing FP in paired plots of 666 m^2 (the average farmer field size in the target region is 1333 m^2, which is

Table 1
Visual rating scale used for assessing the extent of damage to chickpea crops in farmers' fields in Bangladesh caused by the major biotic constraints of collar rot, BGM and pod borer

Rating	Qualitative description	Biotic constraint		
		Collar rot	BGM	Pod borer
1	Minimal	<5% seedlings killed	Minimal loss of pods on lower nodes	<5% pods damaged
2	Low	5–10% seedlings killed	Pods missing on lower nodes	5–10% pods damaged
3	Moderate	10–15% seedlings killed	Fungal hyphae seen on flowers preventing pod formation	10–15% pods damaged
4	High	15–25% seedlings killed	Fungal lesion on stems and leaves of lower canopy, buts pods forming near top of canopy	15–25% pods damaged
5	Severe	>25% seedlings killed	Fungal lesions with sporulation on vegetative parts; very few pods forming	>25% pods damaged

1 bigha, the local unit of area measurement). There were 100 such comparisons across five districts in each of 2002–2003 and 2003–2004, and a further 20 in two new districts in 2004–2005. After receiving training, along with inputs for chickpea cultivation that they do not normally use (seed of improved varieties, TSP, pesticides), farmers implemented OFEs, with regular monitoring from BARI and Department of Agricultural Extension (DAE) personnel. The OFEs were established in clusters of five around a village, within selected blocks of an upazila (sub-district). Prior to sowing land was ploughed with either tractor-drawn tynes, a power tiller or bullock-drawn mould-board plough. Seed and fertilizer were hand broadcast, the field again ploughed and then levelled. All plots were grown without irrigation. Sowing was done mostly during 20 November to 10 December. Although it was planned to sow the ICM plots after the FP plots, this proved difficult for farmers to implement due to their preoccupation at that time with harvesting of rice and sowing of post-rice crops. Thus, both treatments were invariably sown at the same time, usually at the delayed time recommended for ICM. Crops matured and were harvested during the latter half of March, although the unusually excessive rain in March 2003 delayed maturity by 1–2 weeks in that season. Grain yields were estimated in 5×1 m^2 quadrats per plot by DAE Block Supervisors or other project personnel. Yields of ICM and FP plots were compared by paired "*t*" test applied for each block. Plots that grew poorly due to factors not related to the ICM practice (e.g. grazing damage) were excluded from the analysis.

Extent of BGM infestation, and of other apparent constraints to chickpea yield, were only qualitatively recorded by project personnel in 2002–2003. It was noted that the rating scale commonly used in screening of chickpea germplasm for reaction to BGM (Pande et al., 2006) did not appear suitable for use in farmers' fields as economic damage occurred at ratings considered as "resistant" (i.e. "1–3"). Thus, an alternative BGM rating scale was developed for field use, along with rating scales for the other major constraints to chickpea yield, collar rot and pod borer (Table 1). Field rankings according to these scales could not be implemented in the 2003–2004 season, as intended, due to inadequate familiarization of field monitoring staff, but were recorded in the OFEs and demonstrations conducted in 2004–2005.

Opinions of participating farmers of ICM compared to FP were recorded, individually during the reproductive crop growth phase and collectively at field days held near crop maturity. These were systematically documented for 39 participating farmers, or farmer groups, in the 2004–2005 season, but only informally recorded in the other seasons. Questions posed to the farmers were:

- Which of the ICM or FP plots appears most promising?
- Which of ICM and FP plots will produce grain of higher quality?
- Which plot will result in a higher grain price?
- In the next season will you follow ICM or FP for chickpea cultivation?

2.4. On-farm demonstrations

After the superiority of ICM over the local chickpea cultivation practice had been confirmed in OFEs, it was decided to scale up dissemination of improved practices through on-farm demonstrations. In 2004–2005, there were 505 demonstrations of ICM in 1333 m^2 plots in the original five districts, and an additional adjacent district, Pabna. In 2005–2006, there were 497 demonstrations at new locations in the original five districts and 145 demonstrations in the three additional districts (Kushtia, Chuadanga and Pabna). As with OFEs, demonstrations were conducted in clusters of five, around a village. Demonstrations were farmer-implemented after training and with on-going monitoring by project personnel, as for OFEs. It was planned that one farmer's plot near a cluster be harvested to serve as a FP control, but this was not always achieved. In 2004–2005, there were 20 demonstration clusters in the original districts, except Faridpur where there were 18 and Pabna where there were 5. The ICM package used in demonstrations was as described above for OFEs in 2004–2005. Incidence of BGM and other crop constraints were estimated as described for OFEs and grain yields were measured in 5×1 m^2 quadrats per plot.

2.5. Profitability

The profitability of chickpea cultivation under FP or ICM was compared with that of other major field crops grown in the target region during the post-rainy season. The levels and cost of inputs and the yields and income from crop products are based on interviews with farmers and DAE personnel in early 2006. Although there was variation in practice between fields, farmers implementing chickpea demonstrations applied, on average, one spray of bavistin and two of insecticide during 2005–2006. The cost of the chemical and of spray application was approximately Tk 500 per application, giving Tk 1500 as pesticide costs. The costs of Vitavax $-200^{\circledR}$, which was applied to the seed before distribution to the farmers, was not included in the pesticide cost calculation as it was not then commercially available, pending government release for use as a pesticide. Any thinning of dense crop canopies as a component of the ICM treatment, which in any case was rarely done, is considered as part of the weeding cost. In calculating income from all crops, the value of the straw and threshing residue was also included, as by-products.

