INCREASED MAIZE PRODUCTION THROUGH CAPACITY BUILDING OF BIOLOGICAL CONTROL PRACTITIONERS IN DPR KOREA


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ABSTRACT.

Maize is one of the most important crops in DPR Korea, but maize production is facing extensive problems because of severe damage inflicted by agricultural pests, particularly the Asian corn borer. Field studies conducted in 2005 and 2006 at three cooperative farms to evaluate the potential of inundative releases of *Trichogramma ostriniae* wasps for Asian corn borer management have shown that the number of Asian corn borer larvae and larval tunnel lengths were significantly reduced in release plots by 63.5% and 64.1% respectively. In contrast, maize yield was significantly increased by 28.2% (fresh weight) in *T. ostriniae* release plots compared to non-release plots. To make use of this potential, four *Trichogramma* rearing facilities have been implemented and personnel responsible for managing the facility and rearing the wasps, have been trained intensively. Strict quality control measures were implemented in these local rearing facilities and results indicate that important parameters of *Trichogramma* quality such as parasitism rate, emergence rate, sex ratio and wing deformity are largely in line with international standards. Furthermore, training of personnel at a cooperative farm level was conducted regarding *Trichogramma* release techniques, including timing of releases based on pest monitoring, as well as impact assessment. We conclude that *T. ostriniae* augmentation based on locally produced wasps can substantially increase DPR Korean maize production, thereby enhancing sustainable agriculture and food security.

INTRODUCTION.

Maize, *Zea mays* (L.) (Poaceae), is one of the most important cereal crops in DPR Korea (DPRK). In 2007, the total area of planted maize had reached over 495,000 ha, which is almost 20% of the total arable land of the country. It is an important source of calories and protein for human nutrition. In DPRK, maize is processed by milling to give a number of intermediary products such as flour and meal. These materials, in turn are used to produce a large number of foods including noodles, cakes and bread. The by-products of milling include the maize germ and the seed-coat. The former is used as a source of high quality edible oil, which is particularly scarce in DPRK. The crop is also extremely important as winter fodder for...
animals. Availability of maize for draught animals is closely related to their nutritional status and therefore, their work efficiency in terms of soil preparation in spring. Thus, maize has an indirect effect on the overall productivity of the agricultural land.

Since the 1970s, maize production in DPRK has been facing extensive problems because of damage inflicted by agricultural pests including the Asian corn borer *Ostrinia furnacalis* Guenée (Lepidoptera: Pyralidae), a widespread moth that attacks maize throughout Asia (Nafus & Schreiner 1991). Yield losses of grain maize due to this particular pest typically range from 10 to 30%, depending on the year and location, but some extremely high damage levels of up to 80% can occur in DPRK. To control Asian corn borer, broad-spectrum synthetic chemical pesticides are applied at cooperative farms during the first generation of the pest, though these direct plant protection products are not always available. Chemical pesticides are extremely difficult to apply during the pest’s second generation, because by this time the maize plants are too tall for conventional treatment and sophisticated machinery would be required. Therefore, biological control using *Trichogramma* wasps have been considered by the government. During the 1980s, the Ministry of Agriculture (MoA) and the scientific advisory services of the Academy of Agricultural Sciences (AAS) were prompted to develop a nation-wide programme on *Trichogramma* application. Thus, the first *Trichogramma* mass rearing facility was established in the mid-1980s under the responsibility of MoA and annual releases of this biological control agent were made in nearly every maize-growing county. A total of 230,000 ha of maize were treated annually with *Trichogramma* between 1980 and the early 1990s. The biological control programme, however, started to fail in 1993 and only 50,000 ha were treated that year. The programme finally collapsed in 1995 when food shortage was severe and all available resources had to be redirected for human nutrition. As a consequence, barley, wheat or maize, required for the mass production of *Trichogramma*, were no longer available. In addition, several technical problems had occurred with the *Trichogramma* production procedure, mostly involving rearing contamination by mites. The impact of the *Trichogramma* release programme at a co-operative farm level was further reduced due to a lack of knowledge by the farmers involved. In fact, they were not comfortable with the application technique and also, farmers working in the rearing units were finding the production of natural enemies to be time consuming and not always efficient.

