Title of Research Proposal: **Biological control of the millet head miner in Niger and Senegal.**

Lead Institution authorized representative: International Crops Research Institute for the Semi-Arid Tropics ICRISAT, William Dar, Director General

Lead Institution Address: Patancheru 502 324, Andrah Pradesh, India, Tel+91 40 3071 3071

Principal Investigator: Dr Malick N Ba
ICRISAT Niamey, BP 12404 Niger
Tel: +227 20722529, E-mail: b.malick@cgiar.org

Research Project Period: 4.5 years

Total Budget: $US 638,788

The authorized organizational representative endorses the submission of the above referenced research proposal to the Kansas State University Management Entity of the Feed the Future Food Innovation Lab for Collaborative Research on Sorghum and Millet. The Kansas State University Sorghum and Millet Innovation Lab (SMIL) is funded by the U.S. Agency for International Development under the cooperative agreement no. AID-OAA-A-13-00047.

Authorized Organizational Representative

[Signature]
William D. Dar
Director General
ICRISAT

Date: 8 Aug 2014
1. Executive Summary
This proposal requests SMIL to provide $US 638,788 over 4.5 years for the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and its collaborators to develop technologies for controlling the Millet Head Miner (MHM) Heliocheilus albipunctella De Joannis (Lepidoptera: Noctuidae). Improved management of this key pest will result in increased pearl millet productivity in Niger and Senegal. The project will be implemented by ICRISAT (Dr Malick Ba led-PI) along with University of Maradi/INRAN in Niger (Led by Dr Ibrahim Baoua and collaborator Laouali Amadou) ISRA-Senegal (Led by Dr Ibrahima Sarr), Virginia Tech-USA (Led by Dr Rangaswamy Muniappan and collaborator Dr George Norton). The proposed project includes three components; i) biological control of the MHM with releases of larval parasitoids ii) biological control of the MMH with releases of egg parasitoids and iii) establishing parasitoid cottage industry.

Project component 1 will significantly increase on-going mass rearing of the larval parasitoid Habracon hebetor Say (Hymenoptera: Braconidae) and fine-tune release techniques for improved control of the MHM. In addition, the egg parasitoid Trichogrammatatoidea spp. (Hymenoptera: Trichogrammatidae) will be tested as a biological control agent of the MHM.

Project component 2 will test Trichogrammatatoidea egg parasitoid as biocontrol agents of the MMM.

Project component 3 will test feasibility of establishing a cottage industry for rearing parasitoids in the Sahel with particular attention to having those businesses owned and operated by individuals or groups of women.

The project will also train two PhD and one MS students at Virginia Tech along with University Cheick Anta Diop in Senegal. Female and Male farmers will also be trained on biological control of key millet insect pests. Finally the project will linkup with a McKnight funded project in Burkina Faso, Mali and Niger, a West-Africa Agricultural Productivity Program funded project in Senegal and the CGIAR-CRP research program on Dryland Cereals to scale up the technologies in all the Sahelian countries. The outcomes of this project will significantly reduce pearl millet grain losses and therefore increase food production and security among smallholders in Niger and Senegal. Moreover, the project will promote the establishment of a cottage industry to rear natural enemies, which will provide revenue to farmers especially women’s cooperatives.
2. Introduction and Objectives

Pearl millet *Pennisetum glaucum* (L.) R. Br. is a crop grown throughout West Africa especially in the Sahel. Niger is the largest producer with 6.9 million hectares and Senegal is another major producer (ICRISAT 2012). Pearl millet is the major staple food of the population of the Sahel particularly for household use. It is a highly nutritious cereal with high protein and iron content. High levels of dietary fiber with gluten-free proteins, and phenolic compounds with antioxidant properties further add to its health value (ICRISAT 2012). Its stover is also a valuable fodder resource and a source of building materials (ICRISAT 2012). Pearl millet is the world’s hardest warm season cereal crop, surviving even on the poorest soils in the driest regions and in the hottest climates. Despite this extreme climatic adaptation, pearl millet suffers from many biotic constraints including insect pests (Nwanze and Harris 1992). Among these, the head miner (MHM) *Heliocheilus albipunctella* (de Joannis) (Lepidoptera: Noctuidae), is a major chronic insect pests of millet in the Sahel including Niger and Senegal. Infestations of *H. albipunctella* are more severe in the drier zones of the Sahel (Nwanze and Harris 1992). Damage of *H. albipunctella* is due to larvae that feed on the panicle and prevent grain formation (Ndoye 1991; Nwanze and Harris 1992). Almost every year outbreaks of the MHM are observed in the Sahel especially on early-planted millet or early maturing material. The MHM inflict significant yield losses ranging from 40 to 85% for *H. albipunctella* (Gahukar et al 1986; Nwanze and Sivakumar 1990; Krall et al 1995; Youm and Owusu 1998).