3. Results

3.1. Weather

Daily temperature and rainfall representative of the project target area are shown in Fig. 2. Jessore and Faridpur are at the western and eastern ends, respectively, of the target region and

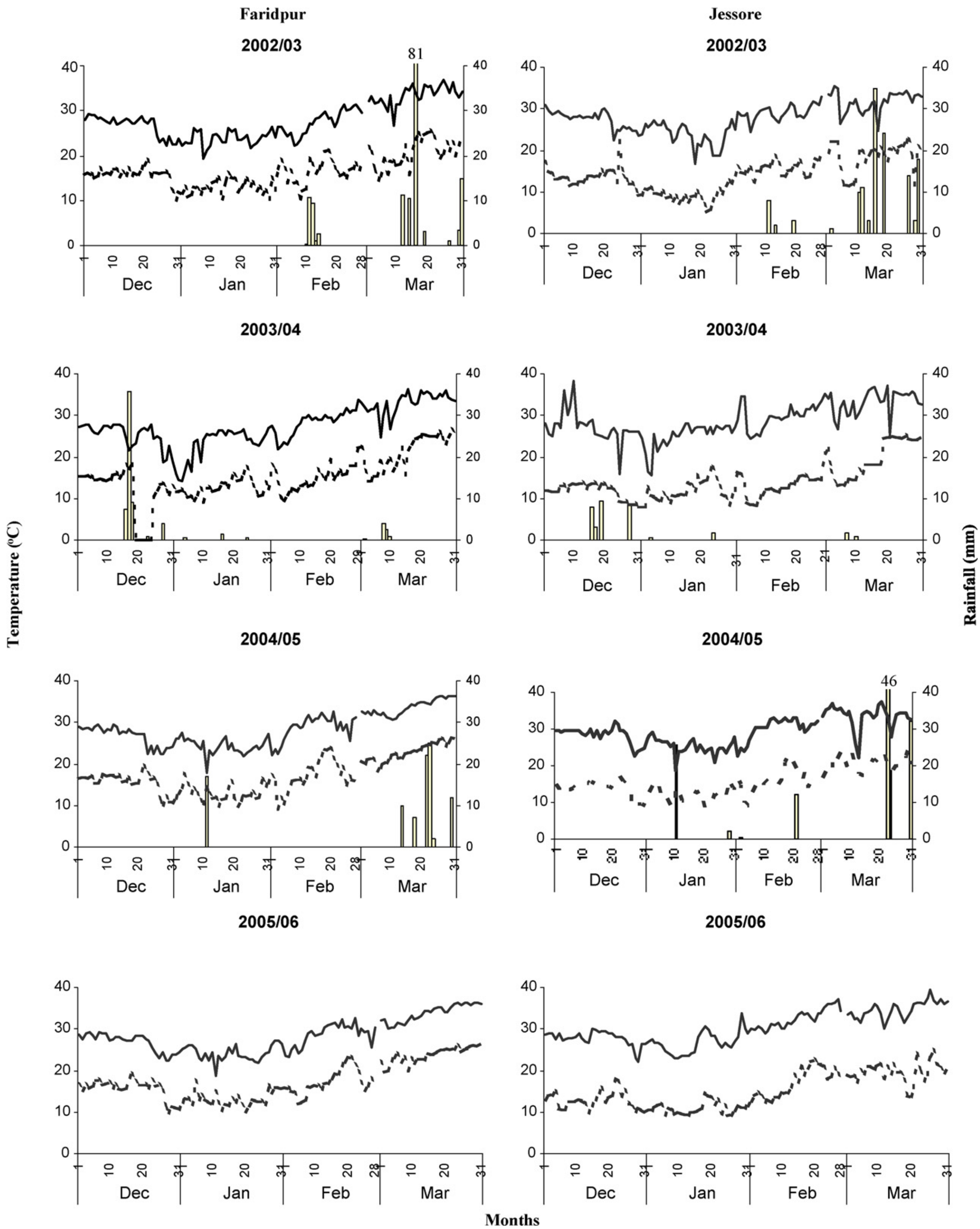

Fig. 2. Daily minimum (broken line) and maximum (solid line) temperatures (°C) and rainfall (mm, as bars) during December–March of the 2002–2003 to 2005–2006 chickpea growing seasons at Jessore and Faridpur. Jessore weather data were recorded by the BARI Regional Agricultural Research Station, Jessore and Faridpur data are from the Bangladesh Bureau of Meteorology.

other project sites have weather patterns similar to, or intermediate between, these locations. Daily temperatures are similar between these two locations, and across the entire target region. Day temperatures during the period of BGM susceptibility, February–March, are usually in the range of 20–30 °C, conducive to BGM development. There is spatial variability in rainfall but rainfall for other sites (data incomplete and not presented) followed similar patterns as for either Faridpur or Jessore. There was >100 mm rainfall across the target region during February–March 2003 (Fig. 2) causing severe BGM infestation of chickpea crops at the reproductive stage. In subsequent seasons, however, minimal rainfall was received during the chickpea growing period (early December to late March), which is a more typical weather pattern of the region. There was significant rainfall during December 2003 (Fig. 2) but the temperature was too low, and crop canopies too small, for BGM to develop as a consequence of the rainy and overcast weather. The heavy rain in late March of 2005 (Fig. 2) was too late to induce a BGM epidemic as crops were already at or near maturity. No rain at all was recorded within the target region during the 2005–2006 growing season.

