BMZ Project Final Report

Enhancing horticultural productivity, incomes and livelihoods through integrated management of aphid pests on vegetables in sub-Saharan Africa

R. Hanna, A. Fotso-Kuate, P. Lava Kumar, E. Djomaha, N. Toukem, M. Dongmo, A. Doumtsop, S. Ramasamy, A. Abang, S. Ekesi, S. Mohamad, W. H. Bayissa, A. B. Singh, R. Houmgny, W. Weisser, S. Keukenou, T. R. Ghogomu

Summry of Final Report submitted to German Ministry of Economic Development and Cooperation

September 2016

International Institute of Torpica Agriculture (IITA)

IITA Transforming African Agriculture CGIAR

Federal Ministry for Economic Cooperation and Development

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Abstract

Through several surveys and field trials we determined species composition and distribution of aphids as well as virus incidence on okra and cabbage in Cameroon and okra and kale in Kenya. On cabbage and kale, the cabbage aphid and false turnip aphid were, respectively, most important in higher and lower altitudes. The cabbage aphid in Kenya was associated with both specialist and generalist natural enemies whereas in Cameroon the specialist parasitoid *Diaeretiella rapae* was absent. Attempts to introduce this parasitoid into Cameroon failed, perhaps because of specific differences in cabbage aphid hosts from Cameroon and Kenya. No parasitoids were associated with the false turnip aphid regardless of location. On okra, the cotton aphid (*Aphis gossypi*) was the most abundant and widespread, but the leaf beetle *Nistora uniformis* turned out to be the major pest of okra, surpassing the importance of aphids in some locations. Regardless of country, aphids attracted heavy use of pesticides which upset the existing guild of natural enemies that could otherwise reduce aphid populations to acceptable levels, as we determined during details field trials in both Cameroon and Kenya. The components of an integrated program for the control of aphids on okra, cabbage, and kale have been identified. This program singly or in several combinations are likely to result in considerable reduction in the use of broadspectrum pesticides and in improved productivity and profitability of vegetables with lower pesticide residues.

Citation

Hanna, R., Fotso-Kuate, A., Kumar, P.L., Djomaha, E., Toukem, N., Dongmo, M., Doumtsop, A., Ramasamy, S., Abang, A., Ekesi, S., Mohamad, S., Bayissa, W.H., Singh, A.B., Houmgny, R., Weisser, W., Keukenou, S., Ghogomu. T.R. (2016). Enhancing horticultural productivity, incomes and livelihoods through integrated management of aphid pests on vegetables in sub-Saharan Africa. Summry of Final Report submitted to German Ministry of Economic Development and Cooperation, September 2016. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. 22pp.

Executive Summary

Through several surveys and field trials we determined species composition and distribution of aphids as well as virus incidence on okra and cabbage in Cameroon and okra and kale in Kenya. On cabbage and kale, the cabbage aphid and false turnip aphid were, respectively, most important in higher and lower altitudes. The cabbage aphid in Kenya was associated with both specialist and generalist natural enemies whereas in Cameroon the specialist parasitoid *Diaeretiella rapae* was absent. Attempts to introduce this parasitoid into Cameroon failed, perhaps because of specific differences in cabbage aphid hosts from Cameroon and Kenya. No parasitoids were associated with the false turnip aphid regardless of location. On okra, the cotton aphid was the most abundant and widespread, but the leaf beetle *N. uniformis* turned out to be the major pest of okra, surpassing the importance of aphids in some locations. Regardless of country, aphids attracted heavy use of pesticides which upset the existing guild of natural enemies that could otherwise reduce aphid populations to acceptable levels, as we determined during details field trials in both Cameroon and Kenya.

Studies on the dynamics of aphids and their natural enemies on all the target crops revealed the timing of peak aphid infestations—generally during declining rainfall or during the dry season—and the diversity and seasonality of associated natural enemies such as syrphids, coccinellids, and other generalist predators. On kale and cabbage, the species composition of generalist natural enemies is approximately similar, but the order of dominance is different, with coccinellids being more abundant early in the crop cycle in Kenya while syrphids are the dominant species in Cameroon. In both crops and in both countries, while generalist predators appear to bring down aphid populations, this happens after the build-up of large populations. There are indications that conditions that favor earlier colonization can improve the action of native natural enemies. The parasitoid *D. rapae* and the fungus *E. neoaphis* also play an important role in aphid dynamics and together with generalist natural enemies are likely to keep aphid populations at low level in the absence of interference by frequent pesticide applications. A similar picture emerges from okra trials in both Cameroon and Kenya with similar composition of generalist predators with a more prominent presence of the parasitoid *A. colemani* in Kenya but with low occurrence in Cameroon, probably due to heavy hyperparasitism. Comparison of farmer management (using insecticides) and researcher management (no insecticides) showed that insecticide use does not affect aphid populations on okra with the exception of the variety Bafia, but on the variety Kirikou, aphid populations were nearly three-folds higher on farmer plots than on researcher plots. These differences could not be explained by differences in natural enemies as the latter were largely similar in the two types of management. Similar studies on cabbage clearly showed greater and consistent control of aphids by farmer insecticide practices, but with negative effects on the abundance of aphid natural enemies. Farmer practices had little impact on DBM populations or parasitism levels by *Diadegma semiclausum*, an introduced parasitoid now confirmed established in Cameroon and causing upward of 35% parasitism of DBM.

Studies on the interactions between ants and aphids on okra, where the two occur quite commonly, has shown that ants under field conditions do not affect aphid populations, but recruitment of ants by aphids protects the plant from damage by the okra leaf beetle. Experiments with interplanting okra with maize and beans show promise in controlling aphids and improving okra yields. These

initial findings require scaling to multiple locations to determine the effectiveness of this approach in reducing pesticide use on okra.

Studies on host plant resistance to aphids in okra have resulted in the identification of four genotypes for which mechanisms of resistance have been identified. In the field surveys and in replicated field trials, we have also identified two local varieties (Cafeier and Bangourain) and one improved variety (Clemson spineless) that support low aphid populations, while leaf beetle damage is common with damage scores never exceeding an average of 2.5 on a scale of 1-5 of increasing damage severity. Among the cabbage cultivars that are commercially available in Cameroon, Globe Master, Green Coronet, and Marcanta are three that support relatively lower aphid populations than three other commercially available cultivars. Efforts are underway to promote the use of these low-aphid cultivars in integrated aphid management.

Ten isolates of entomopathogenic fungi (eight *Metarhizium anisopliae* and two *Beauveria bassiana*) have been screened against the three target aphids on okra and the crucifers. Of these isolates, three *M. anisopliae* isolates showed considerable promise due to high mortality of all three target aphids in laboratory and screenhouse trials. One *M. anisopliae* isolate, ICIPE 62, has shown best promise and is presently being developed as a commercial aphid biopesticide in Kenya.

The project has trained eight postgraduate students, four PhD (2 males and 2 females), and four MSc students (3 females and 1 male). All except one female student are from the African continent and all are presently either employed or continuing their research through postdoc or PhD opportunities. In addition to the student training, two farmer IPM training courses were conducted in Cameroon and Kenya.

In summary, the components of an integrated program for the control of aphids on okra, cabbage, and kale have been identified. This program will likely depend on the following options: (1) conservation biological control through habitat management and reduced use of broadspectrum pesticides; (2) exchange of efficient parasitoids (e.g., *D. rapae* and *A. colemani*) and entomopathogens (e.g., *N. fresenii* and *E. neoaphis*), (3) promotion of conditions that favor epizootics of entomopathogens; (4) selection and promotion of resistant and moderately resistant varieties with commercially acceptable horticultural traits and market suitability; and (5) commercialization of biopesticides that can limit aphid populations while conserving existing natural enemies. Singly or in several combinations, these IPM options are likely to result in considerable reduction in the use of broadspectrum pesticides and in improved productivity and profitability of vegetables with lower pesticide residues.