Control strategies, including cultural management, host plant resistance, and the use of insecticides (Gahukar 1989; 1990 a.b.; 1992; Nwanze and Sivakumar 1990), have been tested with limited success and applicability (Nwanze and Harris 1992). Biological control with releases of parasitoids is feasible for controlling insect pests when efficient biocontrol agents are available (Neuenschwander 2003; Overholt et al 2003; Obrycki et al 1997). The history of commercial mass production of natural enemies spans a period of roughly 120 years and more than 230 natural enemies are commercial used in augmentative biological control programs (van Lenteren 2012).

Augmentative biological control was recently successfully tested in the Sahel for controlling the millet head miner (MHM) with releases of the parasitoid wasp *Habrobracon (=Bracon) hebetor* Say (Hymenoptera: Braconidae) (Payne et al 2011; Ba et al 2013; Baoua et al 2013). Parasitism of up to 80% of the MHM larvae (Payne et al 2011; Ba et al 2013) resulted in an increase in yield of at least 30% (Baoua et al 2013). So far, the biological control of MHM with the parasitoid *H. hebetor* only targets 3rd and later instar larvae of MHM when some damage has already occurred. Moreover, timely release of parasitoids is essential for success. A more effective/early control of MHM may be achieved with releases of egg parasitoids and timely releases of the larval parasitoid *H. hebetor*. Indigenous *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) and *Copidosoma (=Litomastix)* spp. (Hymenoptera: Encyrtidae) parasitoids were observed parasitizing 48% and up to 60% MHM eggs, respectively in Senegal (Ndoye and Gahukar 1995; Bal et al 1993). In Niger, three egg parasitoids, *Trichogrammatatoidea* sp. nr. *lutea* (Hymenoptera: Trichogrammatidae), *Telenomus anates* (Hymenoptera: Scelionidae) and an unidentified encyrtid parasitized up to 40% of eggs (Nwanze et al 1995). The indigenous egg parasitoids are still present in the region. The most recent survey on MHM egg parasitoids in Niger was carried out in 2004 and reported 10% egg mortality due to *Trichogrammatatoidea* spp (Garba and Gaoh 2008). In Senegal in the Nioro region up to 40% egg mortality due to *Trichogrammatatoidea* spp. was recorded in the 2013 rainy season (Ngom...
This provides evidence of the value of *Trichogrammatatoidea* spp. in addition to *H. hebetor* for biological control of the MHM. Trichogrammatid egg parasitoids have been successfully utilized for biological control of several lepidopteran pests worldwide. They are the most widely used biological control agents in the world (Li-Ying 1994; Smith 1996; Knutson 2005; Wang et al 2014). *Trichogrammatatoidea* sp. could develop on several lepidopteran cereals in West Africa (Muli et al 2010) and could be easily mass reared on eggs of the rice moth *Corcyra cephalonica* Stainton (Pyralidae) (Kalyebi et al 2005; Migiro et al 2007; Shadrack and Srinivasan 2012; Rimbing et al. 2013).

Thus, the central focus of the proposed 4.5 year project is to further develop and deploy biological control of the millet head miner in Niger and Senegal.

3. **Testable Hypotheses**

Progress made in the last decade with the biological control program of the MHM gives a strong indication that much can be achieved within the next decade and there is an opportunity to introduce egg parasitoids for MHM.