Probabilities of occurrence of the seasons experienced during this study were calculated based on rainfall data from 1948 to 2005 for Jessore. The probability (P) of a season with as much or more rainfall in February–March as in the severe BGM season of 2002–2003 is $P = 0.16$. A season with <10 mm rainfall in January and February and <20 mm in March is considered a dry Rabi season, least conducive to BGM infestation. Such seasons occurred in 2003–2004 and 2005–2006, at $P = 0.14$.

Irrespective of winter rainfall, chickpea crops grew on residual soil moisture and normally reached maturity without suffering from water stress, due to the high moisture holding capacity of the soil. However, even in seasons with minimal or no rainfall, it was observed that BGM caused flower drop in chickpea plots without ICM, and thus reduced podding and potential yield, particularly when the plant population or vegetative growth was sufficient to form a closed crop canopy (Knights and Siddique, 2002; Pande et al., 2006)

3.2. On-farm trials

The most effective treatment in minimizing effects of collar rot was seed treatment with Vitavax-200®; only the comparison of this treatment with the control is indicated in Table 2. Seed treatment significantly increased yield at two of three locations each in 2004–2005 and 2005–2006. However, the extent of yield increase varied markedly across location and season, despite all test sites having been chosen as infested with collar rot in previous seasons. In the chickpea Mother Trials, the "local" entry yielded significantly less than either BARI chola 5 or ICCL 87322 in 2004–2005 but there was no significant difference between these entries in 2005–2006 (Table 3).

Table 2
Effect of Vitavax-200® on plant mortality at about 1 month after emergence and grain yield (t ha^{-1}) of chickpea variety BARI chola 5 at three locations during the 2004–2005 and 2005–2006 seasons

Treatment	Mortality (%)			Grain yield (t ha^{-1})		
	District					
	Magura	Jessore	Faridpur	Magura	Jessore	Faridpur
2004–2005						
Vitavax-200®	19.6	20.1	1.8	1.17	1.28	0.84
Control	30.1	38.8	13.6	0.77	0.74	0.88
Trial mean	24.4	30.4	8.4	0.97	1.02	0.85
Significance	NS[a]	$P < 0.05$	NS	$P < 0.001$	$P < 0.001$	NS
S.E.[b]	3.2	5.5	9.7	0.048	0.045	0.202
2005–2006						
Vitavax-200®	14.0	11.6	17.3	1.04	0.98	1.10
Control	12.3	21.4	40.3	0.89	0.83	0.83
Trial mean	13.7	15.5	33.5	0.94	0.88	0.89
Significance	NS	$P < 0.001$	$P < 0.001$	$P < 0.05$	NS	$P < 0.01$
S.E.[b]	2.5	2.3	4.3	0.047	0.066	0.069

[a] NS = not significantly different at $P = 0.05$.
[b] Standard error of difference between any two means.

Table 3
Grain yields of (t ha^{-1}) of improved (BARI chola 5, ICCL 87322) and "local" chickpea entries in Mother Trials in 2004–2005 and 2005–2006 seasons (mean of allocations)

Entry	Season	
	2004–2005	2005–2006
BARI chola 5	1.05	1.18
ICCL 87322	1.11	1.06
"Local"	0.79	1.11
Trial mean	0.95	1.13
Significance	$P < 0.01$	NS[a]
S.E.[b]	0.067	0.092

[a] NS = not significantly different at $P = 0.05$.
[b] Standard error of difference between any two means.

3.3. On-farm evaluations

Frequent rainfall and overcast conditions during March 2003 induced a severe BGM epidemic (as described by Haware, 1998 and Pande et al., 2006). The continuing wet weather caused excessive vegetative growth, conducive to development of BGM, and rendered spraying with fungicide and insecticide largely ineffective as the chemicals were washed off the crop canopy by subsequent rain. Thus overall yields of chickpea were low in the 2002–2003 season, but they were invariably higher when ICM practices were followed (Table 4). Where yields >1 t ha^{-1} were obtained, in some plots at Agra, Monirampur, Barabazar and Madhukali, farmers used >2 sprays both of fungicide and insecticide. As this was the first year of the project, there was considerable scope for more effective training of farmers in timely implementation of integrated ICM procedures.

In the 2003–2004 season, the only rainfall during the growing season occurred in mid-December. Severe BGM infestation, sufficient to cause necrosis of older tissues and even plant death, as in the previous season, did not occur generally. However, in some locations where the canopy was completely closed, severe BGM did occur. During February it was observed that most of the earlier formed flowers did not form pods, presumably due to BGM infection. Thus, only the upper nodes on a branch formed pods, thereby reducing the yield potential of the crop. However, attempts to rate extent of BGM incidence (Table 1), and of other constraints, were not successful in this season. Grain yields exceeding 1 t ha^{-1} were realized in most of the ICM plots (Table 5), with individual plot yields of up to 1.8 t ha^{-1} at Agra, Jessore and Mandirbaria, Jhenaidah.