DETAILED REPORT

1. Basic data

Name of IARC	*International Institute of Tropical Agriculture*
Project title	*Enhancing horticultural productivity, incomes and livelihoods through integrated management of aphid pests on vegetables in sub-Saharan Africa*
Funding type, GIZ Project Number and Contract Number	*Project no.: 10.7860.9-001.00* *Contract no.: 81132671*
Reporting Period	1 April 2011 to 31 March 2016
Project Coordinator and Project Scientists	Project coordinator: Dr Rachid Hanna, IITA-Cameroon, 2008 BP (Messa), Yaoundé, Cameroon; Ph. +237 223-7434; r.hanna@cgiar.org; Principal staff members participating in the project Dr Apollin Fotso Kuate (IITA-Cameroon) Dr P. Lava Kumar (IITA-Nigeria) Mr Armand Doumtsop (IITA-Cameroon) Mrs Edwige Djomaha (PhD student, Cameroon) Ms Nadia Toukem (MSc student, Cameroon) Mr Steve Soh (MSc student, Cameroon) Ms Raiisa Houmgny (MSc student, Cameroon) Mr Michel Dongmo (MSc student, Cameroon)
Project Partners	***Kenya*** Dr Sunday Ekesi (*icipe*) Dr Samira Mohammad (*icipe*) Mr Wakum Hundessa Bayissa (PhD student, *icipe*) Dr Monica Waijango (Kenya Agricultural Research Institute [KARI])—no longer with KARI ***Cameroon*** Dr Sevillor Kekeunou (University of Yaounde I) Dr Richard Ghogomu (University of Dschang) Mrs Edwige Djomaha (University of Dschang) ***AVRDC*** Dr Srinivasan Ramasamy (AVRDC-Taiwan) Mr Albert Abang (PhD student, AVRDC-Cameroon) ***Germany*** Dr Wolfgang Weisser (TUM)

	Akanksha Singh (PhD student, TUM)

2. Final Report

State of Project Implementation

The project logframe outlined six outputs with a number of activities within each output. The state of project implementation is provided below for each output with reference to the timetable in Annex 3 of the project document.

Output 1—activity 1.1**:** Distribution, abundance of aphids and their damage level, and associated natural enemies. Countrywide surveys were conducted in Cameroon and Kenya in 2011 and continued in non-covered areas in Kenya in 2012 and repeated in Cameroon in 2013. Aphids and their associated natural enemies have been identified and curated. Georeferenced maps of the collected data have been produced. A second survey was conducted in Cameroon in Year 4 to determine changes in aphid infestations and farmer practices. This activity is 100% completed for Year 4 and 90% overall.
Output 1—activity 1.2**:** Prevalence, distribution, and diversity of aphid-transmitted viruses in the target countries. This activity was conducted in conjunction with activity 1.1. Virus incidence during the surveys was quite low with okra mosaic and turnip mosaic viruses being the most prevalent. The second survey in 2013 provided additional information on the severity of viruses infecting the target crops, which indicated that viruses do not play a significant role in okra and cabbage production in the two target countries. This is 100% completed for 2014 and 85% overall.
Output 2—activity 2.1**:** Dynamics, colonization patterns, and dispersal of *Aphis gossypii* in okra, and *Brevicoryne brassicae* and *Lipaphis pseudobrassicae* on cabbage and kale. This activity has moved again ahead of schedule in the target crops in both target countries. This is 100% completed.
Output 2—activity 2.2**:** Climate matching studies were initiated for the exchange natural enemies as planned. One parasitoid (*Diaeretiella rapae*) was cultured in Kenya and a limited number was sent to Cameroon where the cultures were established and biological studies were initiated. Unfortunately, for unknown reasons, the colony crashed and we have renewed it from the same source from Kenya to continue with the planned studies. We will need to continue with the determination of *B. brassicae* diversity and conduct specific biological studies to understand the interactions of *D. rapae* with specific cabbage aphid populations. This activity is 50% completed for Year 4 as well as overall for the project.
Output 2—activity 2.3**:** The fungus *Neozygites fresenii* was identified from Cameroon and Kenya and specimens have been preserved for planned studies. Problems were encountered with multiplication of preserved mummies. Because of the initial problems in student recruitment and prioritization of other activities (e.g., development of a biopesticide; see later in the text) and the need for in vivo culturing of the fungus, further research on *N. fresenii* has been shelved until perhaps the second phase of the project.
Output 3—activity 3.1**:** Screening for resistance and identifying resistance mechanisms for *Aphis gossypii*. This activity has moved rather well for okra. Nine aphid-resistant or tolerant okra lines were identified and used in a second multilocational trial in 2014, which has been completed but final recommendations on their use are still awaiting further in-depth G×E analysis. Nevertheless, two of the accessions have been used by the Cameroon-based AVRDC okra breeder in his okra improvement program. This activity is 100% completed.
Output 3—activity 3.2**:** Evaluation of available cabbage and kale cultivars for their suitability to *B. brassicae* and *L. pseudobrassicae*. This activity on cabbage in Cameroon, which is part of a PhD

student's project, is 100% completed for Year 4. We added a component on the phonological modeling of the cabbage and turnip aphids on two cabbage cultivars to help us to predict their distribution and activity patterns in the two targeted countries. We have completed the phenology of the cabbage aphid,mapped its distribution (both using the Insect Life Cycle Modeling [ILCYM] software developed by CIP), and are presently engaged in developing the phenology of the turnip aphid on the same cabbage cultivars. This activity is 100% completed.
Output 4—activity 4.1: Development of entomopathogens based on *Beauvaria bassiana* and/or *Metarhizium anisopliae*. Three highly virulent *M. anisopliae* strains have been identified out of 10 isolates tested (including two *B. bassisana*) in laboratory and screenhouse tests. One isolate, ICIPE 62, was retained and is presently being developed as a biopesticide for four target species, *B. brassicae, L. pseudobrassicae, A. gossypii,* and *M. percisae*. This activity is 100% completed.
Output 4—activity 4.2**:** This activity was planned with the NARS partners. We have conducted field tests in Cameroon on cabbage and okra. Additional activities were planned in both Kenya (biopesticide) and Cameroon (biopesticides and natural products) but were not completed. This activity is 75% completed overall.
Output 5—activity 5.2**:** All PhD and MSc student have completed their degrees; all except one have defended. The last one will defend in June 2017.
Output 6—activities 6.1 and 6.2**:** These were carried out in Kenya and Cameroon and are 100% completed pending publication of results.

SLO Contribution

Quantify the beneficiaries the project has reached / involved actually and - in case – describe reasons for divergence in relation to the initial numbers as stated in the project proposal.

1. Thirty instead of 60 NARS staff and 300 instead of 200 farmers in two instead of three countries (as agreed at the start of the project) were trained in vegetable IPM.
2. One private sector (RealIPM) adopts biopesticide developed for aphid control.
3. Four okra genotypes and two cabbage genotypes were identified for incorporation in aphid IPM package.
4. Establishment and spread of the parasitoid *Diadegma semiclausum* and impact on diamondback moth assessed.
5. Four PhD students and three MSc students received their degrees through the project.
6. Prevailing aphid management practices and pesticide use on okra, cabbage and Kale in two countries; but we were not able to quantify level of pesticide reduction. It was sure however that at least the number of targeted farmers were sensitized to alternatives to pesticides.

Achievement of the Purpose

How do you rate the achievement of the Purpose (i.e. utilization of the research outputs, as defined in the Logical Framework Matrix) in quantity and quality?
Scale: 1 – 6
3 = satisfactory rating, falling short of expectations but with positive results dominant

Achievement of the Goal

How do you rate the achievement of the Goal (i.e. direct benefits for target groups, as defined in the Logical Framework Matrix) in quantity and quality?
Scale: 1 – 6
3 = satisfactory rating, falling short of expectations but with positive impacts dominant

Gender Equity aspects

How do you rate the consideration of gender equity aspects as defined in the Project Proposal?
Scale: 1 – 6
2 = good rating, fully in line with the expectations, no significant defect

3. Major Research Findings

***Output 1—activity 1.1*: Distribution, abundance of aphids and their damage level, and associated natural enemies.**

We conducted several baseline and follow-up surveys on cabbage and okra in Cameroon and kale and okra in Kenya throughout the project. These surveys provided the baseline distribution and species composition of pest aphids and natural enemies in the three crops in the two target countries. The follow up surveys provided information on these species. Abundance and distribution have changed overtime during project implementation.

In Cameroon, the cabbage aphid *Brevicoryne brassicae* was the most abundant aphid in the areas of the western highlands where cabbage production is widespread. A shift toward dominance of the false turnip aphid occurs in low altitude areas where cabbage is grown but in much more limited quantity. We did not find any parasitoids associated with either of the two aphid species, but several generalist predators, particularly at least two species of syrphid flies could be found in large numbers and later were shown to exert substantial mortality on both aphid species. Regardless of location, the dominant aphid occurred in large numbers and could cause up to 60% losses in cabbage production if left uncontrolled. Several ant species were also found associated with the aphids. The diamondback moth (DBM), *Plutella xylostella*, was the most important lepidopteran pest associated with cabbage at all altitudes. It was evident however that the earlier introductions of the parasitoid *Diadegma semiclausum* in the West and Northwest regions of Cameroon have resulted in the establishment of this effective parasitoid. Later follow-up studies showed that its distribution was widespread with significant impact in the control of DBM.

