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Economic feasibility of an augmentative biological control industry in Niger

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ABSTRACT

Farmers in Niger are vulnerable to high millet yield losses due to the millet head miner, *Heliocheilus albipunctella* De Joannis (Lepidoptera: Noctuidae), for which pest control options are limited. Researchers have developed a procedure to multiply and spread an augmentative biological control agent *Habrobracon hebetor* Say (Hymenoptera: Braconidae) which is effective in limiting millet yield losses due to the pest. This study assesses the economic viability of small businesses to produce and sell biological control agents. It analyzes the profitability of the businesses under alternative pricing regimes given estimated costs to produce and distribute biological control agents. The economic assessment provides budget analysis for potential businesses and discusses options for scaling, price setting, and organizing. Our study suggests that the small *H. hebetor* industry should turn a profit in Niger at relatively low prices for the biological control agents of $3.00-$4.00 per bag with 15 bags needed per village. Competitive wages are achievable for the businesses that sell to at least 13 villages. Each business would hire three workers from late May to late August. Commercialization of *H. hebetor* would generate opportunities for wide geographic distribution of the technology on a sustainable basis in Niger.

1. Introduction

Niger is among the poorest countries in the world with an annual per capita income of less than $1000 (World Bank, 2017). Agriculture accounts for 80 percent of employment and 40 percent of income (World Bank, 2013). Millet, sorghum, and cowpeas are the primary crops, with millet accounting for 70 percent of cereal production (Institut National de la Statistique, 2013). The lowest income quintile of the population spends more than 50 percent of its income on cereals, especially millet (Aker et al., 2009). Farmers in Niger rely on pearl millet as a primary source of food and income because it grows on poor soils and under moisture stress (Food and Agriculture Organization, 2016).

The most serious pest affecting millet production in Niger is the millet head miner (MHM) *Heliocheilus albipunctella* De Joannis (Lepidoptera: Noctuidae), which causes major yield losses if untreated (Gahukar et al., 1986; Nwanze and Sivakumar, 1990; Krall et al., 1995; Youm and Owusu, 1998). Farmers reported an average yield loss of 40 percent due to MHM in a recent survey (Ba et al., 2013).

Several studies have examined the life cycle and behavior of the MHM and identified its potential natural enemies (Guevremont, 1981, 1982; 1983; Gahukar et al., 1986; Bhatnagar, 1989; Gahukar, 1990; Ndoye, 1992; Youm and Gilstrap, 1993; Krall et al., 1995; Henzell et al., 1997; Youm and Owusu, 1998; Baoua et al., 2009). Infestations occur annually, and are especially severe in early-planted or maturing millet and in areas with sandy soils (Gahukar, 1987; Youm and Gilstrap, 1993; Nwanze and Sivakumar, 1990). In Niger, adult MHM moths lay their eggs on millet panicles as they emerge from early August to early September. Eggs hatch three to five days later, and larvae begin feeding on the millet panicle (Gahukar, 1989). Larval development takes about 30 days, and then the full-grown caterpillar drops to the ground and burrows to pupate (Youm and Kumar, 1995). The caterpillar remains in the ground for most of the year until it re-emerges about six weeks after the first rains, which begin in late May or June (Nwanze and Sivakumar, 1990). The millet head miner produces one generation per year.

Common pest control methods such as applying pesticides, breeding for host plant resistance, and using cultural controls have proven

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ineffective or impractical for MHM (Gahukar, 1989, 1990, 1992; Nwanze and Sivakumar 1990; Baoua et al., 2009). However, multiplication and release of the beneficial insect *Habrobracon hebetor* Say (Hymenoptera: Braconidae) has emerged as a promising control strategy. *H. hebetor* is a tiny wasp that parasitizes up to 95 percent of MHM larvae, improving yields by up to 41 percent (Ba et al., 2013; Baoua et al., 2014). The *H. hebetor* wasp stings the MHM larvae, causing paralysis and stopping metamorphosis, and then lays eggs on the larva (Youm and Gilstrap, 1993). Over 10 wasp larvae, feeding on the host, can develop in one host larva. The maturation process requires about 7 days from egg to adult (Youm and Gilstrap, 1993). Research is underway to optimize the effectiveness of *H. hebetor*'s release.

H. hebetor and the MHM are native to the African Sahel region including Niger. Until the mid-1970s, *H. hebetor* exhibited a natural parasitism of MHM of 64–95 percent and yields were minimally effected (Guevremont, 1983; Bhatnagar, 1984). However, the Sahel no longer provides a suitable environment for the beneficial parasitoids to naturally build and maintain a population large enough to mitigate millet losses to MHM (Payne et al., 2011). The natural parasitism often occurs now after the crop has been damaged (Gahukar et al., 1986; Bhatnagar, 1989; Youm and Gilstrap, 1993).

Consequently, a strategy has been developed to augment the level of *H. hebetor*'s population and release the beneficial insects at the appropriate time. Since 2006, mass releases of *H. hebetor* have been tested by the national agricultural research institutes of Niger, Mali, and Burkina Faso (Institut National de la Recherche Agronomique du Niger, INRAN; Institut de l'Economie Rural, IER, in Mali; and Institut de l'Environment et de Recherches Agricoles, INERA, in Burkina Faso). These institutions, in partnership with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Niamey, have designed effective rearing and release techniques for *H. hebetor.* ICRISAT and INRAN first undertook efforts to rear *H. hebetor* in Niger in 1998, with several experiments to refine practices to release the parasitoids (Payne et al., 2011).