Since 2004, the Centre for Agricultural Bioscience International (CABI) has been working with the DPRK to re-establish an effective integrated pest management (IPM) programme for Asian corn borer control in maize, based on inundative releases of *Trichogramma ostriniae* Pang and Chen (Hymenoptera: Trichogrammatidae) to improve maize production and thereby enhance sustainable agriculture and food security within the country (Zhang *et al.* 2006, 2007). The major aims of this current project were to: (1) re-establish an effective and localized mass production technique for *T. ostriniae*; (2) test the efficiency of *T. ostriniae* field releases; and (3) re-establish *Trichogramma* rearing facilities at the county level with sustainable mass production and high quality standards. Capacity building of DPR Korean biological control practitioners on *Trichogramma* production, quality control and release technology has also been a major aim throughout the implementation of project activities.
MATERIALS AND METHODS.

Efficiency of *Trichogramma* Releases.

In 2005 and 2006, field experiments were conducted to evaluate the effectiveness of *T. ostriniae* releases in maize fields located at the three project cooperative farms (Namsam experimental station, Wongyo and Sokgyo cooperative farms). Eight maize plots per location were randomly assigned to either the *T. ostriniae* release treatment or the control treatment where no wasps were released. Plot size was approximately 0.25 ha (50 m × 50 m). Plots were separated from each other by at least 200 m to minimize the chance of *T. ostriniae* dispersal from release plots to control plots. In all the plots, the maize variety Chongyun No 4 was planted at a density of 54,000 plants per ha (Zhang *et al.* 2006, 2007).

The *T. ostriniae* egg cards used for the study (Fig. 1) were produced with seed culture of the wasps from DPRK, by Hengshui Tianyi Biocontrol Company (HTBC) in China. Releases were made when the first host egg mass was observed in the field. Three releases were done against the 1st generation of Asian corn borer (beginning of June to mid-July) with 3-5 day intervals between releases. Another two releases were conducted against the 2nd generation of Asian corn borer (end of July to beginning of September), again after the first egg masses of that generation were observed. In each plot of 0.25 ha, 42 egg cards, each with approximately 900-1000 parasitized eggs, were set out, resulting in a density of about 150,000 parasitoids per ha for each release.

![Fig. 1. *Trichogramma ostriniae* egg cards (left) and their application (right) in the maize fields at experimental plots in 2005 and 2006 in DPR Korea.](image)

In order to evaluate the effectiveness of *T. ostriniae* releases, larval damage was assessed in September at or shortly prior to harvest. In each plot, 100 plants were sampled in a diagonal line within the plot (10 plants × 10 rows) with rows chosen randomly. The number of holes caused by Asian corn borer larvae, per plant, were counted. Each plant was dissected, and the larval tunnel lengths were measured. In addition, maize yield was estimated in each plot by weighing the wet
mass of all the husked maize ears collected from the plants in a Pyong (1 Pyong = 3.3 m$^2$) at five randomly selected locations. Calculations were made for the proportion of decrease or increase of 1$^{\text{st}}$ and 2$^{\text{nd}}$ generation Asian corn borer larvae, the tunnel length, and the fresh yield in *Trichogramma* release plots compared to control plots. Data from all three cooperative farms and all plots, both years and both generations was used to analyse the effect of *Trichogramma* releases on plant damage and maize yield. Data was log transformed if needed to match assumptions of parametric statistics. Subsequently, full factorial ANOVA was used to compare the results between release and control plots.

**Establishment of *Trichogramma* Rearing Facilities.**

In a first step, an Experimental *Trichogramma* Rearing Facility (ETRF) was established in 2005 at the Plant Protection Institute (PPI) of AAS in Pyongyang as a resource centre for stock culture rearing, small-scale production *Trichogramma* wasps for research, and as a basis for further expansion of the technology and the associated knowledge needed to run the facilities within the country (Zhang et al. 2006). A Maize IPM Focus Group (MIFG) with four research entomologists from AAS-PPI was established to implement project activities on a daily basis. Technical equipment for mass production of both *T. ostriniae* and the host moth, *Sitotroga cerealella* (Oliv.) (Lepidoptera: Gelechiidae), was introduced from HTBC of China for pilot testing at ETRF (Zhang et al. 2007).

In a second step, the establishment of a *Trichogramma* Rearing Facility (CTRF) at a county level was conducted to allow production of the parasitoids close to farms where releases were planned (Zhang et al. 2007). Two locations, Mangyongdae District of Pyongyang City Province and Koksan County of North Hwanghae Province were selected for introducing Chinese production technology and scaling up of production capacity to cover 700 ha of maize fields each. A production team including a manager, a technician and workers (6 staff per facility) was mobilized by MoA and County Farm Management Board. Technical equipment shipped from China was installed at each location.