Table 1. Abundance of cabbage and turnip aphids and diamondback moth (DBM) larvae and their parasitism by *Diadegama semiclausum* in three cabbage-growing regions of Cameroon.

Region	Cabbage aphid		Turnip aphid		DBM Larvae		%DBM parasitism	
	2013	2014	2013	2014	2013	2014	2013	2014
Northwest	539.5	44.8	33.2	5.85	2.06	0.45	45.2	16.3
Southwest	0.17	50.3	0.77	2.02	0.54	3.18	0.00	0.00
West	75.8	68.5	0.29	14.42	0.29	0.57	34.5	20.3

For kale in Kenya, the cabbage aphid was the most widely spread aphid species which also occurred in large numbers and caused significant damage in some areas, particularly where pesticides were used for DBM control. However, in the drier areas, the peach aphid *Myzus percisae* was the most common while the cabbage aphid was nearly absent. The parasitoid *Diaeretiella rapae* was found widely associated with the cabbage aphid in Kenya. Attempts to introduce the parasitoid to Cameroon failed for unknown reasons. Further reflections on this issue pointed in the direction of potential endoysmbionts present in cabbage aphids in Cameroon that could have prevented the establishment and buildup of the parasitoid. This is an object of ongoing research.

For okra in Cameroon, the cotton aphid, *A. gossypii* was the most widely spread species while a species of leaf beetle,*N. uniformis,* was most damaging to okra and emerged later as the most significant pest species of okra in Cameroon. Two species of commonly occurring parasitoids, *Aphidius colemani* and *Lysiphlebus testaceipes*, were found associated with the cotton aphid, but their prevalence and impact were minimal most likely due to the presence of hyperparasitoids that limit the impact of the two species. Several ant species were encountered in association with the cotton aphid. Their role in aphid biology and population dynamics was later clarified through screenhouse and field studies. Similar findings were obtained from the surveys on okra in Kenya.

The surveys in both countries provided data that were used in developing proper sampling methods for the target pest species and their natural enemies to reduce sampling time and cost. They also identified practices and crop varieties that were later used in experiments in developing control options for the target aphid species.

Output 1—activity 1.2**:** Prevelance, distribution, and diversity of aphid-transmitted viruses in the target countries. This activity was conducted in conjunction with activity 1.1 in both Cameroon and Kenya. In Cameroon, virus infections of okra were recorded in 6 out of the 7 surveyed regions. Virus severity ranged from 1 (absent) to 5 (most severe), with most infections being of the 2 and 3 levels (on a scale of 1–5, with 1 indicating virus absence and 5 indicating severe infections). Viruses on cabbage were recorded only in the Southwest region in Cameroon, with only one field showing moderate virus symptoms in the West region. Leaf samples are presently being analyzed with PCR to determine the identity of the viruses. Our overall conclusion is that viruses, while present, do not play a significant role in the production of the three target crops in the two target countries.

Output 2—activity 2.1**: Dynamics, colonization patterns and dispersal of *A. gossypii* in okra and *Brevicoryne brassicae* and *L. pseudobrassicae* on cabbage and kale.**

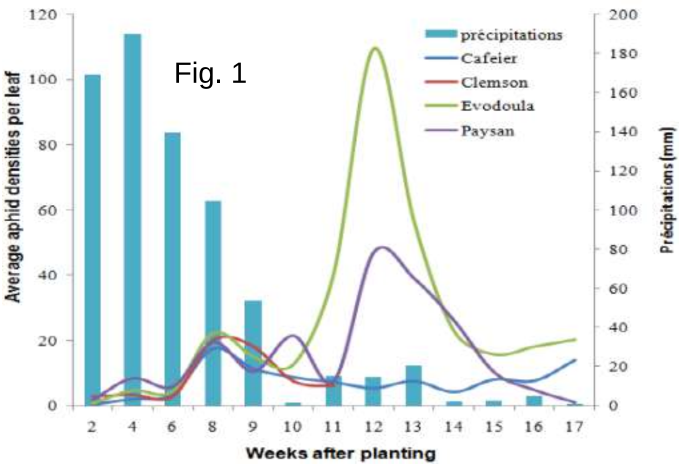
Research within this activity consisted of conducting screenhouse and field experiments to determine the relationship between aphid abundance and their impact on crop growth and yield and the role of natural enemies in controlling the aphids.

Two field experiments (dry and wet seasons) were conducted on-station at the University of Dschang farm and on three farms in West and Northwest Cameroon, using the most prevalent cabbage varieties in the two regions (according to the survey conducted under Output 1). In the Dschang experiments, *B. brassicae* was the dominant species during the rainy season with higher abundance of *L. pseudobrassicae* during the dry season, although overall numbers were low during the rainy season. Syrphids (two species) and the entomopathogenic fungus *E. neoaphis* were the most prevalent natural enemies. DBM was more abundant also during the dry season and its parasitism by *D. semiclausum* was lower than in the dry season experiment (see Output 3). The varieties Green Coronet, Globe Master, and Marcanta were the least favorable for the buildup of aphid populations while Marcanta supported the least DBM populations and should be promoted as a component of cabbage variety choice by farmers.

			Abundance, incidence or damage per plant					
Locality	Variety	Management	Aphids	% infection	Predators	DBM	% DBM parasitism	DBM damage
Baleveng	Globe	Researcher	2628.7 ± 1701.7	0 ± 0	0.296 ± 0.096	0.193 ± 0.079	37.3 ± 21.7	1.97 ± 0.079
	Globe/Green Coronet	Farmer	0.441 ± 0.287	0 ± 0	0.042 ± 0.024	0.492 ± 0.178	26.9 ± 19.5	2.09 ± 0.063
Foumbot	Globe	Researcher	6725.8 ± 2822.6	6.55 ± 4.07	0.37 ± 0.084	6.62 ± 2.78	18.2 ± 9.04	3.14 ± 0.19
	Globe/Green Coronet	Farmer	82.5 ± 43.2	1.13 ± 0.73	0.094 ± 0.073	4.47 ± 1.45	22.4 ± 7.02	2.89 ± 0.182
Santa	Green Coronet	Researcher	3340.8 ± 2845.9	0.429 ± 0.353	0.976 ± 0.371	3.17 ± 1.06	32 ± 10.6	2.47 ± 0.161
	Green Coronet	Farmer	332.9 ± 241.5	0 ± 0	0.144 ± 0.051	3.21 ± 1.09	36 ± 13.2	2.54 ± 0.144

The on-farm trials (adjoining table) clearly showed that farmer practices of two insecticide applications of cypermethrin for cabbage aphids and DBM, have resulted in good control of the aphids and that naturally occurring predators were not able to prevent the buildup of large aphid populations on cabbage. In contrast, DBM densities and damage level were not affected by pesticide applications but there were considerable differences in DBM parasitism especially in the higher altitude fields of Baleveng and Santa. 100% of the parasitoids were identified as *D. semiclausum*, a parasitoid released in the Santa area in 2009 (by an *icipe*-led BMZ project. Plans are underway to determine the extent of the distribution of this parasitoid in Cameroon.