A release technique using jute bags filled with millet, rice moth larvae, *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae) (food for *H. hebetor*), and impregnated *H. hebetor* was first attempted in 1999, yielding promising results (Garba, 2000). By 2000, the scientific groundwork had been laid for an effective biological control solution, but there was little institutional support to facilitate transfer of the technology to farmers (Payne et al., 2011). Since 2006, efforts have been made to: (1) implement on-farm testing of a biological control system, (2) train students, technicians, extension agents, and farmers in biocontrol techniques, (3) conduct further research on control of the head miner; and (4) evaluate pearl millet varieties for resistance to the head miner (Payne et al., 2011).

Based on research and testing results, Ba et al. (2014) lists the current best practices for on-farm *H. hebetor* releases. The technique involves placing two mated-female *H. hebetor* in a 7 cm × 10 cm jute bag filled with 200 g of millet grain, 100 g of millet flour, and 25 rice moth larvae (*C. cephalonica*). A set of 15 jute bags are placed around a village's farms, with three bags placed on a centrally-located farm and three bags placed on farms in each cardinal direction (N, S, E, W) from the central farm. Typical villages have a diameter of 1 km, and bags can be placed up to 500 m from the central farm although most are placed within 100–200 m. Bags can be suspended from the ceilings of straw granaries, or if straw granaries are not available, they can be protected against wind and rain and hung from trees or wooden stakes. Parasitoids reproduce and multiply within bags, and their offspring escape through the jute mesh and disperse. A new generation emerges after 7–14 days, with the average development time around 12 days. One bag generates 57–71 parasitoids (Ba et al., 2014). If 15 bags are utilized, approximately 1000 parasitoids are released within 12 days, and the population can build to over a million within four weeks. *H. hebetor* can travel up to 5 km from release point and parasitize 90% of MHM larvae under this procedure, resulting in a yield increase of 34% (Baoua et al., 2014).

Unfortunately, INRAN and ICRISAT lack the capacity to annually breed and distribute *H. hebetor* to farmers on a large scale. Augmentative biocontrol is often a commercial endeavor (Van Lenteren, 2012). It has been applied on more than 30 million ha worldwide, and approximately 350 species of natural enemies are commercially available (Van Lenteren et al., 2017). The largest demand is in greenhouse crops in Europe and the United States. Africa accounts for only about two percent of the market for commercial augmentative biological control agents (Cock et al., 2010).

Establishing a small private *H. hebetor* industry in Niger may be feasible due to the minimal capital investment and labor required to raise the insects. Maintaining the source of insects requires little effort for most of the year and full-time work for only two months to mass multiply and distribute the insects. The technology is effective, and many farmers indicate that they would be willing to purchase bags of *H. hebetor* (Ba et al., 2013). Commercialization of the *H. hebetor* would generate opportunities for wide geographic distribution of the technology on a sustainable basis.

Private production and distribution may make the beneficial insects widely available to farmers, but public research institutions can play a role in initiating the process due to the nature of the market and the technology. The market consists of subsistence farmers living in scattered, sometimes isolated, rural areas. Millet fields typically surround small villages, although occasionally individual farm-households are separate from village centers, especially if they possess several livestock. The technology, while not complicated, does require training of the businesses to multiply the insects, time the insect distribution to farmers, set initial prices, and determine the geographic scope of their market.

Testing of the technology followed by village focus-group discussions revealed that commercialization of the biological control technology may encounter a "free rider" problem in that *H. hebetor* in open fields will spread up to five km from its release point (Baoua et al., 2014; Ba et al., 2014). Because all farmers within that radius of release benefit from the parasitoids' activity, farmers could have an incentive to wait for their neighbors to buy the beneficial insects so that they can receive the benefits without incurring the cost. Free riding could potentially make it difficult for businesses producing the beneficial insects to sell sufficient quantities to cover costs.

The primary objective of this study is to assess the economic feasibility of establishing a beneficial-parasitoid industry despite the potential free-riding problem. The study documents expected costs and returns of businesses created to produce and distribute *H. hebetor.* It also briefly discusses the possibility of cooperative arrangements for purchasing the beneficial insects at the village level to minimize free riding. Such arrangements might take advantage of existing farmer federation networks in Niger that provide farmer groups with inputs, financial services, and technical assistance. The study describes potential risks to the businesses and considers the appropriate size of businesses given economies of size and other parasitoid distribution issues.

2. Materials and methods

A list of expenditures to multiply and distribute *H. hebetor* to villages were obtained from laboratories currently involved in *H. hebetor* research and multiplication and from pilot testing the insect multiplication and distribution process with six small "businesses" which were set up for that purpose. Cooperative purchasing arrangements through existing farmer federations were examined that would provide positive net benefits for each participant farmer while excluding non-participants from receiving the same benefits.

Nigerian farmer federations may play an important role in the distribution of *H. hebetor* because they already provide benefits to farmer participants through access to agricultural inputs, financial services, marketing and storage assistance, and farm consultations and other communications that are not available to non-participants. These federations have significant participation by farmers in major millet-growing regions. The largest federations include Mooriben (Dosso and Tillaberi), FUMA Gaskiya (Maradi), Husa'a (Guidan Ider, Tahoua), and FUBI (Zinder). The federations are comprised of organizational units called unions, and each union is comprised of many village-level groups called "groupements". Farmers pay member fees to join a groupement, groupements pay fees to a union, and unions pay fees to the federation.