In the districts which were first included in 2004–2005, yields of 0.8–1.4 t ha^{-1} were obtained in ICM plots of OFEs, with a yield advantage of 30–60% over FP plots (Table 6). In this season about 20 mm of rainfall was received in mid-January 2005 and BGM infestation prevented pod formation on lower nodes, more so in dense canopies. Visual ratings made on these plots in 2004–2005 indicated that collar rot, BGM and pod borer were more prevalent in FP than ICM plots (Table 7). Although collar rot was rated as higher in FP plots, plant population was similar between the two treatments, probably because of the higher seed rate usually applied to FP plots. Use of a less susceptible variety and seed treatment with fungicide in ICM was unable to eliminate collar rot, only reduce it in comparison to FP. Similarly, there was still considerable damage attributable to pod borer in the ICM plots, indicating scope for further improvement in implementation of IPM measures.

3.4. Demonstrations

In the 2004–2005 season, mean yields exceeded 1 t ha^{-1} in all of the five original project districts, and approached that level in

Table 4
Mean grain yields (t ha^{-1}) for clusters (usually 5) of on-farm evaluations of recommended integrated crop management (ICM) as compared with normal farmer practice (FP) for chickpea cultivation across five districts of Bangladesh, 2002–2003 season

District	Upazila	Block	Mean grain yield (t ha^{-1})		Increase of ICM over FP (%)	Probability[a]
			ICM	FP		
Jessore	Bagherpara	Agra	0.47	0.33	41	<0.001
	Bagherpara	Betalpara	0.19	0.14	36	<0.05
	Sadar	Lebutala	0.33	0.26	25	<0.05
	Monirampur	Jaljhara	1.06	0.71	50	<0.01
Magura	Shalikha	Hazrahati	0.31	0.26	18	<0.001
	Shalikha	Boira	0.62	0.52	19	<0.05
	Sadar	Ichakhada	0.64	0.48	33	<0.001
	Mohammadpur	Shreepur	NP[b]	NP[b]		
Jhenaidah	Kaliganj	Barabazar	0.99	0.97	2	NS
	Sadar	Potahati	0.39	–[c]		
	Kotchandpur	Kushna	0.31[d]	–[c]		
	Maheshpur	Mandirbaria	0.85	0.67	27	<0.001
Faridpur	Sadar	Ishan Gopalpur	0.25	0.21	20	<0.05
	Sadar	Kanaipur[e]	0.49	0.39	25	<0.05
	Boalmari	Kadirdi	0.30	0.21	39	<0.001
	Madhukhali	Bagat-01	0.92	0.81	14	<0.05
Rajbari	Sadar	Khan Khanapur-01	0.33	0.19	76	<0.01
	Sadar	Khan Khanapur-02	0.30	0.11	194	<0.01
	Pangsha	Madapur-02	0.24	0.17	44	<0.05
	Pangsha	Kalikapur-02[e]	0.25	0.17	43	<0.05
Overall mean[f]			0.50	0.39	28	<0.001

The chickpea variety was BARI chola 5, except where it is indicated that ICCL 87322 was used.
[a] Probability (P) of significant treatment difference according to a paired "t" test; NS = not significantly different at P = 0.05.
[b] Not presented—two comparisons abandoned and the remaining three yielded <0.05 t ha^{-1}.
[c] Yield not recorded in FP.
[d] Mean of three plots only as other two plots were earlier abandoned.
[e] ICCL 87322 instead of BARI chola 5 was used in the ICM treatment.
[f] Excluding Shreepur, Potahati and Kushna Blocks.

Pabna. Standard deviations of cluster mean yields were particularly low in Jessore, Jhenaidah, Magura and Pabna, indicating stability of yield across locations (Table 8). As for OFEs, yields were greater in ICM plots than in adjacent FP plots, but not significantly so in Faridpur and Rajbari districts. Visual ratings of major biotic stresses were as described for OFEs conducted in 2004–2005.

In the 2005–2006 season, when there was no rainfall during the cropping season, mean grain yields were again in the vicinity of 1 t ha^{-1}, except in Kushtia (Table 9). Standard deviations were lowest in Rajbari and Kushtia, with a greater spread between "good" and "poor" plots in the other districts. The highest yield achieved was 1.9 t ha^{-1} at Khan Khanapur-4 Block, Rajbari Sadar Upazila. Yields of ICM plots were invariably greater than those in adjacent FP plots and of a similar magnitude to those recorded in previous years (Table 9). Major constraints to chickpea yield observed in demonstrations in this season were collar rot and pod borer.

3.5. Profitability

A chickpea yield of 1 t ha^{-1} was used to calculate profitability of following the ICM package, based on the results of OFEs and demonstrations presented above which suggested that this yield level is readily achievable by farmers implementing ICM. In OFEs, a mean yield increase of around 30% over FP plots was achieved in ICM plots and thus a yield level of 0.75 t ha^{-1} was chosen as representative of FP yields; this is similar to the national mean yield for chickpea (Rahman et al., 2000; FAOSTAT, 2007). Even considering the lower input costs for FP, the profitability of ICM was one-third higher than that of FP (Table 10). The profitability of chickpea under ICM was estimated to be about 50% higher than that of maize, double that of boro (irrigated, post-rainy season) rice, and triple that of wheat (Table 10). This is a consequence of the high relative price per unit of chickpea grain compared to grain of cereal crops and the considerably lower input costs for chickpea. Irrigation and fertilizer costs, in particular, inflate the input costs for cereals.