Similar experiments in western Kenya during the short and dry seasons provided good baseline information on



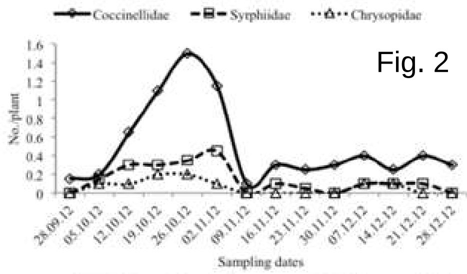
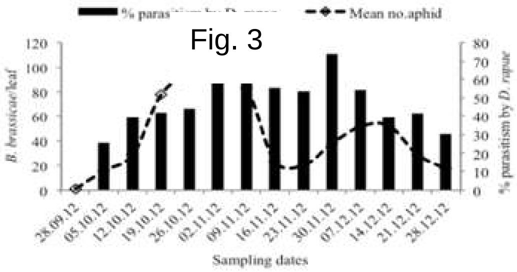


Fig. 1b



the dynamics of aphid populations and their natural enemies on kale (Figs. 1,2,3). A notable difference from the Cameroon data is the presence of largely *B. brassicae* and relatively high parasitism, which is completely absent from Cameroon, and the higher porpoprtion of coccinellids compared with syrphids and other predators. Three parasitoid species (*Diaeretiella rapae, Aphidius* spp, *and Ephedrus* spp.) and two hyperparasitoids (*Syrphophagus aphidivorus* and *Pachyneuron* spp.) were reared from mummified aphids in both seasons. Among the three parasitoid species, *D. rapae* was found to be the predominant accounting for over 95% of the parasitoids collected. Additional natural enemy exclusions (with cages) showed that these natural enemies are able to provide considerable control of aphid infestations.In on-station experiments we quantified the dynamics of aphid populations on four okra varieties widely used in Cameroon (as shown in the country-wide survey). Of the four principal varieties, Evodula was most infested while Cafeier was least infested and that the cotton aphid *A. gossypii* was the only aphid species on okra in the trial. It was also evident, as observed in the country-wide survey, that parasitism by insect parasitoid was naturally very low (not exceeding 5% at peak level) and consequently contributed very little to limiting aphid densities. Nevertheless, parasitism was density dependent in all four varieties tested. In contrast, several species of generalist predators (cooccinellids—45%; syrphids—21%; spiders—18%; staphylinids and other predator beetles—16%; chyrsopids—1%) play an important role in limiting aphid infestations.
In on-farm trials, we established four experiments to compare farmer and researcher managed okra fields in five locations with the difference being farmers' use of insecticides for aphid and leaf beetle control.

.
The results presented in the adjoining table 2 provide a general assessment of the failure of current farmer practices in managing aphids and leaf beetles in

		Abundance or damage per plant				
Okra Variety	Management type	Aphids	% Parasitism	Predators	Leaf beetle	Beetle damage
Bangourain	Researcher	23.6 ± 4.0	0.117 ± 0.108	0.110 ± 0.020	1.74 ± 0.65	2.35 ± 0.27
	Farmer	31.4 ± 4.41	0.569 ± 0.211	0.083 ± 0.016	0.76 ± 0.36	1.59 ± 0.129
Bafia	Researcher	74.9 ± 15.1	0.072 ± 0.042	0.117 ± 0.029	2.05 ± 0.91	2.5 ± 0.268
	Farmer	6.15 ± 1.10	3.125 ± 2.02	0.075 ± 0.030	0.1 ± 0.1	2.01 ± 0.281
Cafeier	Researcher	42.1 ± 5.32	0.034 ± 0.032	0.146 ± 0.018	1.63 ± 0.67	2.01 ± 0.329
	Farmer	36.0 ± 8.12	0.397 ± 0.279	0.300 ± 0.089	0.95 ± 0.95	2.42 ± 0.95
Kirikou	Researcher	147.2 ± 17.0	0.014 ± 0.014	0.361 ± 0.053	0.81 ± 0.36	2.05 ± 0.159
	Farmer	486.2 ± 109.8	0.182 ± 0.153	0.260 ± 0.048	0.6 ± 0.34	1.88 ± 0.287

their fields. Except in one case, with the variety Kirikou (where farmer practices aggravated aphid infestation), farmer practices did not result in significant reductions in aphid densities (and consequently damage levels). While leaf beetle numbers were generally lower in farmer managed fields, this difference did not translate into significant differences in leaf beetle damage levels.

We also conducted experiments on the effect of border vegetation on aphid colonization. Maize border reduced aphid colonization by nearly three folds. Similar results were obtained with okra, indicating that border vegetations can considerable reduce rates of aphid colonization and therefore the aphid populations in both kale and okra and can be incorporated as an option in aphid management on vegetables.

Our surveys had shown that okra in Cameroon is often intercropped with other annual crops such as maize and beans. We spent a considerable effort to determine—first in an on-station trial and later in an on-farm trial—the effects of intercropping on infestations of *A. gossypii* and other pests and beneficial invertebrates and impact on okra yield. In the first experiment, conducted from April–August 2014, we intercropped maize and bean with okra in all possible combinations with high and low density intercropping. In the first experiment, the numbers of all pests (except aphids) and spiders were higher in low density plots regardless of intercrop. Aphid densities were not affected by the presence of other crops, but maize reduced leaf beetle numbers, while the presence of beans increased whitefly densities. Generalist predators were higher in monocrop than intercrop, contrary to predictions of the resource concentration hypothesis that generalist predators tend to favor higher vegetation diversity compared with specialist natural enemies. Under the conditions of our experiments, aphids densities did not reach sufficiently high levels to affect okra fruit yield in the various treatments, although this is difficult to conclude since the experiment did not include a check in which aphids were excluded with pesticides. The highest realized okra yield was from monoculture, high density plots and least from okra-maize high density plots.

The data from the second and on-farm trials (with Clemson and Kirikou—as Cafeier had very poor germination rate and was subsequently dropped) showed that aphid densities were generally lower in the presence of maize while generalist predators showed the same patterns as in the on-station trial. Surprisingly, however, okra yield was higher in both maize and beans intercrop compared with the control for Kirikou, while intercropping did not show much of an effect on Clemson. These results corroborate to some extent the on-station trials conducted with Clemson only, while Kirikou seems to benefit from intercropping. It should be noted however, that okra yields in the on-farm trials were far below those from on-station trials, despite similar management approaches. We will be conducting further experiments in 2015 to gain further understanding of the effect of intercropping on okra pests and okra yield, and use a simple economic analysis for yield and income on per unit area basis to compare the tradeoffs of intercropping and monocropping.

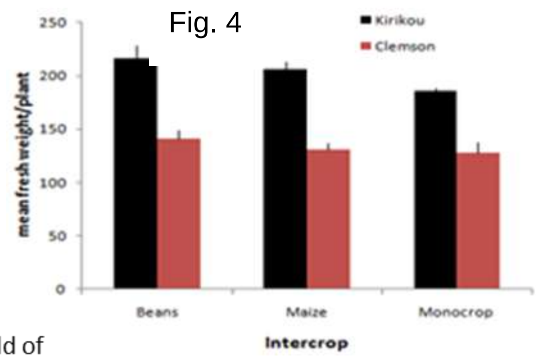


Table 3. Effect of imidaclorprid and neem applications on yield of three okra varieties.

Variety	% increase in fresh yield compared with control	
	Imidacloprid	Neem
Cafeier	29.2	50.8
Clemson	18.8	14.8
Kirikou	-6.8	-16.2

We conducted a second on-station experiment to compare the effects of insecticide treatments (neem seed extracts and imidacloprid) on aphid and leaf beetle populations and yield of three okra varieties (Table 3). Neem and imidaclorprid are both useful insecticides in suppressing aphid populations, but surprisingly not to the extent claimed in the literature, as aphid populations were never reduced to very low numbers but nevertheless they were consistently and substantially lower than in the non-treated plots. Leaf beetle numbers and their damage levels were not affected significantly by treatment. Nevertheless, okra yields were higher in the neem and imidacloprid treatments except for Kirikou variety, which had high aphid densities. We will conduct additional studies in 2015 to understand the negative effects of insecticides on the yield of Kirikou yield. These results indicate that neem seed extracts, available commercially, can be an effective and economical alternative to aphid control in okra. We will conduct two farmer participatory trials in Cameroon in 2015 to determine the effects of insecticide application on aphid populations.

Output 3—Screening for resistance and identifying resistance mechanism for* A. gossypii *on okra.
A total of 271 okra accessions were evaluated in three preliminary screening trials in Taiwan and Cameroon of which 21 accessions were retained. Of these 19 were tested (due to poor germination of remaining two accessions). Out of 19 accessions, only three accessions: TOT6599, TOT3145, and TOT2769 were consistently rated as resistant to aphids.

An additional 96 okra accessions were screened against aphids in a preliminary screening trial in AVRDC HQ, Taiwan resulting in the selection of four moderately resistant accessions (TOT2742, TOT2760, TOT2788, and TOT3857). These were subsequently screened in Cameroon to confirm the resistance. Eleven locally collected okra varieties were included in this trial. However, only one accession (TOT2788) was found to be resistant from this trial. Another 64 okra accessions were screened against aphids in a preliminary screening trial in AVRDC HQ, Taiwan, of which eight accessions were rated as resistant to aphids. These selected resistant accessions will be screened in a replicated trial in Cameroon to confirm their resistance to aphids during 2013. Biochemical and biophysical properties of three resistant okra accessions (TOT6599, TOT3145, and TOT2769) in comparison with the susceptible accession (TOT8237) were determined. Leaf nitrogen content was the only discriminating parameter between resistant and susceptible genotypes (higher in the latter). There was also no significant difference among the accessions with respect to several physical parameters (trichome density of bottom and middle leaves, and leaf toughness) except that trichome density was higher on young leaves of two of the resistant genotypes on the younger leaves, indicating that this could be a factor in aphid resistance in okra. Further studies on settling behavior showed that aphids did not discriminate against the susceptible and resistant okra accessions for oviposition and feeding after 72 h of release.