Mooriben and FUMA Gaskiya were chosen to host the set of pilot-tested *H. hebetor* businesses. Mooriben is sub-divided into 30 farmer unions with over 56,000 members in 1500 groupements in 700 villages in western Niger (Mooriben, 2017). FUMA Gaskiya is composed of 21 unions with 420 groupements and around 15,700 members. Input shops of Mooriben and FUMA Gaskiya can play a potentially important role in distributing the *H. hebetor* technology. These shops are one-stop service centers that provide members with agricultural inputs and advice on their use. They take advantage of bulk sales and collective purchases to reduce input costs to their members (Mooriben, 2012).

Leaders of the two federations recognize the potential role that they could play in commercializing *H. hebetor*, and have expressed interest in helping to establish small businesses for multiplication, sales, and distribution of the beneficial insect. Leaders indicate that individual groupements could purchase the insects using a small portion of their dues and place them in the villages. Individual farmers would still be free to purchase them if they desired.

It may be necessary for the businesses that multiply and distribute *H. hebetor* to meet total costs, not just variable costs, in the first year because they may not be able to assume the risk of being unprofitable while fixed costs are being paid. The most costly inputs for the business are the rearing rooms for raising parasitoids and the feed for rice moth larvae. Our business feasibility study will assess how many *H. hebetor* bags must be sold to cover all costs and justify the business investment.

2.1. Pilot test

Five farmer unions of the Mooriben and FUMA Gaskiya federations, as well as one agricultural input firm, were chosen by ICRISAT and INRAN to pilot-test the multiplication and distribution of *H. hebetor* in 2015. These six quasi-"business" units were provided equipment and training to rear and release *H. hebetor*. Each unit sent 2–3 people to INRAN's station in Maradi for a week-long training in which they learned to multiply insects, prepare bags, sensitize farmers to beneficial insects, place bags in fields, and evaluate success. Most of the bags were sold, at a price that covered costs, to non-governmental organization (NGO) projects that distributed them free to farmers; few bags were sold directly to farmers during the pilot test.

Selling parasitoids only to NGO projects is not a sustainable distribution strategy for *H. hebetor* as projects eventually end. Farmers also may be less likely to purchase *H. hebetor* if they grow accustomed to receiving free beneficial insects. However, the pilot-test was a useful source of information on the costs of multiplying and distributing the beneficial insects, the depth of training required, and issues encountered in operating the units.

People who worked in the six units responded to a questionnaire about their experiences in multiplying and selling *H. hebetor*. Five out of six units were able to independently rear and sell parasitoids in a timely manner. One unit failed to multiply insects fast enough, resulting in the unavailability of parasitoids at the critical time in the MHM development. However, this unit was able to obtain parasitoids from one of the successful units to fill customer orders. The parasitoids were sent by bus in boxes and they survived the journey with negligible losses.

Armed with information from the pilot test, a feasibility analysis was conducted for establishing the small businesses. The analysis addressed seven components: operations, input costs, labor, profitability, market potential, risk, and farmer benefits. The operations component identifies the time and equipment needed to rear and sell *H. hebetor*. Input cost and profitability analyses develop budgets for varying prices and quantities sold. Budget information is also used to conduct break-even analyses for various outputs and prices (break-even output = total costs ÷ revenue; breakeven price = total costs ÷ expected output). The labor component examines the income that might be earned per worker in the businesses and compares it to the daily wage in alternative employment. The market potential component examines the geographic scope of the market, which has implications for the size of individual businesses and the number of businesses required. The risk component considers how businesses might adapt to potential risks. The farmer benefits component estimates the economic gains for farmers from the biological control.

3. Results

3.1. Operations

Rearing *H. hebetor* on the factious storage pest, the rice moth (*Corcyra cephalonica* Stainton), is a relatively simple process that requires multiplying and releasing the parasitoid within a short time period. Rearing a sufficient number of parasitoids by a target date requires businesses to consider when millet is planted in a particular year and the expected pest and parasitoid life cycles. Government extension agents or the farmer federations can help identify the planting dates for specific villages so the businesses know when they are likely to be at high risk for MHM infestation. Farmers need release of *H. hebetor* when millet plants begin to flower. Parasitoid bags can be placed in the field at that time and *H. hebetor* emerge and disperse in the fields. Farmers plant their millet after the first rains from late May to late June. Millet plants usually flower in August or early September, and the millet head miner begins damaging plants shortly after. Businesses will need a large number of parasitoid bags by early August, which implies they must multiply the parasitoids in June or July. The businesses will receive mated parasitoids from ICRISAT, INRAN, or the government plant protection services (DPV) in June or early July and commence the multiplication process. Within a week, a mated female placed in a petri dish with 25 *C. cephalonica* larvae can produce 25–30 offspring. A large stock of *C. cephalonica* must be multiplied in advance by businesses to serve as feed for *H. hebetor* during the rearing process and in field bags for releases. To secure enough rice moth larvae, mass-rearing of rice moths must start in mid to late May. INRAN and ICRISAT can provide businesses with an initial stock of millet infested with rice moth larvae during the first year, and in subsequent years businesses can collect their own in millet storage granaries. Businesses can maintain a colony of the moths year round in their facilities.