3.6. Farmer opinions

All of the 39 farmers or farmer groups said that ICM plots were superior to FP plots and that they would follow ICM practices for chickpea in the next season, provided the necessary inputs were available and that the required cash or credit to purchase them was on hand. Three out of 39 respondents considered that there was no difference in grain quality between ICM and FP, while the rest thought that grain from ICM plots was of superior quality. Five respondents considered that the price of grain from ICM and FP plots would be similar while the rest thought that grain from ICM plots would realize a higher price.

4. Discussion

Farmers were able to implement ICM packages to obtain substantial yield advantages under weather conditions which induced both upper and lower extremes of BGM infestation. In OFEs of the 2002–2003 season, when BGM infestation was severe due to the unusually wet conditions at the crop reproductive stage, implementation of ICM practices clearly improved yields. Nevertheless yield levels with ICM usually remained low primarily due to BGM but also because of inability to control pod borer. This was the first year of the project and training of farmers and extension

Table 5
Mean grain yields (t ha^{-1}) for clusters of five (unless otherwise indicated) of on-farm evaluations of recommended integrated crop management (ICM) as compared with normal farmer practice (FP) for chickpea cultivation across five districts of Bangladesh, 2003–2004 season

District	Upazila	Block	Mean grain yield (t ha^{-1})		Increase of ICM over FP (%)	Probability[a]
			ICM	FP		
Jessore[b]	Monirampur	Jaljhara	1.110	0.73	53	<0.001
	Bagharpara	Agra	1.37	1.08	26	<0.01
	Bagharpara	Betalpara	0.89	0.72	24	<0.001
Magura	Shalikha	Boira[c]	1.16	1.07	9	NS
	Sadar	Ichakhada	1.30	1.00	30	<0.001
	Mohammadpur	Binotpur	1.53	1.33	15	<0.01
	Shalikha	Hazrahati[d]	0.81	0.71	13	<0.05
Jhenaidah	Sadar	Shadhuhati[e]	1.05	0.84	26	<0.05
	Koatchandpur	Kushna	1.49	1.20	24	<0.001
	Kaligonj	Ragunathpur	1.42	1.14	24	NS
	Moheshpur	Mandirbaria	1.53	1.26	21	<0.05
Faridpur	Sadar	Bil Mohammadpur[f]	0.98	0.83	18	NS
	Sadar	Domrakandi[g]	1.20	0.45	167	NS
	Madhukhali	Bagat[h]	1.61	1.37	17	<0.05
	Boalmari	Goshpur	0.68	0.55	22	<0.01
Rajbari	Sadar	Khan Khanapur-02	0.98	0.78	25	<0.001
	Sadar	Khan Khanapur-04	0.91	0.73	24	<0.001
	Pangsha	Kalikapur	0.91	0.62	45	<0.001
	Pangsha	Madapur	0.96	0.72	32	<0.01
Overall mean			1.20	0.96	25	<0.001

The chickpea variety was BARI chola 5, except where it is indicated that ICCL 87322 was used.
[a] Probability (P) of statistical difference determined by paired "t" test; NS = not significantly different at P = 0.05.
[b] Site at Bahadurpur Block, Jessore Sadar abandoned due to grazing damage.
[c] Mean values for four plots of ICCL 87322.
[d] Mean of four evaluations.
[e] Mean of three evaluations, two plots were discarded due to poor establishment caused by collar rot.
[f] One evaluation discarded due to severe collar rot.
[g] Results for two evaluations of BARI chola 5; ICCL 87322 was used for the other three evaluations and yields were <0.60 t ha^{-1}.
[h] Results for three evaluations using BARI chola 5; ICCL 87322 was used for the other three evaluations and yields were <0.85 t ha^{-1}.

personnel in ICM practices proved to be less effective than desired. However, where participating farmers were more rigorous in their application of pesticides, at Agra, Monirampur, Barabazar and Madhukali, yields in the vicinity of 1 t ha^{-1} were obtained (Table 4).

There was little rainfall during each growing season after 2002–2003, thus minimizing the possibility of BGM epidemics. Nevertheless, it was observed that the number of nodes forming pods was inversely proportional to density of the crop canopy, although this relationship was not quantified. Even without rainfall or overcast conditions, humidity remained high throughout the day within closed canopies, with free water apparent on lower leaves in dense canopies well into the afternoon. These conditions are conducive to BGM development (Pande et al., 2006). Even under these limited rainfall conditions implementation of ICM resulted in significant yield increases in OFEs and demonstrations, across locations and seasons.

The major objective of this study was to facilitate farmer evaluation of ICM practices for chickpea, where the ICM package comprised additions to the normal farmer practice in order to manage previously established biophysical constraints to chickpea for the target region. The comparison of ICM with FP only quantified the net effect of the improved practice. Quantification of component effects within the present study was not logistically feasible across the target area; this would have required multi-plot tests (e.g. in factorial or omission design) intensively replicated. Further, extent of yield reduction by factors such as BGM, collar rot and P deficiency is field specific; and severity of pod borer damage varies considerably across space and time. However, attempts were made to visually rate the degree of damage attributable to the major biotic constraints (Tables 1 and 7).