Considering the data presented:

i) We hypothesize that effective and economically profitable control of MHM can be achieved through combined inundative releases of egg parasitoids and the larval parasitoid *H. hebetor*. Based on research conducted under experimental conditions, we predict that numbers and longevity of emerging *H. hebetor* parasitoids can be significantly improved through optimization of rearing techniques, releases techniques and timely release of parasitoids. We also predict that releases of the indigenous egg parasitoid *Trichogrammatatoidea* spp. will cause significant mortality MHM eggs, thus decreasing larval number and the damage they cause to millet.

ii) We hypothesize that MHM Trichogrammatid egg parasitoid could be mass reared on a factitious host like *C. cephalonica*. Trichogrammatid has been successfully mass reared on *C. cephalonica* (Kalyebi et al 2005; Rimbing et al 2013).

iii) We hypothesize that biological control of MHM with *H. hebetor* can form the basis for the establishment of a new private sector cottage industry. *H. hebetor* is quite easy to handle and is routinely mass reared and commercialized (Schöller 2001). Individuals with minimum capital investment could easily operate a parasitoid rearing business if properly trained.
The overall objective of the project is to significantly reduce insect pest damage to millet for improvement of crop productivity.

For this purpose we will pursue the following specific objectives:

i) Assess effectiveness of indigenous egg parasitoids for controlling MHM

ii) Optimized *H. hebetor* rearing and release techniques for better control of MHM larval populations

iii) Assess the economic feasibility of establishing a cottage industry for parasitoid production

4. Research Strategy

4.1. Justification

Over the past decades, scientists in the Sahel have identified biocontrol agents for MHM and MSB but lacked the necessary resources to fully develop and scale-up biocontrol programs that could positively impact millions of millet producers. The lead PI of the proposed project along with the INRAN PI have demonstrated the potential of *H. hebetor* for biological control of the MHM (Payne et al, 2011; Ba et al., 2013; Baoua et al., 2013). So far *H. hebetor* has only been used for biocontrol of warehouse insect pests (Brower et al, 1996; Prozell and Scholler, 2003). Even though open field mass releases of *H. hebetor* are effective for controlling the MHM, the large-scale and sustainable use of this approach has not yet been realized in the Sahel. The release technology that has been developed involves placing two mated *H. hebetor* female parasitoids in 15 cm × 25 cm jute bags containing 200 g of millet grains and 100 g of millet flour, together with 25 larvae of the rice moth *C. cephalonica* (Ba et al. 2013). The jute bags are suspended from the ceiling of traditional straw granaries and parasitoid offspring are able to escape through the jute meshes and straw granaries to disperse and parasitize MHM larvae in millet fields (Ba et al. 2013). However, there have been some failures of this technology, because for unknown reasons some bags do not produce parasitoids. Moreover, in many cases the emerging offspring was male biased which reduces control because only females parasitize MHM larvae. There are several studies that demonstrate that the ratio of hosts to parasitoids influences the number of emerging *H. hebetor* parasitoids and their sex ratio (Yu et al. 2003, Gündüz and Gülle 2005, Eliopoulos and Stathas 2008, Landge et al. 2009, Ghimire and Phillips 2010, Farag et al 2012). In addition, nutritional quality of *C. cephalonica* has also been critical to parasitoid performance (Kumar and Shenhar, 2003; Nathan et al 2006; Rimming et al., 2013). Therefore the proposed project aims to improve *H. hebetor* mass rearing and release techniques to pave the road for its commercial use in the Sahel to control the MHM. During the first and second year of the project, we will fine-tune *H. hebetor* rearing and release techniques. Additionally, timely release of *H. hebetor* parasitoids is essential for successful control of the MHM. Several studies have shown the critical need for timely releases of biocontrol agents for effective augmentative biological control programs (van Lenteren, 2012). Thus, we will conduct a range of experiments on the timing of release of *H. hebetor* to optimize parasitism of MHM.

Another limitation of augmentative biological control of MHM is that the parasitoid only attacks
3rd and later instar larvae of MHM when some damage to millet panicles has already occurred. In this project we will improve control of MHM by releasing egg parasitoids in addition to H. hebetor. Opportunities to use egg parasitoids have been recently demonstrated in Senegal where the parasitoid *Trichogrammatoides* sp. parasitized up to 40% of MHM eggs (Ngom, 2013). In addition, the egg parasitoid *Telenomus anates* (Hymenoptera: Scelionidae) needs to be tested for biological control of the MHM. In year 1, we will evaluate the seasonal occurrence of egg parasitoids of MHM in Niger and Senegal. In years 1 and 2, we will investigate their biology in the laboratory. In year 3, promising parasitoids will be tested in small-scale releases. In year 4 we will test combining releases of the most promising egg parasitoid along with the larval parasitoid for controlling the MHM.