3.2. Input costs

The business is a relatively low-cost operation. A detailed list of major expenditures obtained from the pilot business and from laboratories involved in *H. hebetor* research and multiplication is available from the authors. The major expenses are two rearing rooms (one for *C. cephalonica* and one for *H. hebetor*), labor, large and small plastic buckets, mating cage, aspirator, jute bags, petri dishes, cotton, honey/sugar, millet, muslin cloth, foreceps, string, rubber, sieve and sieve plate, and marketing.

It is impractical to define business costs for a single bag of *H. hebetor* or even for the bags required for a single village as per unit costs would be too high for the firm to be profitable. A practical approach is to define the costs for a set of *H. hebetor* bags that would be minimally profitable and then to explore costs and profits for multiples of that number of bags.

The minimum set of *H. hebetor* bags are defined here as the number of bags sold to 13 villages, which implies 195 *H. hebetor* bags if each village receives 15 bags as recommended (Ba et al., 2014; Baoua et al.,

Table 1
H. hebetor enterprise budget.

Items	Value per 13 villages or 195 bags in US$
Revenue	
13 villages x 15 bags at $3.34 per bag	$651.14
Variable Costs	
Labor	$65.11
Disposable equipment and inputs	$29.32
H. hebetor bags (includes jute bag and millet mixture)	$55.35
Miscellaneous (10% of other variable costs)	$14.98
Total variable costs	$164.76
Income above variable costs	$486.38
Fixed Costs	
Rooms	$400.70
Equipment	$26.38
Marketing	$8.35
Total fixed costs	$435.43
Total costs	$600.19
Estimated profit	$50.95

2014). The number 13 is based on data from INRAN's insect-rearing laboratory. *C. cephalonica* larvae, the feed for *H. hebetor*, are commonly bred in 47 × 44 cm plastic buckets that, if initially filled with 100 larvae, can easily produce 200 jute bags worth of larvae (5000 larvae) in one month. Two hundred jute bags divided by 15, the number of bags needed per village, equals 13.33, or approximately 13. In essence, a single large bucket can safely produce enough bags of larvae for at least 13 villages. An enterprise budget for a business selling 195 *H. hebetor* bags to 13 villages is presented in Table 1. The budget assumes that *H. hebetor* bags are priced at $3.34 per bag, the price used by the pilot businesses. We indicate below how profits differ as the price changes.

Marketing costs should be relatively low. Information on the availability of *H. hebetor* bags for delivery to villages and farmers can be transmitted by the business through farmer federation networks and community radio broadcasts. Government extension agents can also provide information to farmers when warning villages of a high risk of MHM infestation. Businesses can invite village representatives to observe the *H. hebetor* rearing process, and information can be transmitted to farmer groups at annual farmer union meetings attended by farmer groupements.

3.3. Labor

Based on the pilot businesses, businesses can be expected to hire three workers and will require labor from late May through late August. From late-May to late-June, the sole business task for a worker is to rear *C. cephalonica* in buckets and occasionally check on the multiplication. This month only requires the equivalent of two days of work, one for set-up and one for monitoring and planning.

From late June to late July, workers mass-multiply *H. hebetor*. Transferring *H. hebetor* between Petri dishes and mating requires one person for 2.5–20 h per week depending on demand and the time of the month. The work becomes more time consuming over the course of the month as the number of *H. hebetor* increases, and daily work hours will increase (Table 2).

The third month involves preparing and selling bags. According to INRAN, two workers can prepare approximately 200 bags in one 8-h workday. In addition, the sales process will require one worker at a store for 4 h per day for the entire month. This worker will handle transactions and explain to customers how to use the bags. One worker will be needed for 2 h per day, regardless of demand, to maintain *H. hebetor* stocks and to help with marketing and miscellaneous tasks.

Businesses are projected to require 24 to 37 of full-time-equivalent workdays (8 h/day) among three workers over three months. The minimum wage in Niger is $50.17/month or about $2.00/day, although many workers earn below this amount and agricultural workers earned $1.12 per day (Tijdens et al., 2012). At the prevailing market price of $3.34/bag, if workers are paid 10% of the gross revenue on commission, as they were in the pilot test, businesses with all market (village) sizes can afford wages of at least pay $1.12/day wage except for those selling to only 13 villages. In other words, competitive wages are achievable for the businesses that sell to more than 13 villages. In the pilot test, workers preferred to work on commission to share in the gains as sales grew. The work does not require much training and workers saw it as an opportunity to obtain above-market wages.

Table 2
Labor hours and full-time-equivalent workdays per season.

	Number of Villages Buying Bags				
	13	26	39	52	65
Labor hours in Month 1	16	16	16	16	16
Labor hours in Month 2	40	50	60	70	80
Labor hours in Month 3	136	152	168	184	200
Total Labor Hours	192	218	244	270	296
Workdays (8 h)	24	27.25	30.5	33.75	37

3.4. Profitability

The budget indicates that the business can earn a profit of $50.95 in the first year (and more in subsequent years after fixed costs are covered). If a business were to double its sales to 26 villages (390 bags), revenue and variable costs would double, but fixed costs would remain the same. Profits would increase to $537.33 (Table 3). Revenue, cost, and profit estimates for various levels of sales are shown with price held constant at $3.34 per bag.

Based on the costs associated with selling to 13 villages shown in Table 1, the break-even output is $600.19 ÷ $50.10 = 11.98 village sales, or 179.70 bag sales. In other words, a village that sells sets of 15 bags at $3.34 per bag earns $50.10 per set and must sell a full set to approximately 12 villages to cover its costs. The break-even price for *H. hebetor* bags based on the costs associated with selling to 13 villages (each purchasing 15 bags) would be $600.19 ÷ 13 villages = $46.17 per village, or $3.08 per bag. Break-even prices for total costs associated with higher outputs (number of villages) are presented on the right in Table 3. If businesses set price too high, competitors may grab their business. If they set it too low, they risk not covering costs. If they set it too low, they risk not covering costs.