In the 2002–2003 season, the reduced podding resulting from severe BGM infestation was obviously the major yield constraint.

Table 6
Mean grain yields (t ha^{-1}) for clusters of five of on-farm evaluations of recommended integrated crop management (ICM) as compared with normal farmer practice (FP) for chickpea (BARI chola 5) cultivation in two districts of Bangladesh, 2004–2005 season

District	Upazila	Block	Mean grain yield (t ha^{-1})		Increase of ICM over FP (%)	Probability[a]
			ICM	FP		
Chuadanga	Damurhuda	Bashadanga/Hossain	1.30	0.98	33	<0.01
	Sadar	Paurashouva	1.43	1.01	42	<0.001
Kushtia	Kumarkhali	Hashimpur	0.87	0.53	64	<0.001
	Sadar	Baradi	0.94	0.70	33	<0.001
Overall mean			1.13	0.80	41	<0.001

[a] Probability of significant difference as determined by paired "t" test.

Table 7
Plant population at maturity and visual rating of major biotic stresses, according to the scales defined in Table 1 in ICM and FP plots in on-farm evaluations and demonstrations in the 2004–2005 season; district means (± standard deviation)

District	Number of plots observed		Plant population (plants m^2)		Collar rot rating		BGM rating		Pod borer rating	
	ICM	FP	ICM	FP	ICM	FP	ICM	FP	ICM	FP
On-farm evaluations										
Chuadanga	10	10	32 ± 2	31 ± 3	2.0 ± 0.0	2.9 ± 0.6	1.2 ± 0.4	2.5 ± 0.5	2.9 ± 0.6	4.0 ± 0.0
Kushtia	10	10	29 ± 6	29 ± 3	2.2 ± 0.4	3.4 ± 0.7	1.0 ± 0.0	2.2 ± 0.4	3.8 ± 0.8	4.4 ± 1.3
Demonstrations										
Jessore	100	4	27 ± 4	25 ± 1	2.2 ± 0.9	4.0 ± 0.0	1.1 ± 0.3	2.7 ± 0.6	3.9 ± 0.8	4.7 ± 0.6
Jhenaidah	100	3	31 ± 3	28 ± 2	2.2 ± 0.7	4.0 ± 0.0	1.1 ± 0.3	2.3 ± 0.6	4.4 ± 0.8	4.7 ± 0.6
Magura	100	4	32 ± 4	31 ± 4	2.2 ± 0.6	3.5 ± 0.6	1.1 ± 0.2	3.0 ± 0.0	4.0 ± 1.1	4.7 ± 0.6
Faridpur	90	4	21 ± 9	22 ± 14	2.6 ± 1.0	3.0 ± 1.4	2.2 ± 0.6	2.0 ± 0.0	4.0 ± 0.6	3.5 ± 1.0
Rajbari	100	3	18 ± 4	21 ± 4	2.5 ± 0.6	3.0 ± 1.4	2.1 ± 1.4	2.5 ± 1.7	3.4 ± 0.8	2.0 ± 0.0[a]

[a] Only one observation.

Ineffective control of pod borer, due to frequent rainfall decreasing effectiveness of insecticide sprays was the next most important factor. These constraints were partially alleviated by the ICM treatment. In the 2004–2005 season, when extent of damage due to biotic stresses was visually rated, collar rot and pod borer appeared to be major yield reducers (Table 7), and to a greater extent in FP plots. Although extent of BGM infestation under farmer field conditions could be rated, it proved difficult to extrapolate these ratings into actual yield loss; more research is required to establish such relationships. Further work is also required to refine visual rating procedures for each of these three biotic constraints so as to improve assessment and attribution of yield loss of chickpea in farmers' fields. A particular problem in the present study was standardization of visual rating among different assessors. Further, based on a limited number of counts of actual damage, there was a tendency to over-rate collar rot and pod borer damage but under-estimate BGM damage. Thus, the assessments summarized in Table 7 can only be considered as first approximations of relative yield loss due to biotic factors.

Although BARI chola 5 is a variety released in a BGM environment and ICCL 87322 has been shown to perform better than other entries in BGM screening tests (Haware, 1998), these varieties did not perform markedly better than the "local" variety in Mother Trials conducted in this study. The improved varieties showed some advantage in 2004–2005 but there was no such advantage in the 2005–2006 season (Table 3). The "local" varieties used in FP treatments in this study usually comprised a mixture of genotypes with lower germination percentage than the "improved" genotypes (BARI chola 5 or ICCL 87322); farmers sometimes use higher seed sowing rates to compensate poorer germination of "local". The extent of difference measured between ICM and FP plots could only be marginally attributed to the varietal difference.

Similarly, addition of TSP to ICM plots was not likely to account for much of the difference observed between ICM and FP. No symptoms of P deficiency in chickpea (Smith et al., 1983) were noted and it is considered that regular application of P fertilizer to cereal crops grown in rotation with chickpea should have had a residual effect on chickpea, thus minimizing response of P application directly to the chickpea crop. Inclusion of TSP in the ICM package was to ensure no P limitation, but the extent to which P fertilization for chickpea is required in the region needs further assessment. Sporadic occurrence of boron deficiency symptoms (Srivastava et al., 2005) was observed but this was not specific to either ICM or FP plots.