To increase long-term sustainability of *Trichogramma* production, a third step aimed to adapt the Chinese mass production technology according to local conditions such as electricity and the availability of other inputs. The major aim was to achieve the same output and quality of *Trichogramma* wasps by using the newly developed local CTRF design. A *Trichogramma* Innovation Focus Group (TIFG) was established at the Central Plant Protection Station (CPPS) of MoA, consisting of *Trichogramma* rearing experts and machinery-making engineers. The objective was to develop a local CTRF design, equipped with locally produced technical equipment that considered the experiences during the 1980s in DPRK. The SunAn *Trichogramma* Rearing Facility in the SunAn District of Pyongyang City was selected at the end of 2007 to be the test site for implementation of the local CTRF design.

**Quality Control.**

Quality control measurements of *Trichogramma* produced at each rearing facility were conducted in 2008, before field releases to control the 2$^{\text{nd}}$ generation of Asian corn borer. A sample of 100 – 150 parasitized *Trichogramma* eggs were randomly chosen from the production and glued to a 10 mm x 10 mm piece of graph
paper to measure parasitism. Ten such paper cards were placed individually into
glass vials with secured lids and held at 25-28 °C and 60 – 80RH. After adult emergence, the number of emerged wasps, the number of females, the number of males and the number of adults with deformed wings were counted. Proportional data was arcsin-sqrt transformed for statistical analysis. Single-factor ANOVA was used to compare the quality control measurements taken among the four rearing facilities.

**Participatory Training on Field Releases and Production.**

Capacity building through knowledge transfer to DPR Korean partners was of high importance for the success of the project. A participatory training and research (PTR) approach was used throughout the project, taking the special situation in DPRK into consideration (Zhang et al. 2006, 2007; Grossrieder et al. 2005, 2008). Partners, especially the MIFG members were actively involved in the project planning process. Training of Trainers (TOT) for the MIFG, conducted by international consultants, was on the *Trichogramma* field releases and impact evaluation, *Trichogramma* mass production with Chinese technology and measurements of quality control etc. Subsequently, the MIFG provided training on these topics to farm extension officers at the project cooperative farms (one extension officer for each cooperative farm), as well as two rearing technicians at the CTRF (one technician for each CTRF). Thereafter, farm extension officers trained work team leaders at their cooperative farms (seven to eight work teams per farm) who further passed the knowledge to the other 50 farmers in their work teams. Rearing technicians, further trained rearing workers at their CTRF (four workers for each CTRF). During this knowledge transfer process, training activities such as lectures, field demonstrations and hands-on experience were made. In addition, CTRF personnel attended two-week training courses focusing on *Trichogramma* mass production technology and business plan development at HTBC in China in 2005, 2006 and 2007, respectively. Finally, comprehensive training material was developed on *Trichogramma* rearing to support knowledge transfer and allow broader dissemination to biological control practitioners across the country.

**RESULTS.**

**Efficiency of *Trichogramma* Releases.**

Release of *T. ostriniae* had large effects on the parameters measured. In fact, the number of Asian corn borer larvae (pooled for 1st and 2nd generation) was significantly reduced in release plots by 63.5% ($F_{(1,72)} = 336.0, P < 0.001$) while larval tunnel length was reduced by 64.1% ($F_{(1,30)} = 161.8, P < 0.001$, see Fig. 2). In contrast, maize yield was significantly increased from 3.1 kg/Pyong to 3.9 kg/Pyong, i.e. by 28.2% on average (fresh weight) in *T. ostriniae* release plots compared to non-release plots ($F_{(1,36)} = 38.67, P < 0.001$).

** Establishment of *Trichogramma* Rearing Facilities.**

ETRF has been successfully functioning since its establishment in 2005. *Trichogramma ostriniae* stock culture, produced at the ETRF, has been delivered to CTRF at Mangyongdae and Koksan (75 g for each CTRF) at the beginning of every production season in March according to schedule. The established ETRF has been
also functioned as the supplier of wasps (around 200 g parasitized eggs in total per field season) for field release at Namsam experimental station and laboratory research, as a source for technical support to CTRF and as a national training center to provide theoretical and hands-on experience to rearing technicians of CTRF on *Trichogramma* production (also see session of Participatory training on field releases and production).

Fig. 2. Percent decrease (-) or increase (+) of Asian corn borer larvae (separated by 1st and 2nd generations), tunnel length and fresh yield in *Trichogramma ostriniae* release plots in comparison to control plots at Namsam experimental station, and Sokgyo and Wongyo cooperative farms in 2005 and 2006.