Even though *H. hebetor* releases give good control of the MHM, outbreaks of the MHM may occur in subsequent years. Because of scarcity of alternate host for the parasitoid to survive during the off-season, releases of parasitoids are needed every growing season. To make the biological control program sustainable, parasitoids need to be available for every year use. Thus in parallel with biological studies in year 1-2, we will also conduct a feasibility analysis on the establishment of a biocontrol cottage industry.

4.2. Specific Activities
The project will conduct the following specific activities:

i) Effectiveness of MHM egg parasitoids
This activity will be conducted under objective 1 and will be the project of a PhD student (Ms Mame Fatoumata Goudiaby). Ms Goudiaby will be enrolled in university Cheik Anta Diop de Dakar in Senegal (co-supervised by the ICRISAT led PI, the collaborator in University of Florida and the ISRA PI). In 2014 and 2015 she will assess seasonal occurrence of MHM egg parasitoids in Senegal during the rainy season. The same survey will be conducted in parallel in Niger by ICRISAT (Western Niger) and UoM-INRAN (Eastern Niger). Eggs of the MHM will be collected in millet panicles and reared until emergence of parasitoids. Occurrence of natural parasitism will be assessed based on number of parasitized eggs out of the total of eggs collected. Emerging parasitoids will be sexed and each of the species will be given eggs of the MHM. Encountered species will be sent to experts for identification/confirmation.

Ms Goudiaby will be based at ICRISAT in Niamey from November 2014 to January 2015 to conduct the laboratory studies. She will hand-carry egg parasitoids collected in Senegal under appropriate permits from the two countries. The laboratory studies will be conducted to construct life tables and assess demographic parameters of parasitoids (tentatively *Trichogrammatoides* sp. and *Telenomus anates*) including adult lifespan, sex ratio, development time, fecundity, net reproductive rate and intrinsic rate of increase. The effects of host age and time of host deprivation on the development and reproductive potential of the parasitoids will be studied. In year 3, superparasitism and interspecific competition among the parasitoid species will be studied. The parasitoids will be maintained in the laboratory on their primary host, and subsequently in the third year of the project (2016) tested for compatibility with eggs of the rice moth *C. cephalonica* and flour moth *Ephestia kuhniella* (Pyralidae). As stated earlier, most *Trichogrammatoides* spp. are polyphagous and may develop on eggs of several lepidopteran species (Dias et al 2010; Muli et al. 2010; Shadrack and Srinivasan 2012). *C. cephalonica* has been the basis for mass production and successful release of *H. hebetor*. *C. cephalonica* is quite easy and cheap to rear. Parasitoids
successfully reared on *C. cephalonica* will be used for small-scale releases in millet fields in Niger/Senegal (year 3-4 of the project). Different approaches will be tested for release of parasitoids:

- the jute bag technique used for mass releases of *H. hebetor* (Ba et al., 2013)
- parasitized eggs glued on cardboard and pined to millet plants
- release of egg parasitoids in small vials
- jute bags with MHM egg parasitoids and MHM larval parasitoids.

For each of the experiment, post release assessment will be carried out to measure parasitoids dispersal, number of parasitized hosts, number of damaged panicles, and grain yield.

ii) **Optimization of *H. hebetor* rearing and release techniques**

This activity will be conducted under objective 2 and aim to enhanced numbers and longevity of emerging *H. hebetor* parasitoids and determine optimal release technique for better control of MHM.

INRAN Niger collaborator (Laouali Amadou) will be enrolled in a PhD program at Virginia Tech with field work/experiments to be conducted at ICRISAT and INRAN in Niger. Laouali Amadou is currently a research assistant at INRAN and holds an MSc from University of Niamey and BSc from University of Zaria (Nigeria). He will conduct the following experiments (year 2-4):

**a- Experiments for optimization of *H. hebetor* mass rearing:**

- Test different rearing media for *C. cephalonica* based on performance of the larval parasitoid *H. hebetor*.
- Identification of *C. cephalonica* optimal larvae stage for *H. hebetor* parasitism, progeny production and higher number of female progeny
- Identification of best host-parasitoid ratio for the greatest number of parasitoid offspring
- Identification of preferred MHM larval stage for *H. hebetor*
- Identification of best host (MHM) parasitoid (*H. hebetor*) ratio for parasitism
- Study intraspecific competition (superparasitism) among *H. hebetor* females

For each of the experiments, we will collect data on *C. cephalonica* parasitism, number of *H. hebetor* progeny, sex ratio of progeny and development time of *H. hebetor*.

