Development and Implementation of a Sustainable IPM and Surveillance Program for the Invasive Tomato Leafminer, *Tuta Absoluta* (Meyrick) in Sudan

By Mohammed E.E. Mahmoud^{*}, Ensaf S.I. Mohammed[‡],
Samira A. Mohamed[‡], Fathiya M. Khamis⁺ & Sunday Ekesi[♦]

Tomato leafminer *Tuta absoluta* is a serious insect pest that originates in South America. In its transatlantic invasion it was first detected in Spain in 2006, then the pest rapidly invaded Africa threatening tomato production in the continent. Since its detection in Sudan in 2010, farmers relied heavily on insecticides to reduce the exploding population of the pest. An Integrated Pest Management Approach (Tuta IPM) to manage the pest was initiated by Agricultural Research Corporation (ARC) in collaboration with the International Center of Insect Physiology and Ecology (ICIPE) and financed by German Federal Ministry of Economic Cooperation and Development (GIZ). The project aimed to determine distribution, host plants, natural enemies as well as to test some novel approaches to control *T. absoluta*. The study regarding spatial distribution showed that, the pest was found all over the country attacking mainly tomato, eggplant, potato, broad bean, watermelon, alfa alfa and other wild plants. Four parasitic hymenopteran parasitoids and two predatory bugs were reported as natural enemies attacking larval stage. Three types of pheromone proofed their efficacy in trapping males of *T. absoluta* were registered for commercial use. Deployment of male lures especially (*Tuta optima*[®]) in water traps in tomato fields from seedling to harvest reduced the population level of the pest as well as the fruit loss percentage to 5%. Water extract of Neem corticated seeds at (5% and 8%) and Khilla leaves reduced the number of insects/leaflet of tomato and the infestation percentage and augmented the yield. Intercropping of tomato with coriander and fenugreek reduced the infestation levels of tomato by *T. absoluta* and improved the quantity and quality of yield when compared to cultivation of tomato as sole crop. Obtained knowledge regarding the pest and its IPM package was disseminated to different stakeholders through filed guide books, brochures, Training of Trainers (TOT), field days and broadcasting programs.

Keywords: Tomato, leafminer, male lures, intercropping, botanical insecticides, knowledge dissemination

^{*} Associate Professor, Agricultural Research Corporation, Sudan.

[±] Agricultural Research Corporation, Sudan.

[‡] International Center of Insect Physiology and Ecology (ICIPE), Kenya.

⁺ International Center of Insect Physiology and Ecology (ICIPE), Kenya.

[♦] International Center of Insect Physiology and Ecology (ICIPE), Kenya.

Introduction

Globally, Tomato (*Solanum lycopersicum*) is the most widely grown and consumed vegetables (Varela et al. 2003). The crop is grown for both the fresh fruit markets and the industrial processing. On other hand tomato is a valuable cash crop for income generation and is a major source of rural employment in the tropics. The crop is also a good source of vitamins and minerals for many impoverished malnutrition rural communities. In Sudan, tomato is second to onion in terms of production area and total annual production which estimated to reach 35,280 ha yielding 504,000 t per annum (Ahmed et al. 2001). Like in many African countries, tomato cultivation has a particular socio-economic significance as it offers employment opportunities for large sector of the rural communities involved in tomato production value chain. Several biotic and abiotic factors, however, constrained tomato production. Ranking high among the former are arthropod pests such as the red spider mite (*Tetranychus evansi*), African bollworm, (*Helicoverpa armigera*), leafminers (*Liriomyza spp.*) and thrips (*Frankliniella spp.*) (Dabrowski et al. 1994).

The problem of arthropods pest infestation in Sudan has been further compounded by the recent invasion by the South American micro lepidopteran moth (*T. absoluta*) in 2010 (Mohamed et al. 2012). As reported by (Mahmoud 2013) since its first detection in the country in a tomato greenhouse around Khartoum area, tomato leafminer has spread to many tomato growing regions of Sudan causing severe losses to the crop in glass houses and open fields ranged from 35% to 80% respectively. The primary management method for *T. absoluta* in various countries is largely based on the use of synthetic insecticides without any concern to the side effects that it may cause. The reliance on insecticides in different countries, has led to the development of resistance of *T. absoluta* to all classes of insecticides (Yalcin et al. 2015, Siquaria et al. 2000 and Lietti et al. 2005) and Africa is will likely to witness the same scenario if we continue use synthetic pesticides. Various natural enemies were reported associated with the pest worldwide and proofed their efficiency such as predatory bugs *Nesidiocoris tenuis* and *Macrolophus* found in the area of the Mediterranean and the Canary Islands, Tunisia, Algeria, Morocco, Egypt, Saudi Arabia, Iran, Israel and Korea (Linnavuori 1975, Luna and Wada 2011, Urbaneja et al. 2009, Zappala et al. 2012, Clavo et al. 2009).

Also different parasitoids especially braconids were recorded in many countries as a promising bio-agents to suppress the population of *T. absoluta* in various countries (EPPO 2005).