One-year of expected profits for various combinations of market size and bag price are shown in Table 4. Larger businesses are profitable at prices as low as $1.25. Low prices should help encourage a high proportion of farmers in a village to purchase the parasitoids or contribute dues to a cooperative purchase that would discourage free-riding.

Four hundred millet farmers (10 households in each of 40 randomly selected villages in millet growing regions) were asked how much they would be willing to pay for the parasitoids. While these farmers may have under- or overstated the amount for many reasons, their responses provide a rough base for comparison when analyzing business profitability under the alternative selling prices and sales volumes. Farmers indicated an average (mean) willingness to pay of $4.35 for *H. hebetor* (median $1.67). The average village size in Niger is approximately 240 households (Mariko et al., 2012). A 240-household village would only need to pay $0.21 per household in order to meet a village payment of $50.10 (15 bags at $3.34 per bag). Less populous villages would need to pay more per-household or face a lower price than $3.34 per bag.

Table 3
Costs, profits, and break-even points by sales volume.

Number of Villages	Revenue	Total Variable Costs	Total Fixed Costs	Total Costs	Profit	Break-Even Price per Village	Break-Even Price per bag
13	$651.14	$164.76	$435.43	$600.19	$50.95	$46.17	$3.08
26	$1302.28	$329.52	$435.43	$764.95	$537.33	$29.42	$1.96
39	$1953.42	$494.28	$435.43	$929.71	$1023.71	$23.84	$1.59
52	$2604.56	$659.04	$435.43	$1094.47	$1510.09	$21.05	$1.40
65	$3255.70	$823.80	$435.43	$1259.23	$1996.47	$19.37	$1.29

3.5. Market potential

The maximum number of profitable businesses will depend on market forces, but INRAN and ICRISAT may influence business origination through their relationships with farmer organizations and their role in providing equipment and expertise to H. hebetor businesses.

Several factors are relevant to business location decisions: presence of the millet head miner, proximity to population centers, being the headquarters of a farmer union, and relationships between local farmer unions and research institutions. Proximity to farms affected by MHM is important and local knowledge can help in identifying hot spots. The MHM is a problem in all areas of Niger that grow millet, and the regions of Dosso, Maradi, Tahoua, Tillabéri, and Zinder have the highest levels of millet production with 560,000 and 760,000 tons per year. Dosso, Maradi, and Tillabéri are home to the farmer federations Mooriben and FUMA Gaskiya. Each of these regions has over 2 million people, with the population spread relatively evenly within them. In Maradi, population density is greatest around and to the south of the city of Maradi. In Tillabéri, density is concentrated in a strip following the Niger River, and Dosso has a relatively even concentration of people across the region. The areas of highest concentration have farmer union headquarters. Farmers and prospective businesses would benefit if businesses located in towns with farmer union headquarters. These towns host union input shops, and using existing market infrastructure would minimize transaction costs for farmers and provide a convenient place for the businesses to sell their product. Farmer unions also provide communication networks that can assist with marketing and spreading technical advice.

INRAN and ICRISAT feel they can identify promising business locations. These institutions are familiar with the farmer unions from prior projects and outreach efforts. A profitable business will require a geographically diversified demand base that extends beyond the boundaries of a single union. Based on experience during the pilot test, *H. Hebetor* can be transported up to 500 km. While the breakeven analysis indicates a minimum of 12 villages is required, each business is likely to serve several more villages to minimize risk and raise profits. If half of the unions set up businesses, Mooriben would have 15 businesses with each serving about 49 villages, and FUMA Gaskiya would have nine businesses with each serving about 18 villages. The number of businesses may also be affected by the decisions of unions to provide (subsidize) rearing rooms.

3.6. Risk

Businesses face many risks due to failure in rearing parasitoids, input cost variation, demand changes, failure of timely bag pick-up by villages, and failure of research institutions to supply *H. hebetor* on time. Failures in rearing or maintaining parasitoids would jeopardize the business, but precautions can be taken, such as agreeing to maintain extra *H. hebetor* across multiple businesses. Businesses can multiply large numbers of *H. hebetor* that exceed what they plan to sell with little additional work or equipment. Beginning the rearing early is a safe way to ensure sufficient levels of parasitoids when needed.

Rearing rooms and labor account for 58 to 78 percent of total costs and those costs should be relatively stable. Rearing rooms may be subsidized by farmer federations, which would lower their cost. Sales may fluctuate from year to year, but businesses should be able to serve a wide enough area that they can absorb fluctuations in demand in specific villages.

The inability of buyers to travel to businesses to retrieve *H. hebetor* on time is a potential risk. If farmers release *H. hebetor* late, they may be ineffective. Businesses may need a delivery back-up plan such as hiring a motorcycle for emergency trips. Assuming a business makes an average delivery trip of 75 km, perhaps targeting multiple villages in a single trip, hiring a motorcycle for the day with fuel would only cost around $8.00. The business should have sufficient funds to cover that cost even if it had to make multiple trips.