**b-Experiments for optimization of *H. hebetor* release:**

- Test direct release of *H. hebetor* adults using different numbers of parasitoids per area of pearl millet
- Releases of *H. hebetor* parasitoids at different stage of millet growth (panicle exertion, flowering)
- Releases of *H. hebetor* parasitoid at different timing of MHM cycle (when eggs of MHM are first detected then one week and 2 weeks later; When first moths are caught in light traps and one, two and three weeks later).

For each of the experiment, post release assessment will be carried out to measure parasitoids dispersal, number of parasitized hosts, number of damaged panicles, and grain yield.
iii) Assessing the economic feasibility of establishing a cottage industry to produce *H. hebetor*

Past research has demonstrated that *H. hebetor* can be used to effectively control MHM, but the question remains as to how sufficient numbers of parasitoids can be produced to meet the demand in the Sahelian region. While we fine-tune the release/rearing techniques for *H. hebetor*, a strategy must be developed to scale up production. Cottage industries have been the basis for commercialization of parasitoids for augmentative biocontrol in other settings (van Lenteren, 2012). Therefore, we will investigate the feasibility of establishing a cottage industry to produce parasitoids. A baseline survey to characterize investment opportunities/analysis for establishing private production units will be conducted. The survey will address grower perceptions of the seriousness of the MHM and MSB problems, willingness to purchase parasitoids, interest in running a franchise in parasitoid rearing and release, among other things. When the parasitoid *H. hebetor* are released on a given farm, the parasitoids spread to surrounding farms. Therefore, the analysis will also evaluate the type of business model to be used such as a cooperative or individually own enterprise, with emphasis on ownership by women. This analysis will include an assessment of how these units could be operated, the economically optimal size and number of units, and the potential impacts for female employment and empowerment. Early in the project, data will be gathered from the baseline survey, from interviews with scientists and other experts, and from the literature to project the local and regional impacts of improved bio-control of MHM and MSB. These data will be incorporated in a benefit cost analysis to project the aggregate economic impacts of the augmentative biocontrol program. Near the end of the project, the benefit cost analysis will be updated with data from the scaled-up production and release of *H. hebetor* to measure realized impacts as well as project additional future impacts. The feasibility assessment of the cottage industry and economic assessment of realized impacts will be the topic of an MSc thesis. The early baseline survey will be conducted with the assistance of students from the host country and a student intern in agricultural economics from Virginia Tech.

4.3. Research team and facilities

The project will be implemented by a team of scientists from ICRISAT in Niger, Virginia Tech and University of Florida in the USA, ISRA in Senegal and University of Maradi- INRAN in Niger. All the scientists have 10 to 20 years experience with biological control of insect pests.

i) ICRISAT

The ICRISAT PI (Dr Ba) led a McKnight funded project on biological control of the MHM with releases of *H. hebetor* from 2006 to 2012 in Burkina Faso (INERA) before joining ICRISAT in 2013. His work consisted on development of on-farm *H. hebetor* parasitoid release ‘kits’ for controlling the millet head miner in Burkina Faso. His findings suggested effective control of the MHM (Ba et al 2013).

Regarding research facilities ICRISAT has developed methods for rearing both MHM and MSB and they were routinely reared at ICRISAT labs in Niamey. For the project, cultures of both species will be reestablished. Both the parasitoid wasp *H. hebetor* and its alternate host *Corcyra cephalonica* are currently maintained in ICRISAT-Niamey.

ii) ISRA

The ISRA PI (Dr Sarr) has been working on MHM since 1996 and has recently reassessed the natural occurrence of MHM egg parasitoids in the Nioro region of Senegal. He has coordinate several projects on insect pests at ISRA with particular interest to conservative biological control in the peanut belt
of Senegal. Dr Sarr is currently coordinating a project funded by WAAPP (West-Africa Agricultural Productivity Program) on millet insect pests. His project consisted on integrated management of pearl millet insect pests with particular focus on crop management, host plant resistance, and conservative biological control. Dr Sarr has recently trained a female MS student (Ms Mame Fatoumata Goudiaby). Our proposed project will select her for a PhD program in University Cheick Anta Diop in Dakar in Senegal. She is already familiar with the topic and is a perfect fit for our project.