Although effects of each yield constraint across space and time were not quantified in this study, it is suggested that this information is not necessary in proceeding to the technology adoption phase. Previous experience has shown that farmers in Bangladesh, and generally, usually do not adopt an entire ICM package as originally presented but modify it according to their individual perceptions and circumstances. The main factors determining such modifications are availability and affordability of recommended inputs and farmers' perceptions of effectiveness of each input in giving a return on investment. Although it was necessary to provide ICM inputs to farmers cost-free in order to engage them in evaluations and demonstrations, subsequent adoption implies that they are willing to invest in the inputs themselves. Thus, it is suggested that farmers themselves would informally assess constraints for their own cropping circumstance which would reflect in the way in which they modify the original ICM package. For example, with respect to our suggestion that P may not be generally required for chickpea, farmers themselves are likely to conduct informal evaluations in their own fields of whether addition of P fertilizer causes a growth and yield response,

Table 8
Mean grain yields for clusters of five demonstrations in six districts of Bangladesh ($n = 20$ clusters in all districts except Faridpur where $n = 18$ and Pabna where $n = 5$) and mean yield in adjacent plots following normal farmer practice in 2004–2005

District	Mean grain yield ± standard deviation (t ha^{-1})		Yield increase in adjacent ICM plots (%)[a]	Probability[b]
	ICM demonstration clusters	Adjacent farmers' plots		
Jessore	1.15 ± 0.078	0.97 ± 0.195	25	<0.05
Jhenaidah	1.25 ± 0.078	1.01 ± 0.041	32	<0.001
Magura	1.20 ± 0.081	1.02 ± 0.071	42	<0.001
Faridpur	1.19 ± 0.222	0.93 ± 0.515	19	NS
Rajbari	1.06 ± 0.216	1.01 ± 0.371	5	NS
Pabna	0.86 ± 0.062	0.42 ± 0.083	104	<0.001
Mean	1.15 ± 0.200	0.87 ± 0.334	32	<0.001

[a] Percentage increase over local farmer practice plot of mean of adjacent cluster of ICM plots.
[b] Probability (P) of significant difference between cluster mean and adjacent farmer's plot determined by "t" test; NS = no significant difference at $P = 0.05$.

Table 9
Mean grain yields of chickpea in ICM demonstration plots, and in adjacent farmers' plots in eight districts of Bangladesh, 2005–2006

District	ICM demonstrations		Farmers' plots		Yield increase in adjacent ICM plots (%)	Probability[a]
	Number	Mean grain yield ± standard deviation (t ha^{-1})	Number	Mean grain yield ± standard deviation (t ha^{-1})		
Jessore	129	0.92 ± 0.331	4	0.67 ± 0.112	36	<0.05
Jhenaidah	95	1.12 ± 0.339	4	0.76 ± 0.075	48	<0.05
Magura	73	1.27 ± 0.355	4	0.75 ± 0.137	70	<0.05
Faridpur	100	1.09 ± 0.184	20	0.85 ± 0.110	27	<0.001
Rajbari	100	1.23 ± 0.175	20	0.94 ± 0.094	31	<0.001
Chuadanga	50	1.11 ± 0.377	2	0.68 ± 0.070	64	NS
Kushtia	45	0.60 ± 0.188	2	0.47 ± 0.072	29	NS
Pabna	50	0.96 ± 0.229	2	0.71 ± 0.021	36	NS
Mean		1.06 ± 0.333		0.82 ± 0.154	29	<0.001

[a] Probability of significant difference determined by "*t*" test; significance was mainly dependent on number of comparisons (n) with non-significance (NS) at $n = 2$.

Table 10
Relative profitability of chickpea, cultivated using either ICM or FP, and boro rice, wheat, maize in western Bangladesh, based on prices applicable to the 2005–2006 post-rainy season, and mean input levels and yields

Item[a]	Chickpea – ICM			Chickpea – FP		
	Quantity (kg ha^{-1})	Rate (Tk kg^{-1})	Cost (Tk ha^{-1})	Quantity (kg ha^{-1})	Rate (Tk kg^{-1})	Cost (Tk ha^{-1})
Inputs						
Seed	37.5	50	1875	50	40	2000
Fert-TSP	100	13	1300			
Pesticides			1500			
Tillage/sowing			2000			2000
Lab-weeding			500			500
Lab-harvest			1500			1500
Lab-postharvest			500			500
Packaging			1000			1000
Total costs			10,175			7500
Outputs						
Grain	1000	40	40,000	750	40	30,000
By-products	700	1	700	500	1	500
Total income			40,700			30,500
Net return			30,525			23,000