Businesses must receive initial mated parasitoid females in late June or early July from INRAN, ICRISAT, or DPV (Crop Protection Service). To address the risk that they do not arrive, one or a few businesses could maintain a low stock of *H. hebetor* throughout the year at a cost of about $6.00. In recent years, *H. hebetor* has been a pest problem every millet season in Niger, and hence the risk is minimal that the beneficial insects will be produced and the MHM fails to appear.

Table 4
Expected first year profit from various combinations of sales and bag price.

Price/Bag	Sales Volume (number of villages purchasing the 15 bags/village)				
	13	26	39	52	65
$0.42	-$456.12	-$476.81	-$497.51	-$518.20	-$538.89
$0.83	-$383.68	-$331.93	-$280.19	-$228.44	-$176.69
$1.25	-$311.24	-$187.06	-$62.87	$61.32	$185.50
$1.67	-$238.80	-$42.17	$154.45	$351.07	$547.70
$2.09	-$166.36	$102.70	$371.77	$640.83	$909.90
$2.50	-$93.92	$247.58	$589.08	$930.59	$1272.09
$2.92	-$21.49	$392.46	$806.40	$1220.35	$1634.29
$3.34	$50.95	$537.34	$1023.72	$1510.10	$1996.49
$3.76	$123.39	$682.22	$1241.04	$1799.86	$2358.68
$4.17	$195.83	$827.09	$1458.36	$2089.62	$2720.88
$4.59	$268.27	$971.97	$1675.67	$2379.37	$3083.07
$5.01	$340.71	$1116.85	$1892.99	$2669.13	$3445.27

Table 5
Value of reduced grain loss to MHM by level of millet production.

Annual Household Millet Production (percentiles based on 2015 farmer survey)	Parasitoid-Induced Grain Loss Reduction (2–41%)	Value of Yield Gains
312.5 kg (10th percentile)	6.3–128.1 kg	$2.08 - $42.27
500 kg (25th percentile)	10.0–205.0 kg	$3.30 - $67.65
900 kg (50th percentile)	18.0–369.0 kg	$5.94 - $121.77
1625 kg (75th percentile)	32.5–666.3 kg	$10.73 - $219.88
3400 kg (90th percentile)	68–1394 kg	$22.44 - $460.02

3.7. Farmer benefits

Farmers are likely to receive substantial benefits from *H. hebetor*. In a study of the relationships among *H. hebetor*, MHM damage, and grain yields, Baoua et al. (2014) found that augmentative releases of *H. hebetor* reduced grain losses from infested plants by 8%–41%, with an average yield reduction of 34%. Their study found that the millet head miner infested 2%–88% of millet plants in fields, with an average infestation of 64%. Combining these infestation rates with the grain loss mean, *H. hebetor*-induced an average yield increase of 21.76 percent per field.

Our farmer survey indicated that the median quantity of millet produced per household was 900 kg, and the millet price for a recent three-year period averaged $0.33 per kg. (FAO, 2016). A farm that produces 900 kg of millet can expect to gain 18 kg–369 kg from *H. hebetor* control, or $5.94 - $121.77 in value (Table 5).

Even the lower of these values is significantly higher than the suggested per-household price of *H. hebetor*. Farmers can expect positive net benefits even at low levels of production and with small yield increases.

4. Discussion

The results of the feasibility analysis indicate that small businesses should be profitable and sustainable means of distributing *H. hebetor* in Niger, with prices that benefit the vast majority of farmers. Businesses can set their prices low enough that farmer incentives to free ride may be overcome even if cooperative purchases are not made in every village. Multiple categories of buyers may be interested in purchasing *H. hebetor* including farmer groupements, local village leaders, NGOs, and individual farmers. Farmer groupements are the main target, but not all farmers or villages belong to a farmer group, so *H. hebetor* businesses would need to target multiple categories of buyers. During the pilot test, some local mayors purchased bags for entire infested villages as a political gesture, and some NGOs did the same as a humanitarian gesture. However, NGO purchases are only periodic, and the primary market would be farmer groupements, local village leaders, and individual farmers.

INRAN and ICRISAT expect that village representatives will travel to central locations to pick up *H. hebetor* bags, as opposed to businesses transporting bags to villages. That is what happened in the pilot study with no significant problems. Transactions will likely occur at farmer union input shops, weekly village markets, or *H. hebetor* rearing facilities. For villages that purchase bags as a unit, the transport cost of retrieving bags should be minimal as most villages can have someone pick up bags during their normal travel as occurred in the pilot. People from villages near the business locations make frequent trips to weekly markets, farmer union input shops, or central towns. Villages far from the businesses may have a trader who travels to those locations.

Business success for augmentative biocontrol firms in the country will depend upon active networks of communication among businesses, research institutions, government extension agents, farmer organizations, and farmers. Research institutions must provide businesses with training to ensure they know how to breed an adequate supply of *H. hebetor* in a timely manner. Government extension agents can play an important role by providing villages and businesses with timely warnings about potential MHM infestations. Businesses should connect with villages early in each growing season so that the villages or groupements can pre-order parasitoids early enough for the businesses to have them ready at the proper time. Farmer organizations, government agents, and research institutions also share responsibility for spreading the word about the *H. hebetor* to farmers. Businesses, coordinating with research institutions and extension groups, can organize farmer sensitization sessions in which farmers travel to businesses to be introduced to the concept of biological control. Businesses must build trust among farmers who may not be familiar with biological control. It is important for businesses to manage risk with contingency plans. For example, businesses can breed more parasitoids than they need in case another business has a failure in rearing. While businesses grow accustomed to rearing practices, ICRISAT, INRAN, and DPV should continue breeding parasitoids as an emergency back-up in case of rearing failures.