### iii) University of Maradi-INRAN

The University of Maradi/INRAN PI (Dr Baoua) led a regional McKnight funded project on biological control of the MHM with releases of *H. hebetor* from 2006 to 2012 in Niger along with other colleagues in Burkina Faso and Mali. Dr. Baoua has been in charge of mass rearing of *H. hebetor* and augmentative releases in Niger. His work suggested that when effective *H. hebetor* releases lead to 30% yield grain increase (Baoua et al. 2013). Dr Baoua has recently moved to University of Maradi where he will continue working on the millet head miner. When at INRAN he has trained research assistant M Laouali Amadou for a MSc. Our proposed project will enroll M Amadou in a PhD program at Virginia Tech. M Amadou is a perfect fit for our project, he has a sound knowledge of the millet head miner and the parasitoid *H. hebetor*.

Regarding research facilities, INRAN has a good entomology laboratory where both the parasitoid wasp *H. hebetor* and its alternate host *Corcyra cephalonica* are currently maintained.

### iv) Virginia Tech University

Our research team in the US will be led by Dr Rangaswamy Muniappan in collaboration with Dr George Norton.

Dr Muniappan is the director of the IPM innovation lab; the former USAID CRSP for pest control in Asia, Latin America and Africa. They have been successful for conducting biological control of the papaya mealybug in India; and develop comprehensive IPM packages for vegetables in West Africa including Senegal.

Dr George Norton is agricultural economics; he is an authority in the domain of impact assessment. His recent research includes assessment of the economic benefits of IPM programs in Africa, Asia, and Latin America, including programs involving biological control.

The US universities will provide PhD/MSc training for students. The INRAN collaborator will be enrolled in a PhD sandwich program with field research being conducted in Niger and academic training at Virginia Tech. He will work on optimization of *H. hebetor* rearing/release techniques. Another MS student from Niger will be enrolled at Virginia Tech to be trained on Agricultural economics. His project will be on economic feasibility of a cottage industry in production of parasitoids.

### 4.5. Linkages with other project

As stated earlier the ICRISAT PI and the University of Maradi PI (Dr Baoua) both led a McKnight funded project on biological control of the MHM with releases of *H. hebetor* from 2006 to 2012 in Burkina Faso and Niger along with other colleagues in Mali. Dr Baoua has recently submitted a proposal to the Mcknight foundation for a new project phase for Burkina Faso, Mali and Niger. Our SMIL project will
mainly conduct basic laboratory studies of parasitoids for enhancement of mass rearing and release techniques. All the technologies that will be developed will be field tested at large scale by the Mcknight project in Burkina Faso, Mali in Niger. The Mcknight project will also work on other approaches including crop management and host plant resistance. In addition, when the economic analysis of our proposed project identifies the appropriate business model for parasitoid commercialization, the Mcknight project will carry out pilot testing of startups in Niger. All the capacity building that will be needed for establishment of a parasitoid production industry will be handled by the Mcknight project. **Finally, the Mcknight project will co-funded M Laouali Amadou PhD training at Virginia Tech.**

In Senegal Dr Sarr is currently coordinating a project funded by WAAPP (West-Africa Agricultural Productivity Program) on millet insect pests. His project consisted on integrated management of pearl millet insect pests with particular focus on crop management, host plant resistance, and conservative biological control. Our proposed project will link up with the WAAPP for dissemination of technologies that will emerge from our work.

ICRISAT and partners have recently secured a project on large-scale diffusion of technologies for sorghum and millet systems in Mali (ARDT-SMS). This project included a component on mass releases of *H. hebetor* for controlling the MHM. When the economic analysis of our SMIL project identifies the appropriate business model for parasitoid commercialization, the ARDT-SMS project will carry out pilot testing of startups in Mali.

### 5. Theory of Change Statement

Our project fits within the ICRISAT led CGIAR Research Program on Dryland Cereal (CRP-DC) vision to achieve an increase in farm-level millet productivity. The current releases of *H. hebetor* will lead to a 30% millet yield increase in individual farms covered by the program. We will improve release techniques of *H. hebetor* to achieve improved control of MHM, and by also targeting eggs of MHM, the overall mortality of MHM will be increased. The overall control of millet insect pests will lead to a projected 40% increase of millet yield in individual farms. Establishment of parasitoid production units will lead to coverage of thousands of hectares in Niger and Senegal and will have a broad regional impact of a projected 10% increase in millet yield, resulting in improved food security and reduced rural poverty. Parasitoid commercialization will also contribute to a reduction of poverty especially for women that will be involved in this business of parasitoid production.