Since the screening is carried out in two locations; Taiwan (Asia) and Cameroon (Africa), we conducted phylogenetic analysis (using mtDNA COI) on several aphid collections (60 individuals) from Cameroon and Taiwan as well as a collection from India. A total of 60 insects were used for cytochrome c oxidase I (COI) sequencing and phylogenetic analysis. The nucleotide sequences of all the populations showed 100% similarity. Hence, the phylogenetic analysis showed that *A. gossypii* in Taiwan and Cameroon are genetically similar.

***Output 3*—**Evaluation of available cabbage and kale cultivars for their suitability to *B. brassicae* and *L. pseudobrassicae*.

A field trial was conducted in Dschang (West Cameroon), one of the largest cabbage producing regions in Cameroon. Six commercially available varieties were used—Green Coronet, Marcanta, Marche de Copenhague, Milor, Globe Master, and Minotaur. The cabbage aphid was the dominant species on all cultivars during the trials, and infestations were highest on Marche de Copenhague and Milor, while Globe Master and Green Coronet supported the least number of aphids. This was also reflected in the differences in damage levels and marketable yields with respect to aphid infestations. As in subsequent trials, syrphids were the dominant natural enemies and appeared to exert substantial effects on aphid infestations. The entomopathogenic fungus *Erynia* (*Pandora*) *neoaphis* was also prevalent with infections reaching a peak of at about 30%. No parasitoids were found on the aphids during the trial.

Most vegetable farmers in Cameroon accept that they use chemical pesticides, and are equally willing

to accept new varieties that are resistant to pests and diseases, to minimize the use of pesticides. Four hundred and forty-five okra germplasms were screened at AVRDC—The World Vegetable Center—to identify resistant accessions to aphids for the management of this pest. Screening trials were conducted under natural field conditions without pesticide application. Aphid infestations per variety were directly scored on one leaf per stratum on three strata of five plants randomly selected. The number of aphids was recorded using the following scale: 0 = no aphids present; 1 = 1 to 10 aphids per leaf; 2 = 11, to 100 aphids per leaf; 3 = 101 to 500. aphids per leaf; and 4 = >500 aphids per leaf. Phenotypic structures and secondary metabolites that could affect the life traits of *A. gossypii* were analyzed. In the case of phenotypic structures, trichome density, hardness, and chlorophyll content of okra leaves were taken into consideration. Concerning secondary metabolites, leaf content of total phenols, total tannins, free amino acids, total sugars, reducing sugars, total nitrogen, and potassium were considered. The implications of mechanisms of tolerance, antibiosis, and antixenosis were evaluated in the analysis of resistance of plants of *Abelmoschus* spp.

Nine okra accessions were therefore identified as resistant or moderately resistant to *A. gossypii*. The most resistant ones were VI041210, VI057245, and Gombo caféier. The farmers’ check Kirikou and VI060694 were the most tolerant. Resistant accessions produced fewer pods than susceptible or tolerant accessions. In this study, non-preference (antixenosis) was not a mechanism of resistance. The non-discrimination between susceptible and resistant accessions in aphid settling behaviour indicates that phenotypic structures and plant metabolites did not influence attraction and settling behaviour. The trichome density was highest on the leaves of the top stratum, higher at the middle stratum, and lower at the bottom. It was lower on VI060794 and the farmers’ check, Kirikou, at all plant strata, and may favour infestation of these susceptible accessions. The current study revealed the role of total nitrogen content in leaves leading to the susceptibility of okra accessions to aphids. VI060794 that was the most susceptible in Taiwan in 2013 and in the second season of the confirmatory screening trial in Cameroon in 2014 had significantly higher leaf nitrogen content than in other accessions. Constitutively, the role of free amino acids, tannins, and total phenols in imparting resistance against *A. gossypii* in the identified okra accessions during our study is inconclusive. Biochemical studies of accessions of okra at 6 and 10 weeks after sowing showed that total phenols and tannins content changed following aphid infestation. Total tannins increased in the resistant accessions and reduced in Kirikou, the susceptible farmers’ check at all plant growth stages. The total sugars, potassium, and reducing sugars played a role in offering resistance in plants with or without aphids. As a susceptible accession, VI060794 had higher nitrogen content significantly at vegetative stage following aphid infestation and at reproductive growth of plant even when plants were not infested. The farmers’ check Kirikou that was one of the most susceptible to aphids had the highest intrinsic rate of natural increase of aphid population, which was significantly different from that of VI057245, one of the most resistant accessions during confirmatory and multi-location trials. When plants were previously infested with aphids at vegetative and reproductive stages, the developmental time was significantly longer on VI041210 than on all accessions except VI060688 at vegetative growth. No mortality of aphids was observed on VI033805, VI033824, and on the farmer’s check Kirikou. Results from the multilocation trials indicate that the farmers’ varieties are more susceptible to aphids than most of the selected resistant accessions, across all agroecological zones.

VI060794 and VI036213 are suitable for resistance to aphids in the western highland; VI060794 and VI039614 in the monomodal humid rain forest; VI060794 and VI051114 for the bimodal humid rain forest and VI060794, VI033824, VI057245, and VI041210 in the Sudano-Sahelian region. VI060794 was also the highest yielding in all ecozones in Cameroon and with some acceptable level of resistance. We recommend the following accessions for the presence of resistant traits: VI041210, VI051114, VI033824, VI057245, and VI036213 for leaf trichomes; VI051114 and VI036213 for fruit size; VI041210, VI060794 and Gombo Cafeier for plant vigor. VI041210, VI057245, and Gombo Cafeier for relatively higher secondary metabolites and lower plant nutrient contents leading to antibiosis. VI060794 presents superior qualities in terms of yields and management of aphids due to its tolerance.

Table 4. Aphid resistance screening in different agroecologies (S = Susceptible; MS = Moderately Susceptible; MR = Moderately Resistant; R = Resistant).

Variety type	Accessions	First and second seasons 2014						
		Buea		Evodoula		Foumbot		M
		First	Second	First	Second	First	Second	S
Farmers' varieties	Bangourain					16.0 MS	65.0 MR	
	Gombo paysan	75.8 S	68.9 MS					
	Kirikou			26.5 MS	83.9 MS			
	Bascko Djo							5
Selected resistance/ moderately resistant accessions with known susceptible accession*	Gombo caféier	63.7 MS	61.1 MR	20.6 MR	67.2 MR	16.0 MS	70.4 MS	0
	VI033805	66.8 MS	57.5 MR	26.4 MS	114.6 HS	16.7 MS	75.3 S	1
	VI033824	64.6 MS	53.7 R	24.6 MS	80.6 MR	15.5 MS	76.4 S	7
	VI036213	55.0 MR	74.7 S	29.5 MS	64.8 R	10.3 HR	53.3 R	3
	VI039614	52.6 R	54.3 R	8.6 R	84.0 MS	17.1 MS	74.5 S	0
	VI041210	63.6 MS	72.3 S	30.0 MS	78.1 MR	15.6 MS	62.3 MR	0
	VI051114	48.1 R	64.2 MS	21.0 MR	72.5 MR	17.0 MS	68.3 MS	4
	VI057245*	61.6 MS	65.7 MS	18.4 MR	74.4 MR	15.0 MR	65.6 MR	2
	VI060688	66.8 MS	54.4 MR	33.4 S	106.7 S	12.9 R	71.5 MS	3
	VI060794	49.6 R	56.6 MR	16.8 MR	60.4 R	15.7 MS	55.1 R	6
	VI060818	60.4 MR	57.6 MR	5.3 R	83.8 MS	16.3 MS	63.3 MR	0

***Output 4*—Development of entomopathogens based on *Beauvaria bassiana* and/or *Metarhizium anisopliae*.**

The pathogenicity of 10 *Metarhizium anisopliae* isolates (obtained from the *icipe* Microbial Bank) was evaluated against the false turnip aphid, the cabbage aphid, and the cotton aphid. Pathogenicity tests were conducted directly from the isolate collections and by passing them through the aphids. The efficacy of the isolates was tested in the laboratory, on potted plants, and in the field. Across the species, ICIPE 30, ICIPE 62, and ICIPE 69 ranked high as potential candidate isolates for management of the three species of aphids, with ICIPE 62 coming out on top as an isolate that can be used to manage all the three species. Field trials with different formulation of ICIPE 62 on kale and okra have been conducted. The results, which are presently being published, showed high mortality due to the fungus on apterous aphids collected from both kale and okra fields following application of the entomopathogen. Overall, the results demonstrate that *M. anisopliae* (ICIPE 62) is an efficient and effective alternative to synthetic pesticides for the management of aphids on crucifers and okra. Information was also collected on the impact of the biopesticide on aphid predators. The results show that the fungus has minimal impact on the predators found in kale and okra agroecosystem. Multi-locational trials are recommended to ascertain the performance of the biopesticides under different agroecologies before being recommended to growers.