Item[a]	Boro rice			Wheat			Maize		
	Quantity (kg ha^{-1})	Rate (Tk kg^{-1})	Cost (Tk ha^{-1})	Quantity (kg ha^{-1})	Rate (Tk kg^{-1})	Cost (Tk ha^{-1})	Quantity (kg ha^{-1})	Rate (Tk kg^{-1})	Cost (Tk ha^{-1})
Inputs									
Seed	60	17	1020	130	22	2860	20	150	3000
Fert-FYM	5000	0.5	2500	0			0		
Fert-Urea	250	6	1500	200	6	1200	550	6	3300
Fert-TSP	100	13	1300	160	13	2080	250	13	3250
Fert-MP	80	13	1040	50	13	650	200	13	2600
Fert-gypsum	50	4	200	110	4	440	250	4	1000
Fert-other, e.g. Zn	5	35	175	0		0	10	35	350
Irrigation			11,225			3800			5625
Pesticides			1500			500			500
Tillage/sowing			2500			3000			3000
Lab-weeding			2250			1200			3000
Lab-harvest			3000			2100			3000
Lab-postharvest			1125			1500			2000
Packaging			2500			2000			3000
Total costs			31,835			21,330			33,625
Outputs									
Grain	4500	9.5	42,750	2200	13.5	29,700	6000	8.5	51,000
By-products	5000	0.75	3750	2000	0.75	1500	5000	0.6	3000
Total income			46,500			31,200			54,000
Net return			14,665			9870			20,375

[a] *Abbreviations*: Fert = fertilizer; FYM = farm yard manure; TSP = triple superphosphate; MP = muriate of potash; Zn = zinc; Lab = labour; Tk = Bangladeshi Taka (US$ 1 ≈ Tk 69).

and omit TSP in future if it does not. Therefore, the next step to be undertaken in converting constraint alleviating-technology into improved farm household livelihoods is to evaluate which components of the ICM package are being adopted, and why; this is intended for future studies.

Current economic circumstances favour chickpea adoption in the target region. Use of ICM options gives a substantial marginal rate of return on input investments over FP (Table 10). Yield levels of chickpea at around 1 t ha^{-1} or more, as often obtained in ICM plots after the 2002–2003 season, make this crop highly competitive with other major field crops grown at the same time of year as chickpea (Table 10). Only intensively cultivated vegetable crops (e.g. onion, garlic, cauliflower, cabbage, eggplant, tomato, etc.) would have higher returns (data not presented). The low input (investment) costs for chickpea cultivation, compared to other crops, make it a particularly promising means for resource-poor farmers to increase their incomes. Chickpea prices in Bangladesh have been rising relative to other grain commodities over the previous decade and this trend is likely to continue unless chickpea reaches over-supply in the market. Although prices of cereal grains such as rice and wheat have increased markedly after 2006, chickpea prices have also continued to increase. A formal survey of farmer opinion in the 2004–2005 season, and informal surveys in the other seasons, indicated farmer awareness of the economic advantage of practicing ICM for chickpea. Their only concern was timely availability of the required inputs and funds available to them for their purchase.

One of the long-standing constraints to adoption of chickpea in Bangladesh is the risk associated with cultivating the crop; BGM and pod borer are major contributors to this risk (Rahman et al., 2000). However, it is possible to achieve relatively low within-district, within-season standard deviations for demonstration plots (Tables 8 and 9). This study shows that by improved management of the major yield constraints it is possible to reduce the risk of cultivation of chickpea to levels that farmers would expect for irrigated cereal crops.

Although the ICM package has proved to be effective in increasing and stabilizing chickpea yields, further improvement in components of the package are required to render it more robust. For BGM management, further on-farm research is required to better specify optimum timing of fungicidal spraying. A key to this would be development of a diagnostic technique to quantify likely loss in yield potential due to flower damage and non-set of pods induced by BGM. For pod borer management, it is suggested that reliance on chemical insecticides needs to be minimized, due to problems of adulteration, development of resistance in *Helicoverpa armigera* to the chemicals, adverse effects on beneficial organisms and toxicity to humans. Development of IPM procedures based on botanical insecticides (e.g. neem products) or *Helicoverpa* nuclear polyhedrosis virus, specific for *H. armigera*, is a priority recommendation (Ranga Rao and Shanower, 1999; Harris et al., 2008). Another priority is to develop farmer-friendly means of managing collar rot. The search for effective biological antagonists to *Sclerotium rolfsii*, which are harmless to humans, needs to continue (Haware, 1998). Current and possible future ICM components need continual refinement to keep input costs within the scope of resource-poor farmers and to maximize marginal return on input investment.

5. Conclusion

The present study has shown that relatively high, reliable and remunerative yields of chickpea can be achieved in the region of Bangladesh where the crop has been in decline for three decades. This depends on the implementation of an ICM package that effectively manages BGM and pod borer in particular. More widespread dissemination of the technology is recommended to give resource-poor farm families of the region this low cost option of both income generation and improving their diet through increased local availability of pulse grain. The ICM strategy evaluated in this study, and in similar such studies in Nepal (Pande et al., 2005), would also have relevance to other chickpea growing areas of the world prone to BGM, especially in adjacent areas of South Asia, viz. northern India, Pakistan and Myanmar, subject to modification of ICM components according to the local suite of chickpea constraints. In Nepal, adoption and impact studies on the introduction of chickpea ICM indicated that around 20,000 farmers were practicing ICM after 7 years of its introduction and this was contributing to improved family income, diet and quality of housing (Pande et al., 2005). Such studies are required in Bangladesh to estimate extent of adoption and improved well-being of farming families attributable to adoption. These studies should also determine which components of the ICM package are being adopted and for what reason, so as to ascertain farmers' ranking of constraints and pinpoint adoption constraints. Facilitation in the development of supply chains is needed to ensure that the required inputs are available and that local agri-business finds marketing of them profitable.

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