---

**Table 1: Theory of Change: Causal pathway from activities to impacts**

<table>
<thead>
<tr>
<th>Activities</th>
<th>Intermediate outputs</th>
<th>Final outputs</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test effectiveness of MHM egg parasitoids</td>
<td>Life tables and demographic parameters of parasitoids assessed</td>
<td>Approaches for release of egg parasitoids tested 1 Ph.D. student completed</td>
<td>Knowledge obtained of optimal approach to release parasitoids</td>
</tr>
<tr>
<td>Optimize <em>H. hebetor</em> rearing and release techniques</td>
<td>Learn effects different rearing medium for <em>C. cephalonica</em>, best host-parasitoid ratio for <em>H. hebetor</em>, preferred MHM larval stage for <em>H. hebetor</em></td>
<td>Protocol for optimal <em>H. hebetor</em> rearing and release; 1 Ph.D. student completed</td>
<td>Knowledge of optimal timing of releases, number of parasitoids to release per ha, and how spread out to make the release points, etc.</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>---------------------------------------------------------------------</td>
</tr>
<tr>
<td>Assess economic feasibility of cottage industry to produce <em>H. hebetor</em> and economic impacts</td>
<td>Initial baseline survey of millet growers, analysis of data from growers, scientists, and literature; ex ante (projected) economic benefits of the parasitoid releases.</td>
<td>Assessment of the feasibility and design of the cottage industry for parasitoid release; revised assessment of the economic benefits of the biocontrol program; 1 MS student completed 1 student intern trained</td>
<td>Reduced losses in millet due to MHM; economically sustainable industry to produce parasitoids; higher incomes for farmers and those producing parasitoids; improved female income, employment, and empowerment.</td>
</tr>
</tbody>
</table>

### 6. Gender Issue Planning

In implementing this project, it is important that key sociocultural and gender issues be fully accounted for. In keeping both ICRISAT and USAID’s as well as participating NARS objectives, our project seeks to improve the social, economic, and environmental sustainability of agriculture by developing/deploying biological control for the control of pest insects that attack millet.

Our project targets millet production improvement through improved control of insect pests of economic importance. We recognize the importance of gender in Niger and Senegal where women frequently have important roles in crop production. Our past experience demonstrated that when the parasitoid *H. hebetor* are released in one village, parasitoids disperse up to 5km away from the release point. Therefore, the biocontrol program does not discriminate against people in the village and will directly benefit both men and women farmers. It is a crop management intervention that is appropriate for women. Gender is embedded in all ICRISAT activities as well as the CGIAR Research Program on Dryland Cereals (CRP-DC) led by ICRISAT. Our proposed project internalized both ICRISAT and CRP-DC gender strategy. It include gender differentiated activities and outcomes specifically targeted to address equitable inclusion of women. In that regard, we are targeting development of a cottage industry for parasitoid production that could be owned by women farmers or women’s cooperatives. When conducting the economic analysis, we will select volunteer women farmers for participation in the survey. This analysis will include an assessment of how these units could be established to encourage female participation in their management, and what the resulting impacts on female employment and empowerment might be. We will strengthen both male and female agricultural training and education, outreach, and adaptive research that emerge from our research efforts. Finally our strategy includes training of one PhD female and one MSc for empowerment of NARS capacity.
7. **Human and Institutional Capacity Development Strategy**

The target countries of the project are Niger and Senegal. These are countries with comparative advantage for production of millet and where ICRISAT and IPM-IL have existing strong institutional partnerships and collaborations. There are several levels of direct beneficiaries of this project. First, both men and women farmers will directly benefit (both economically and ecologically) with better insect control in their millet crops. Second, this project will provide substantial host country capacity building for national agricultural research programs, including considerable training for host country scientists (Table 1), technicians, and local extension agents. One MSc and one PhD student will be recruited for training in Virginia Tech in a sandwich system with fieldwork to be done in host countries and academic training in the US. In addition, one PhD will be fully trained locally with co-supervision from US collaborators. Third, for *H. hebetor*, the biocontrol agent currently in the final stages of development, there is potential for the development of a cottage industry owned by farmers’ unions or private individuals that will produce biocontrol agents for local and regional use. These would ultimately provide a possible revenue source for women at a village-level. Technologies developed by the project will be disseminated to government extension agents, NGOs and farmers’ organizations through short-term training and demonstrations (most of this will be handled by the Mcknight project). Although this project will only involve research in Niger and Senegal, the project outcomes could potentially benefit all West African countries in which pearl millet is a major staple food and feed crop. Drs. Ba and Baoua are collaborating with fellow researchers in Burkina Faso and Mali within a Mcknight funded project on the BC of the MHM. In addition to graduate students, we will train NARS scientists, extension agents, farmers union in Senegal, Niger along with Burkina Faso and Mali (in collaboration with Mcknight project)