Augmentative biological control has moved from a small cottage industry in the 1970s to a large commercial industry today with over 500 private producers of invertebrate biological control agents (Van Lenteren et al., 2017). Data are scarce about overall sales volume, but the overall market for biological control agents (invertebrates and microorganisms) approaches $2 billion annually and is growing rapidly (Dunham, 2015; Van Lenteren et al., 2017). Little information is available on firm profitability within the biocontrol industry, but most firms are small, employing less than 10 people and only a few (less than 10) employing more than 50 (Van Lenteren et al., 2017). A small fraction of the firms producing beneficial insects are located in Africa, and to our knowledge, ours is the first study published on their profitability there.

The *H. hebetor* industry in Niger was set in motion in 2015 with the pilot program, which demonstrated that workers can be trained to independently rear *H. hebetor* in a timely manner. The pilot program provided limited insight into the feasibility of farmers cooperatively purchasing parasitoids at the village level, as most purchases were made by NGOs. However, some village chiefs purchased bags using local village council funds and focus group discussions indicated that cooperative purchases are likely. Our study suggests that such purchases are economically feasible and that a small industry producing and distributing *H. hebetor* should turn a profit. Augmentative biological control is in its infancy in most of Africa, but this study indicates the potential to establish and sustain it, at least for a major pest such as the millet head miner in Niger.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.cropro.2018.03.014.

References

Aker, J.C., del Ninno, C., Dorosh, P.A., Mulder-Sibanda, M., Razmara, S., 2009. Niger Food Security and Safety Nets. Social Protection & Labor Discussion Paper No. 1418, World Bank Group.

Ba, M.N., Baoua, I.B., N'Diaye, M., Dabire-Binso, C., Sanon, A., Tamò, M., 2013. Biological control of the millet head miner *Heliocheilus albipunctella* in the Sahelian region by augmentative releases of the parasitoid wasp *Habrobracon hebetor*: effectiveness and farmers' perceptions. Phytoparasitica 41 (5), 569–576.

Ba, M.N., Baoua, I.B., Kaboré, A., Amadou, L., Oumarou, N., Dabire-Binso, C., Sanon, A., 2014. Augmentative on-farm delivery methods for the parasitoid *Habrobracon hebetor* Say (Hymenoptera: Braconidae) to control the millet head miner *Heliocheilus albipunctella* (de Joannis)(Lepidoptera: Noctuidae) in Burkina Faso and Niger. BioControl 59 (6), 689–696.

Baoua, I., Ba, N.M., Ndiaye, M., Dabire, C., Tamo, M., 2009. Rapport d'activite's du projet de gestion integree de la mineuse de l'epi de mil au Sahel. McKnight Foundation Collaborative Crop Research Program, Minneapolis, MN Unpublished report.

Baoua, I.B., Amadou, L., Oumarou, N., Payne, W., Roberts, J.D., Stefanova, K., Nansen, C., 2014. Estimating effect of augmentative biological control on grain yields from individual pearl millet heads. J. Appl. Entomol. 138 (4), 281–288.

Bhatnagar, V.S., 1984. Rapport D'Activite (Novembre 1982-Octobre 1983). Programme de Lutte Biologique. Projet CILSS de lutte integree, Nioro du Rip, Senegal).

Bhatnagar, V.S., 1989. Lutte biologique contre la chenille mineuse de l'épi du mil. pp. 5–8 Sahel PV info 1/2.

Cock, M.J., van Lenteren, J.C., Brodeur, J., Barratt, B.I., Bigler, F., Bolckmans, K., Consoli, F.L., Haas, F., Mason, P.G., Parra, J.R.P., 2010. Do new access and benefit sharing procedures under the convention on biological diversity threaten the future of biological control? BioControl 55 (2), 199–218.

Dunham, W.C., 2015. Evolution and future of biocontrol. In: Presentation at the 10th Annual Biocontrol Industry Meeting (ABIM), Basel, Switzerland, October 20th, 2015. http://www.2bmonthly.com/wp-content/uploads/2015/11/Bill-Dunham-2BMonthly-Evolution-Future-of-Biocontrol-Industry-copy.pdf, Accessed date: 10 September 2017.

Food and Agriculture Organization of the United Nations, 2016. FAOSTAT Database Query, Food and Agriculture Organization of the United Nations. Rome, Italy. Retrieved from http://faostat3.fao.org/browse/Q/QC/E.

Gahukar, R.T., Guevremont, H., Bhatnagar, V.S., Doumbia, Y.O., Ndoye, M., Pierrard, G., 1986. A review of the pest status of the millet spike worm, Raghuva albipunctella De Joannis (Noctuidae: Lepidoptera) and its management in the Sahel. Int. J. Trop. Insect Sci. 7 (04), 457–463.

Gahukar, R.T., 1987. Relationship between spike worm (*Raghuva albipunctella*) infestation and flowering of pearl millet, and some sources of resistance. Agronomie 7, 595–598.

Gahukar, R.T., 1989. Insect pests of millets and their management: a review. Int. J. Pest Manag. 35 (4), 382–391.

Gahukar, R.T., 1990. Overview of insect pest management of cereal crops in sub-Saharan West Africa. Indian J. Entomol. 52 (1), 125–138.

Gahukar, R.T., 1992. Effect of various fertilizers and rates on insect pest/pearl millet relationship in Senegal. Trop. Agric. 69 (2), 149–152.