Since its establishment in early 2006, CTRF Mangyongdae has been progressing step by step with an output of *Trichogramma* products for field release to
cover 64 ha, 350 ha and 700 ha of maize fields in 2006, 2007 and 2008, respectively. Aiming to manage the facility sustainably, a business plan has been developed as a model document for CTRF Mangyongdae with components including organizational structure and terms of references, annual input and output calculations, machinery maintenance and depreciation costs, products distribution plan etc. Also starting in 2006, CTRF Koksan is one year behind the production schedule, i.e. the production was approximately 350 ha in 2008.

The local CTRF design was developed by TIFG with construction design blueprints for all technical equipment. Overall electricity consumption of the local CTRF design was reduced by 66.7% in comparison to the Chinese production system. In addition, the local CTRF design would be able to produce Trichogramma successfully with limited access to electricity over time. For example, an oven run by coal is used to sterilize the medium and other rearing materials. Depending on availability, the medium used for rearing *S. cerealella* larvae can be either barley (as in the Chinese production system) or maize grains as in the traditional DPRK rearing system. In consideration of potentially high humidity (up to 90%) in July and August, host moth rearing cages were designed with improved air ventilation and wooden host larvae rearing containers were constructed instead of using stainless steel. Host egg collection and purification machinery are operated manually, therefore without the dependence of electricity. A traditional cold storage room, made from ice was built for overwintering *T. ostriniae* eggs. The local design has been partially tested in SunAn with an output of *Trichogramma* products for field release to cover 200 ha of maize fields in 2008.

Quality Control.

Results of quality control measurement at the four *Trichogramma* rearing facilities are shown in Fig. 3. Parasitism varied between 67.3% at ETRF PPI and 90.9% in CTRF SunAn with highly significant differences among the different rearing facilities (ANOVA; $F = 45.4$; df = 3,35; $p < 0.001$; Fig. 3A). Pairwise comparisons revealed that differences between individual facilities were also highly significant (Tukey's HSD test, all $p < 0.001$) except for PPI-Mangyongdae ($p = 0.395$).

The emergence rate observed was always higher than 90% although differences among the rearing facilities are significant ($F_{(3,31)} = 5.991$, $P = 0.002$; Fig. 3B). Highly significant differences were observed in the sex ratio of production among the different rearing facilities ($F_{(3,36)} = 19.7$, $P < 0.001$; Fig. 3C). Sex ratio at ETRF PPI (69.7%) and CTRF Mangyongdae (77.7%) was significantly higher than at CTRFs SunAn (49.0%) and Koksan (56.7%) ($p < 0.05$). The proportion of healthy females without deformed wings was higher than 93.4% for all the rearing facilities with no significant differences among the different rearing facilities ($F_{(3,36)} = 1.32$, $P = 0.283$; Fig. 3D).
Fig. 3. Quality control measures for *Trichogramma* wasps produced at four *Trichogramma* rearing facilities in DPR Korea: (A) mean parasitism rate, (B) emergence rate, (C) sex ratio, and (D) proportion healthy females. Different letters above the column bar indicates the significant differences at p<0.05.

**Participatory Training on Field Releases and Production.**

With the PTR approach, four MIFG members were fully trained by international consultants and Chinese *Trichogramma* experts on *Trichogramma* field releases and mass production and they became master trainers during the project implementation. The 13 technical officers and rearing technicians from CPPS and CTRF were trained by MIFG on *Trichogramma* mass production at the ETRF of AAS-PPI, from which, three rearing technicians from CTRF provided further training to another 12 workers at their rearing facilities. At the cooperative farm level, three extension officers were trained by MIFG on *Trichogramma* releases, who then transferred this knowledge to 22 work team leaders and 1,100 farmers in their work teams. Two AAS-PPI scientists and four CPPS and CTRF managers were also trained on business plan development of CTRF at HTBC in China. A direct effect of the training was, for the first time, the development of a business plan for CTRF Mangyongdae on *Trichogramma* production in DPRK. In addition, three AAS-PPI scientists, one technical officer of CPPS, three rearing technicians and 12 workers of CTRF were trained on quality control measurement of *Trichogramma* products.
As an important tool for training activities, a *Trichogramma* Rearing Manual has been developed as a didactic training material within the project. In 2009, 1,000 Korean copies of each manual will be distributed to a larger audience of biological control practitioners across the country.

discussion.