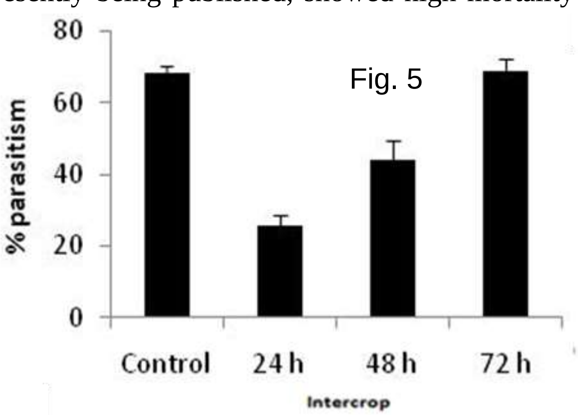


Fig. 5

Most hyphomycete fungi have a broad host range and can also attack non-target organisms including parasitoids. It is therefore imperative that the knowledge of interactions between these organisms is acquired before they are recommended for integration for the management of a particular pest. We developed and carried out tests of the interactions between the candidate entomopathogen (ICIPE 62) and parasitoids of aphids. Two experiments were conducted in this regard: (1) aphid species were first exposed to their respective parasitoids and later treated with *M. anisopliae* (ICIPE 62) and (2) aphids were first treated with *M. anisopliae* ICIPE 62 and later exposed to their respective parasitoids. The results demonstrate that the interval between host exposures to the parasitoid could be an important variable in determining when a fungal-based biopesticide can be applied for the management of *B. brassicae*. The decrease in parasitism rate at the early stages of interaction (i.e., 24 and 48 h) suggests a negative impact of the fungus on the early instar of *D. rapae*. At the advanced stage of development, it is probable that the parasitoid produced certain toxic substances that suppress fungal development permitting emergence as has been demonstrated for some braconid parasitoids.

4. Assessment of Research Findings

The project brought together the strength of four principal collaborators—IITA, *icipe*, AVRDC, and TUM—along with universities in Cameroon and Kenya to provide fundamental understanding of the aphid species and their impact on three target crops in two countries. Much of the research was conducted through postgraduate student training, all African except the student trained at TUM. The knowledge on aphid species distribution and impact on the crop, their associated natural enemies, and that they attract large amounts of synthetic pesticides have provided the basis for developing alternatives to synthetic chemicals targeting aphids in particular agroecologies. IITA with its presence in Cameroon has led the coordination of this research in Cameroon where the TUM and AVRDC students conducted their research. The project has strengthened the ties and partnership among all the four partners, each providing their own comparative advantage. TUM has facilitated the fundamental research on the interaction of the cotton aphid on okra with ants and the impact of vegetative diversity on its abundance and impact. We now know that interplanting okra with maize and beans could have a differential impact on the aphid and the damage it causes to okra, which also depends on okra varieties. These studies have also determined that ants tending the aphid do not protect aphids—because of low levels of background parasitism—but could reduce damage by leaf-feeding insects. These studies highlight the importance of direct and indirect interactions in the biological control of pests and show that effective pest control can be achieved by understanding the complex interactions within tropical agricultural systems.

AVRDC brought to bear on the project its okra germplasm collection and its knowledge and experience in investigating host plant resistance to insects and pathogens, in the end identifying sources and mechanisms of resistance of okra to the cotton aphid. This is a major contribution to the project.

Icipe brought to the project its strength in biological control and development of biopesticides. *Icipe*'s research has led to the discovery and development of a biopesticide that is presently commercially available and that can target multiple pests and crops thereby increasing the likelihood and viability for development by the private sector.

IITA played the central role in coordinating the activities of this research—of which all except the research by *icipe*, included IITA's direct involvement. At the level of Cameroon, we have much greater understanding of the role of aphids in okra and cabbage production and we developed alternative approaches based on the botanical pesticide neem as an effective nontoxic insecticide for aphid control on both crops, regardless of aphid species and location. IITA also developed sampling approaches for monitoring aphids on okra and cabbage and determined the role of conserving generalist natural enemies, such as syrphids, in the management of aphids on okra and cabbage and identified local cabbage and okra varieties that can be integrated in aphid management along with neem seed oil and interplanting as alternatives to the use of toxic insecticides in aphid control. IITA also identified that the leaf beetle *N. uniformis* is a key pest of okra that is even more important than aphid, and for which there are very limited means of control outside of synthetic insecticides. Recommendations for the further development of control options for this insect are included in Section 13.

An important finding from Cameroon is the widespread establishment and impact of the DBM parasitoid *D. semiclausum*. This parasitoid is contributing to widespread suppression of DBM, further reducing the use of synthetic insecticide on cabbage.

IITA added another aspect to the project which was not originally planned but substituted for activities that could not be carried out. This is the phenological modeling of the cabbage aphid and the false turnip aphid on two cabbage varieties and mapping its distribution under current and future climate change scenarios using the ILCYM software developed by CIP and implemented through the recently concluded BMZ project. Model predictions match fairly well aphid distributions in Cameroon and indicate that climate change will cause considerable reductions in its distribution and abundance, except for the some pockets in the Western Highlands of Cameroon. The warming climate has however the opposite effect on the false turnip aphid as it is predicted to expand its range and displace cabbage aphid at higher altitudes.

Last but not the least, the local university partners in Cameroon and Kenya played a key role in the training of African PhD and MSc students. The project has contributed to strengthening the relationship between these universities and international research institutions like IITA, *icipe*, and AVRDC.

5. Knowledge Sharing and Partnerships for Impact

The project has spent much of its resources in developing alternatives to synthetic pesticides for the management of aphids and other insects on okra, cabbage, and kale. While several components were carried out under natural conditions and in farmer's fields, the project period did not allow for widespread transfer of the knowledge to farmers and other users through practical demonstration. The project developed guidelines for aphid management but these need to be widely implemented for effective use. It should however be noted that the knowledge has been transferred through the host of trained students and the publications that have been widely disseminated through the literature, but the project has come short when it comes to widespread transfer of knowledge to farmers and other end users.

6. Training

Four PhD students and four MSc students completed their research and training through the project. The PhD student (Mrs Edwige Djomaha, Cameroonian) is presently a lecturer at the University of Dschang. The PhD student (Hundessa Bayissa, Ethiopian) attached to the project at *icipe* has completed his PhD and is presently teaching and conducting research in Addis Ababa. Albert Abang (Cameroonian PhD student) working on okra resistance to aphids has completed his PhD research but because of a hitch in his record at the University of Yaoude I (they lost his records and had to reestablish them) he is scheduled to defend by June 2017 at the latest. Akanksha Singh, Indian and PhD student at TUM, has split her time between TUM and IITA-Cameroon. She has completed her PhD research and defense and is presently on a temporary employment at TUM. Raisa Houmgny Fonkou, Cameroonian student, completed her MSc on okra aphids and has now joined the Ministry of Agriculture and Rural Development. Another MSc student (Nadia Toukem, Cameroonian) completed

her MSc and is presently in a PhD program with IITA on pollinator diversity on cocoa (funded by ProCISA). A third MSc student (Grace Kinyanjui, Kenyan) completed her studies on the genetics and DNA barcoding of Kenyan populations of cabbage and okra aphids. A fourth MSc student (Steve Soh, Cameroonian) completed his studies on the phenology of the cabbage aphid and false turnip aphid on two cabbage varieties and is presently enrolled in a PhD program at *icipe*.
In addition to degree training the project conducted several farmer awareness and training of farmers through either individual interaction through the surveys and the field experiments, or organized group training on detection, monitoring, and management of aphids.