<table>
<thead>
<tr>
<th>Table 1. Training details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topic</strong></td>
</tr>
<tr>
<td>Biology of egg parasitoids of MHM</td>
</tr>
<tr>
<td>Optimization of <em>H. hebetor</em> rearing/release technique</td>
</tr>
<tr>
<td>Economic feasibility of cottage industry to produce parasitoids</td>
</tr>
</tbody>
</table>

8. **Communication Planning:**

At ICRISAT and in the CRP-Dryland cereals, communication of research activities is very important. For this reason both ICRISAT and the CRP-Dryland cereals do have a dedicated communications and information manager. Our communication strategy will be handled at the institutional level with the help of the communication officers of ICRISAT and CRP-Dryland cereals. Activities of the project will be posted on the ICRISAT and the CRP-DC websites. We are also expecting the SMIL website to host specific
pages for each of the project. The sister IPM-IL web site will also be used to disseminate project findings. Data generated by the project will be disseminated to first users (millet farmers in Niger and Senegal) through direct interaction (extension activities in collaboration with the Mcknight project). Major findings will be published in open access peer reviewed journals and disseminated to partners. In addition, posters and flyers will be edited for large-scale dissemination of knowledge technologies developed by the project. Communication of project results will also be shared at scientific conferences.

The project team will be communicating through emails and Skype when needed. Meetings will also be organized in one of the host countries with all the team at the beginning, middle and end of the project to discuss project activities and findings.

9. Conflict of interest statement

In this project we will work on biological control of the MSB and MHM. We are seeking full funding from SMIL-IL for the component of our project on egg parasitoids and fine-tuning *H. hebetor* rearing and release techniques. All the economic analysis for identification of a business model for implementation of parasitoid production units will also be handle by the SMIL project. We are expecting the Mcknight funds to be used for establishment of parasitoids startups and training of farmers/business owners on rearing of parasitoids for large-scale production of parasitoids for Niger, Mali and Burkina Faso. In addition, the Mcknight project will handle large scale filed testing. This project will develop technologies for increasing of pearl millet productivity. This fits very well within the ICRISAT led CGIAR-CRP on Dryland-Cereals. For millet insect pests, the approach of the CRP-DC is based on integrated pest management with major focus on host plant resistance. Our biocontrol approach is complementary to that and fits well within an integrated pest management approach.

The time commitment of the team is as follows:

- Dr Ba (ICRISAT PI) will dedicate 30% of his time to the project (25% donated).
- Dr Sarr (ISRA-PI) and Dr Baoua (UoM-INRAN PI) will dedicate each 25% of their time.
- Dr Rangaswamy Muniappan (Virginia Tech PI) will dedicate 5% of his time for training of PhD student and assist him for development of his thesis project and writing his thesis. Dr Muniappan will also advise the team at ICRISAT, ISRA, UoM for their experiments protocols. He will also contribute to papers writing.
- Dr George Norton (Virginia Tech collaborator) will dedicate 5% of his time for training of MS student and assist him for development of his survey protocols, analyses of his data and writing his thesis.
Literature cited


ICRISAT (2012) A global alliance for improving food security, nutrition and economic growth for the world’s most vulnerable poor. Master document of the CGIAR Research Program on Dryland Cereals. International Crops Research Center for the Semi-Arid Tropics (ICRISAT), Hyderabad, India, 185pp


Knutson A (2005) 'The Trichogramma Manual: A guide to the use of *Trichogramma* for Biological Control with Special Reference to Augmentative Releases for Control of bollworm and Budworm in Cotton. (Texas Agricultural Extension Service)


Muli B.K., Schulthess F and Van Den Berg J. (2010). Performance of *Trichogrammaeidea* sp. nr *lutea* Girault (Hymenoptera: Trichogrammatidae) collected from *Mussidia* spp. in Kenya on eggs of six lepidopteran hosts. *J Appl Entomol* 134, 521-530