The use of pesticides for Asian corn borer control in DPRK is not a very promising option due to problems with application against the 2nd pest generation, farmer health concerns and irregular availability. Therefore biological control by using *T. ostriniae* wasps as a component of an IPM strategy, is one of the remaining tools available for maintaining profitable maize production in DPRK. In fact, the use of *Trichogramma* is considered a sustainable option for corn borer pest control in many countries of the world (Li 1994; Smith 1996) and inundative releases of *Trichogramma* spp. to control Asian corn borer have been successful in a number of Asian countries, especially China (Li 1994; Wang et al. 2005). Like in China, *T. ostriniae* was found to be the dominant species recovered from field collected Asian corn borer eggs at project cooperative farms in DPRK (Zhang et al. 2006). In the present study, inundative releases of *T. ostriniae* (5 releases, in total 750,000 wasps per ha) have substantially suppressed Asian corn borer larval damage, while at the same time maize yield has increased. Except for Namsam in 2006, where yield increase is less obvious, differences in yield increase was between 25.9% and 41.6%, thus rather consistent over farms and years. These results indicate that *T. ostriniae* releases provide a promising IPM tool in DPRK maize fields. The use *T. ostriniae*, will not only significantly improve maize production but will also have a significant positive environmental impact, because negative short- and long-term effects of synthetic chemical pesticides on farmer health as well as on the environment will be avoided. A number of studies have clearly shown that beneficial insects will be harmed less by *Trichogramma* wasps compared to insecticides (Babendreier et al. 2003a, b).

For each programme involving inundative biological control agents, quality issues are of the highest relevance and concern (van Lenteren 2003). Although quality control was conducted only before the first release to control 2nd generation Asian corn borer, i.e. after eight production cycles, the results presented here for the four rearing facilities reflect high standards of *T. ostriniae* quality. Except for a lower parasitism rate at ETRF PPI and CTRF Mangyongdae and a noticeable lower sex ratio (% females) at CTRF SunAn and Koksan, the quality of the produced egg cards is in line with international standards (Bigler et al. 1987; Lundgren & Heimpel 2003). Based on promising results regarding quality of *T. ostriniae* products and the capacity of covering 700 ha of maize fields, the local CTRF design will be further tested and potentially improved in 2009 at another four different locations in maize production areas of DPRK, taking into consideration a business plan.

Best results with *Trichogramma* worldwide in the past have been based on trained personnel who provide not only the product alone but also extension support to the end-users in the field (Smith 1996). In the current project, three extension officers and 1,100 farmers at project cooperation farms have been trained to release *Trichogramma* wasps in their maize fields. Training has also been focusing, to some extent, on rearing personnel at CTRF. An important basis of any further training exercise will be the recently developed *Trichogramma* rearing manual in Korean
language which will be widely used by the rearing personnel as a guideline for good rearing practices.

With an average of 28.2% yield increase achieved in the present study, it is expected that large-scale application of *T. ostriniae* releases would contribute significantly to stabilize the country’s maize production as well as support community efforts to avoid reversion into a food emergency situation. With further support (from the Swiss Agency for Development Cooperation and the European Commission), it is envisaged that the local CTRF design would be multi-replicated at up to 24 different locations across the country in the next three years. At least 72 cooperative farms and 25,200 farmers will benefit from the established CTRFs in the near future by receiving biological control agents for Asian corn borer control and achieving subsequent yield increases. Assuming that the relative yield increase is similar to the current project (28.2%), it is expected that an increase of 1.07 t/ha could be achieved (based on a national average maize yield of 3.79 t/ha in 2005/2006, see FAO 2008). This means that if 24 new facilities are established, and they produce according to the business plan, the annual maize production of DPRK would increase by 17,955 t (16,800 ha x 1.07 t per ha yield increase).

**CONCLUSIONS.**

With the success of the maize IPM project as shown above, the DPR Korean government is currently planning to implement this approach to over 200’000 ha in the near future. In preparation for this, a national workshop was held in 2008 at the established CTRF SunAn with 75 *Trichogramma* experts from the whole country to exchange knowledge, to evaluate the traditional rearing method and local CTRF design, and to spread the adapted advanced rearing technology. Altogether, a number of positive developments may eventually enable large scale IPM in maize to become a reality, including: (1) relevant stakeholders clearly gained beneficial experience during the current project; (2) training of farmers will be improved; (3) a Farmers’ Manual for Maize IPM will be developed; (4) model CTRFs together with a business plan and a rearing protocol, including quality control methods are available; and (5) the recent adoption of cabbage IPM guidelines as part of the national crop protection policy (Grossrieder et al. 2008). These developments clearly indicate the possibility of IPM becoming institutionalized at the national level in DPRK.

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