7. Lessons Learned

While every effort was made to implement the project as planned, several events and issues affected its implementation.

1. We had planned to work on cabbage and okra in both Cameroon and Kenya. It became clear during the initial planning that it would be much better to concentrate on kale in Kenya since cabbage had received considerable attention previously through other BMZ projects. The focus was then shifted to kale through which a third aphid species that required our attention was encountered in Kenya.
2. The project was designed to develop management options for aphids, but it was clear after the initial surveys and field experiments that the leaf beetle *N. uniformis* was a major pest that drives management of pests on okra. The project needed to adjust to this reality but that adjustment was not sufficient to finalize the development of management options for this pest.
3. One of the female PhD students fell ill for over a year which delayed a great deal of the work on aphids in Cameroon.
4. The TUM collaborator changed university and there was considerable delay in recruiting the PhD student for that component of the project. Potential PhD students should be identified even during proposal development.
5. Having the TUM and AVRDC students working with the IITA team in Cameroon was very useful for the integration of project activities.
6. That *icipe* had a collection of already available fungal isolates was extremely useful in the development of the aphid biopesticide for multiple aphid species which also facilitated its uptake for commercialization by the private sector.

8. Outlook Future Research and Development Pathway

While the project has accomplished much of what was planned, several areas remain to be addressed, particularly those that were identified as priority for further research. The following is an outline of the areas requiring further research needs:

1. On cabbage and kale both the false turnip aphid and the cabbage aphid were identified as major pests. There are several natural enemies associated with them that could contribute to their management. There is a need to further develop approaches to conserve existing natural enemies that can provide substantial contribution to aphid suppression.
2. The parasitoid *D. rapae*, which can provide substantial control of the cabbage aphid in Kenya, is completely absent from Cameroon, despite following all protocols that should have facilitate its establishment. There is a need to determine the cause of such a failure. Present evidence points to differences in the genetics and associated endosymbionts of the cabbage aphid populations in Cameroon which apparently harbor endosymbionts (preliminary evidence obtained recently) that can confer resistance of the aphid to its parasitoids. This phenomenon

requires further research.

3. Interplanting okra with maize has been shown to be an effective natural way of reducing aphid infestations and should be scaled out in okra-producing areas.
4. Neem has been shown to be an effective natural alternative to synthetic insecticides for both cabbage and okra, but product availability is limited and quality control is absent. Funding of pilot neem production facilities to make it available to farmers, in collaboration with the private sector, could be quite useful, especially since neem can be used on multiple crops. ProCISA could be interested in using neem for cocoa mirid control if it is available at an economically competitive price.
5. *Neozygites fresenii* is an effective entomopathogen of the cotton aphid, but cannot be multiplied and used as a biopesticide, except on aphid hosts, which limits its application and use through release and natural spread. A sister species has been produced on artificial medium which could be tested on *N. fresenii* for further development of a biopesticide.
6. The biopesticide developed by *icipe* needs to be tested in Kenya and Cameroon through multilocational trials.
7. Okra resistant/tolerant varieties need to be further developed and their traits incorporated into varieties accepted by farmers.
8. The okra leaf beetle turned out to be a major pest of okra that requires further research into its management. We have started testing existing biopesticides being developed at IITA Cameroon for banana weevil and cocoa mirid for their potential use against okra leaf beetle. IITA Cameroon is also in touch with collaborators in the UK for the development of pheromones for monitoring and mass trapping of the beetle as an option for its management.
9. There is substantial need for scaling out existing technologies and control options through large-scale trials with farmers. These efforts will need to emphasize an integrated approach considering the entire vegetable system for effective simultaneous management of multiple pests.
10. There is a need to promote organic vegetable production. A future project should consider how to promote organic vegetable production in Cameroon and Kenya and perhaps elsewhere. IITA has initiated a pilot organic vegetable production that makes use of what we have gained from the present project and to apply it to a system that includes 21 fruit and leafy vegetables. There is considerable potential for training young people in organic production.
11. Phenological modelling using the ILCYM software has shown promise in predicting the effect of climate change on the cabbage and false turnip aphids. This should be also applied to DBM and its parasitoid *D. semiclausum*, and the cabbage aphid parasitoid *D. rapae*.
12. Conduct socioeconomic evaluations of the implementation of vegetable IPM with emphasis on the role of gender in uptake and success of various IPM options.

9. Summary

Through several surveys and field trials we determined species composition and distribution of aphids as well as virus incidence on okra and cabbage in Cameroon and okra and kale in Kenya. On cabbage and kale, the cabbage aphid and false turnip aphid were, respectively, most important in higher and lower altitudes. The cabbage aphid in Kenya was associated with both specialist and generalist natural enemies whereas in Cameroon the specialist parasitoid *Diaeretiella rapae* was absent. On okra, the cotton aphid was the most abundant and widespread, but the leaf beetle *N. uniformis* turned out to be the major pest of okra, surpassing the importance of aphids in some locations. Regardless of country, aphids attracted heavy use of pesticides which upset the existing guild of natural enemies that could otherwise reduce aphid populations to acceptable levels, as we determined during details field trials in both Cameroon and Kenya.

Studies on the dynamics of aphids and their natural enemies on all the target crops revealed the timing of peak aphid infestations—generally during declining rainfall or during the dry season—and the diversity and seasonality of associated natural enemies such as syrphids, coccinellids, and other generalist predators. On kale and cabbage, species composition of generalist natural enemies is approximately similar but the order of dominance is different, with coccinellids being more abundant early in the crop cycle in Kenya while syrphids are the dominant species in Cameroon. In both crops and in both countries, while generalist predators appear to bring down aphid populations, this happens after the build-up of large populations. There are indications that conditions that favor earlier colonization can improve the action of native natural enemies. The parasitoid *D. rapae* and the fungus *E. neoaphis* also play an important role in aphid dynamics and together with generalist natural enemies are likely to keep aphid populations at low level in the absence of interference by frequent pesticide applications. A similar picture emerges from okra trials in both Cameroon and Kenya with similar composition of generalist predators with a more prominent presence of the parasitoid *A. colemani* in Kenya but with low occurrence in Cameroon, probably due to heavy hyperparasitism.

Studies on the interactions between ants and aphids on okra, where the two occur quite commonly, has shown that ants under field conditions do not affect aphid populations, but recruitment of ants by aphids protects the plant from damage by the okra leaf beetle. Experiments with interplanting okra with maize and beans shows promise in controlling aphids and improving okra yields. These initial findings require scaling to multiple locations to determine the effectiveness of this approach in reducing pesticide use on okra.

Studies on host plant resistance to aphids in okra have resulted in the identification of four genotypes for which mechanisms of resistance have been identified. Among the cabbage cultivars that are commercially available in Cameroon, Globe Master, Green Coronet, and Marcanta are three that support relatively lower aphid populations than three other commercially available cultivars.

Ten isolates of entomopathogenic fungi (eight *Metarhizium anisopliae* and two *Beauveria bassiana*) have been screened against the three target aphids on okra and the crucifers. One *M. anisopliae* isolate, ICIPE 62, has shown best promise and is presently being developed as a commercial aphid biopesticide in Kenya.

In summary, the components of an integrated program for the control of aphids on okra, cabbage, and kale have been identified. This program will likely depend on the following options: (1) conservation biological control through habitat management and reduced use of broadspectrum pesticides; (2) exchange of efficient parasitoids (e.g., *D. rapae* and *A. colemani*) and entomopathogens (e.g., *N. fresenii* and *E. neoaphis*), (3) promotion of conditions that favor epizootics of entomopathogens; (4) selection and promotion of resistant and moderately resistant varieties with commercially acceptable horticultural traits and market suitability; and (5) commercialization of biopesticides that can limit aphid populations while conserving existing natural enemies. Singly or in several combinations, these IPM options are likely to result in considerable reduction in the use of broadspectrum pesticides and in improved productivity and profitability of vegetables with lower pesticide residues.

10. Publications, Papers, Reports and other Media

10.1 Peer-reviewed articles in periodicals (give DOI number)

Abang, A.F., R. Srinivasan, R. Hanna, S. Kekeunou, T. Chagomoka, J.C. Chang, and C.F. Bilong Bilong. 2014. Identification of okra (*Abelmoschus* spp.) genotypes resistant to aphid (*Aphis gossypii* Glover) in Cameroon. African Entomologist 22(2): 273–284. DOI: 10.4001/003.022.0201.