Garba, S., 2000. Lutte biologique contre la mineuse de l'epi *Heliocheilus albipunctella* De Joannis, avec l'utilisation du parasitooïde *Bracon hebetor* Say. IPRIFRA, Katibougou, Mali Mémoire de fin d'étude.

Guevremont, H., 1981. Etudes sur l'entomofaune du mil: rapport annuel de recherches pour l'année 1980, vol. 31 Centre National de Recherches Agronomiques de Tarna, Laboratoire d'entomologie, Maradi, Niger.

Guevremont, H., 1982. Etudes sur la mineuse de l'épi et autres insectes du mil: Rapport annuel de rechèrches pour l'année 1981 Centre National de Recherches Agronomiques de Tarna Section Protection des Végétaux, Maradi, Niger.

Guèvremont, H., 1983. Recherches sur l'entomofaune du mil. Rapport annuel de recherches pour 1982. Centre National de Recherches Agronomiques de Tama, INRAN (Institut national de Recherches Agronomiques du niger, Maradi, Niger.

Henzell, R.G., Peterson, G.C., Teetes, G.L., Franzmann, B.A., Sharma, H.C., Youm, O., Ratnadass, A., Toure, A., Raab, J., Ajayi, O., 1997. Breeding for resistance to panicle pests of sorghum and pearl millet. In: Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl Millet: September 22-27, 1996. Holiday Inn Plaza, Lubbock, Texas (p. 255).

Institut National de la Statistique, 2013. Annuaire Statistique-demographie, 2008-2012. Niger).

Krall, S., Youm, O., Kogo, S.A., 1995. Panicle insect pest damage and yield loss in pearl millet. In: Proceeding of an International Consultative Workshop on Panicle Insect Pest of Sorghum and Millet. ICRISAT Sahelian Centre, Niamey, Niger, pp. 135–145.

Mariko, D., Malik, S., Mohamoud, O., 2012. Building Resilience in the Sahel through Cereal Banks. Food for Peace West Africa Issue #9.

Mooriben, 2012. Plan Operationnel 2011. http://www.mooriben-niger.org/IMG/pdf/Rapport_d_activit_2011vf.pdf, Accessed date: 24 May 2017.

Mooriben, 2017. Qui Sommes Nous? Accessed at http://www.mooriben-niger.org/IMG/pdf/DEPLIANT_MOORIBEN_2_.pdf , Accessed date: 24 May 2017.

Ndoye, M., 1992. Biologie et dynamique des populations de *Heliocheilus albipunctella* (de Joannis), ravageur de la chandelle de mil dans le Sahel. In: Séminaire sur la Lutte Integrée contre les Ennemis des Cultures Vivrieres dans le Sahel, [2. Seminar on Integrated Pest Management of Food Crops in Sahel]. Bamako (Mali). 4-9 Jan 1990.

Nwanze, K.F., Sivakumar, M.V.K., 1990. Insect pests of pearl millet in Sahelian West Africa—II. *Raghuva albipunctella* De Joannis (Noctuidae, Lepidoptera): distribution, population dynamics and assessment of crop damage. Int. J. Pest Manag. 36 (1), 59–65.

Payne, W., Tapsoba, H., Baoua, I.B., Malick, B.N., N'Diaye, M., Dabire-Binso, C., 2011. On-farm biological control of the pearl millet head miner: realization of 35 years of unsteady progress in Mali, Burkina Faso and Niger. Int. J. Agric. Sustain. 9 (1), 186–193.

Tijdens, K., Besamusca, J., Ngeh Tingum, E., Nafiou, M.M., 2012. Wages in Niger: Wage Indicator Survey 2012.

Van Lenteren, J.C., 2012. The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. BioControl 57 (1), 1–20.

Van Lenteren, J.C., Bolckmans, K., Kohl, J., Ravensberg, W.J., Urbaneja, A., 2017. Biological control using invertebrates and microorganisms: plenty of new opportunities. BioControl. http://dx.doi.org/10.1007/s10526-017-9801-4.

World Bank, 2013. Agricultural Sector Risk Assessment in Niger: Moving from Crisis Response to Long-term Risk Management. Agriculture and Environmental Services (AES) Department & Agriculture, Rural Development, and Irrigation (AFTAI) Unit in the Africa Region. http://siteresources.worldbank.org/INTAFRICA/Resources/257994-1349215552505/niger-risk-assessment-english.pdf, Accessed date: 23 May 2017.

World Bank, 2017. Data Indicators. http://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD?view=chart, Accessed date: 14 May 2017.

Youm, O., Gilstrap, F.E., 1993. Life-fertility tables of bracon hebetor Say (hymenoptera: Braconidae) reared on *Heliocheilus albipunctella* de Joannis (Lepidoptera:Noctuidae). Int. J. Trop. Insect Sci. 14 (04), 455–459.

Youm, O., Kumar, K.A., 1995. Screening and breeding for resistance to millet head miner. In: Nwanze, K.F., Youm, O. (Eds.), Panicle Insect Pests of Sorghum and Pearl Millet, Proceedings of and International Consultation Workshop, 4–7 October 1993. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, pp. 201–209.

Youm, O., Owusu, E.O., 1998. Assessment of yield loss due to the millet head miner, *eliocheilus albipunctella* (Lepidoptera: Noctuidae) using a damage rating scale and regression analysis in Niger. Int. J. Pest Manag. 44 (2), 119–121.