Abang, A., R. Srinivasan, S. Kekeunou, M. Yeboah, R. Hanna, M.Y. Lin, A. Tenkouano, and C. Bilong Bilong. 2016. Relationship of phenotypic structures and allelochemical compounds of okra (*Abelmoschus* spp.) to resistance against *Aphis gossypii* Glover. International Journal of Pest

Management 62: 65–63. DOI: 10.1080/09670874.2015.1095372.

Abang, A.F., C.M. Kouame, M. Abang, R. Hanna, and A.K. Fotso. 2014. Assessing farmer knowledge of diseases and insect pests of vegetable and management practices in Cameroon. International Journal of Vegetable Science 20: 240–253. DOI: 10.1080/19315260.2013.800625.

Abang, A.F., C.M. Kouame, M. Abang, R. Hanna, and A.K. Fotso. 2013. Vegetable growers' perception of pesticide use practices, cost, and health effects in the tropical region of Cameroon. International Journal of Agronomy and Plant Production 4: 873–883. Available online at http:// www.ijappjournal.com.

Bayissa, W., S. Ekesi, S.A. Mohamed, G.P. Kaaya, J.M. Agacha, R. Hanna, and N.K. Maniania. 2016. Selection of fungal isolates for virulence against three aphid pest species of crucifers and okra. Journal of Pest Science DOI: 10.1007/s10340-016-0781-4.

Bayissa, W., S. Ekesi, S.A. Mohamed, G.P. Kaaya, J.M. Wagacha, R. Hanna, and N.K. Maniania. 2016. Interactions among vegetable infesting aphids, the fungal pathogen *Metarhizium anispoliae* (Ascomycota: Hypocreales) and the predatory coccinellid *Cheilomenes lunata* (Coleaptera: Coccinellidae). Biocontrol Science and Technology 6(2): 274–290. DOI: 10.108/09583157.2015.1099148.

Djomaha, E.S., R.T. Ghogomu, R. Hanna, E.S. Ngatat, and N.F. Lontsi. 2016. The effects of extract of *Azadirachta indica* (Neem) oil and Imidacloprid (IRON 30SC) on the population dynamics of *Brevicoryne brassicae*, *Lipaphis pseudobrassicae*, and *Plutella xylostella* on white cabbage. International Journal of Agronomy and Agricultural Research. 8(4): 135–142. ISSN: 2223-7054 (Print) 2225-3610 (Online).

Singh, A., S.E. Zytynska, R. Hanna, and W.W. Weisser. 2016. Ant attendance of the cotton aphid is beneficial for okra plants: deciphering multitrophic interactions. Agriculture and Forest Entomology 18: 270–279. DOI: 10.1111/afe.12159

Singh, A.,J. Braun, E. Decker, S. Hans, A. Wagner, W. W. Weisser and S. E. Zytynska. 2014. Plant genetic variation mediates an indirect ecological effect between belowground earthworms and aboveground aphids. BMC Ecology 25.DOI:10.1186/s12898-12014-10025-12895.

Abang, A., R. Srinivasan, S. Kekenou, R. Hanna, and C.F. Bilong Bilong. Effects of okra germplasms on the development and reproductive performance of *Aphis gossypii* Glover (Hemiptera: Aphididae). In review in Journal of Applied Entomology.

Singh, A., W.W. Weisser, R. Houmgny, and S.E. Zytynska. Minimize space, maximize production: Benefits of intercropping at high densities for okra farmers in Cameroon. In review in Pest Management Science.

Abang, A.F., R. Hanna, and R. Srinivasan. Estimates of flea beetles (Podagrica spp.) population and the influence of okra (Abelmoschus spp) variety on the degree of defoliation. For submission to Scholarly J. of Agric. Sci.

Abang, A., R. Srinivasan, R. Hanna, S. Kekeurnou, A. Tenkouano, R. Kemga, and C.F. Bilong Bilong. Mechanism of resistance of okra (Abelmoschus spp) to the cotton and melon aphid Aphis gossypii Glover (Hemiptera: Aphididae).Draft in review for submission to Journal of Applied Entomology.

Djomaha, E., R. Hanna, and T.R. Ghogomu. Seasonality and population dynamics of *Brevicoryne brassicae* L. and *Lipaphis pseudobrassicae* D. on white cabbage in the western highland of Cameroon. Draft in progress for submission to the Journal of Economic Entomology.

Djomaha, E., R. Hanna, and T.R. Ghogomu. Effect of the aphids *Brevicoryne brassicae* L. and *Lipaphis pseudobrassicae* D. on yield of white cabbage (Brassica oeleracea L.). Draft in progress for submission to Crop Protection.

Hanna, R., A.F. Abang, A. Fotso, P.L. Kumar, and S. Kekeunou. Survey on dynamics, distribution and abundance of aphids of okra and associated natural enemies. Draft in review for submission to Crop Protection.

Hanna, R., A.F. Abang, and R. Srinivasan. Influence of season, agroecology and okra germplasm the flea beetle *N. uniformis* population and damage. Draft in review for submission to African Crop Science Journal.

Hanna, R., E. Djomaha, A. Fotso, A. Abang, R. Ndemah, and R. Ghogomu. Distribution and abundance of primary pests of white cabbage in Cameroon—implications for targeting development and implementation of integrated management option. Draft in progress for submission to the Journal of Integrated Pest Management.

Soh, S., R. Hanna, S. Kekeunou, and S. Nanga Nanga. Phenological modelling and climate change impact on distribution and abundance of the cabbage aphid *Brevycorine brassicae* on two cabbage varieties. In review for submission to Climate Change.

Toukem, N.K., R. Hanna, and S. Kekeunou. Impact of okra varieties treated with neem extracts and Imidacloprid on the incidence of flea beetle *N. uniformis* and cotton aphid *Aphis gossypii* under field conditions. Draft in review for submission to Crop Protection.

10.2 Conference presentations and other documents

Djomaha, E., R. Hanna, R. Ghogomu, and A. Fotso. 2013. Effet des saisons de culture sur la dynamique de la population des ravageurs et de leurs ennemis naturels sur les variétés de chou. Oral presentation in the 20th Biennial Conference of the African Association of Insect Scientists, Yaoundé, Cameroon, 28-31 October 2013.

Singh, A., S. Zytynska, R. Hanna, and W. Weisser. Understanding multi-trophic interactions for biocontrol of aphids on the tropical vegetable crop Okra: agricultural implications in Cameroon, West Africa. Abstract of oral presentation submitted to Gesellschaft für Tropenökologie, gtö, 25–28 February 2014, Freising (Germany).

Toukem, N., R. Hanna, and S. Keukenou. Evaluation of some okra varieties and some insecticidal products on the control of okra (*Abelmoschus esculentus* L. Moench) insect pests in field. Poster presentation abstract submitted to Global Development Network.

10.3. Theses

Djomaha, Edwige. 2017. Bionomics and management of aphids associated with cabbage in the highlands of Cameroon with emphasis on interactions between aphid and diamondback moth management. PhD Dissertation, University of Dschang, Dschang, Cameroon.

Abang, Albert. 2017. Development of okra resistance to the cotton aphid. PhD Dissertation, University

of Yaounde I, Cameroon.

Singh, Akanksha. 2016. Multitrophic interactions in an okra-aphid-ant system. PhD Dissertation, Technical University of Munich.

Hundessa Wakuma Bayissa. 2016. Fungal entomopathogens for aphid management: variability in pathogenicity, species attributes and interactions with other natural enemies. PhD Dissertation, University of Nairobi, Kenya.

Houmgny, Raiisa. 2012. Dynamique de la population du puceron *Aphis gossypii* Glover (Homoptera : Aphididae) sur quatre variétés de gombo (*Abelmoschus esculentus* L.) et identification de ses ennemis naturels dans la région du Centre Cameroun. Mémoire de l'Universite de Yaounde I.

Soh, Steve. 2014. Phenologie de puceron de choux, *Brevicoryne brassicae*, sur deux variétés de choux et modalisation de leur distribution sous présent et future scenarii de changement climatique. Mémoire de Master II. Universite de Yaounde I.

Toukem, Nadia. 2015. Effet varietal et de quelques insecticides sur la dynamique de l'entomofaune de Gombo *Abelmoshus esculentus* (L.) Moench, 1794 en champ. Mémoire de Master II. Universite de Yaounde I.