The use of botanicals; especially Neem *Azadirachta indica* which consists of Azadirachtin, a complex tetranortri-terpenoid, indicated their efficacy as anti-feedant, toxic and repellent to *T. absoluta* without any incidence of resistance was reported (Kona et al. 2014, Yalcin et al. 2015). Given the recent invasion history of the pest in Africa, ecological data such as distribution, population dynamic and host range is virtually lacking. Sound knowledge of such information represents the cornerstone for pest management. Also the pest being an alien to Africa there is less likelihood of occurrence of efficient natural enemies that can combat the

exploding population of this pest. Because *T. absoluta* has developed resistance to various classes of pesticides, the use of biorationals (including biopesticides and botanicals) is being recommended for management of the pest. For better understanding of all above prerequisites a program was formulated by Agricultural Research Corporation of Sudan in collaboration with International Center of Insect Physiology and Ecology and funded by GIZ with the following specific objectives:

- ✓ To establish the distribution, abundance, dynamics, host plants of *T. absoluta* in Sudan.
- ✓ To characterise the host range of *T. absoluta* in Sudan.
- ✓ To catalogue the indigenous natural enemies of *T. absoluta* across the country.
- ✓ To evaluate the trapping potentiality of some male pheromones.
- ✓ To evaluate performance of some insecticides against *T. absoluta* and its natural enemies.
- ✓ To test efficacy of different extracts of some botanicals for management of *T. absoluta*.
- ✓ To raise awareness about the pest and to recommend IPM package for its control.

The Phase 1 of the program started in 2012 and terminated in 2016. During the contract period various activities were concluded and the obtained findings of different objectives are as follows.

Materials and Methods

Spatial Distribution of T. Absoluta

Since its detection in Sudan 2010, surveys were conducted in different states in open fields and in glass house produced tomato in Sudan using male attractants in locally made water traps and using detergent as killer. The survey was conducted in tomato production areas in 13 states of Sudan. For each site longitude and latitudes were recorded using Magilan[®]GPS.

Host Plants of T. Absoluta

In each area where traps were settled, each plant showed the symptoms of infestation by *T. absoluta* from the family Solanaceae or any other was collected, preserved in ventilated container and sent to the laboratory for investigation through rearing out. The emerged adults were identified using specific key.

Temporal Distribution of T. Absoluta

Tomato in Sudan is grown in summer and winter seasons, study regarding the seasonal abundance of *T. absoluta* was conducted in four states for early and late sown tomato.

In each study site, male pheromone water traps were deployed in the fields coincided with transplanting of tomato seedlings. Catches of traps were recorded weekly, traps water and detergent were renewed after recording the insects and the pheromones were renewed after 8 weeks as recommended by the manufacturer. Data regarding temperature were obtained from the adjacent Metrological Station.

Natural Enemies of T. Absoluta

Infested tomato plants by larvae of *T. absoluta* were collected and kept in ventilated containers and observed daily for the presence of parasitoids. Emerged parasitoids were collected, preserved in alcohol and sent to the Natural History Museum (NHM) UK for identification.

Role of Sex Pheromones in Mass Trapping of T. Absoluta and Increasing Yield of Tomato

Evaluation of the Effectiveness of Male Pheromones for Trapping T. Absoluta

Three Male lures TUA-Optima 0.8 mg; Tuta Long life and TUA-100N) were evaluated in two states in Sudan for their effectiveness on trapping males of *T. absoluta* using water traps; 24 pheromone traps/hectar, with detergent. The experiment was settled as Randomized Complete Block Design, the area for each treatment was 0.5 hectar and each treatment was replicated three times. All cultural practices were applied as recommended by Agricultural Research Corporation of Sudan and no any insecticide was applied during the whole study period. No of trapped males per trap per week was recorded and data were analysed using SAS statistical Computer based program and means were separated applying Duncan Multiple Range Test.

Role of Male Pheromones in Mass Trapping of T. Absoluta

Other study was conducted in 2 states (Dongola and Sennar) to determine the role of mass trapping of males of *T. absoluta* using pheromones in decreasing infestation and increasing yield of tomato in a participatory approach with farmers. Thousand pieces of pheromones were donated to farmers and installed in water traps with a detergent at dose rate 24 pheromone traps/hectar. The pheromone traps were deployed from the seedling stage of tomato up to the harvest and were renewed two times during the season. The yield

Evaluation of the Efficacy of Some Insecticides to Control T. Absoluta

Due to the reliance of farmers on insecticides for management of *T. absoluta*, trials were conducted in order to recommend and register effective insecticides

belonging to different groups. Consecutive trials were conducted to release some effective and safe use of insecticides in different Sudanese environment. Also, the role of some insecticides on the population of natural enemies was evaluated.

Insecticidal Potency of Water Extracts of Some Botanicals on *T. Absoluta*

The insecticidal activities of aqueous extracts of five local plants (Neem *Azadirachta indica*, Garlic *Allium sativum*, Argel *Solenostemma sp.*, Coriander *Coriandrum sativum* and Khella *Ammi visnaga* (L.) LAM plants) were evaluated against *T. absoluta* under greenhouse condition in comparison to standard insecticide (Biotrne 1.8% EC) and the untreated control in a Complete Randomized Block Design Experiment. The number of larvae of *T. absoluta* and infestation level of each treatment were recoded pre and post spray of different treatments.

Intercropping of Tomato with Coriander or Fenugreek for Controlling *T. Absoluta*

Also study was conducted to assess the effect of intercropping of tomato with coriander (*Coriandrum sativum* L.) or fenugreek (*Trigonellafoenum-graceum*) and compared to sole grown tomato in a Randomized Complete Block Design trial and same procedure applied above for evaluation was applied in this trial.

Results and Discussion

Distribution and Host Plants

The survey for the distribution and host plants of *T. absoluta*, revealed the presence of the pest all around the country. *T. absoluta* was reported to be established and wide spread in Northern, River Nile, Khartoum, Sennar, Kassala, Gezira, White Nile, Blue Nile, North Kordofan, South Kordofan, Gedarif and Darfur States presented in Table 1 with high number of captured males ranged from 50 to 700 males/trap/day.

Surveys in Sudan confirmed that Tomato (*Solanum lycopersicum*) is the main host plant attacked severely by *T. absoluta* with loss percentages up to 100% (Figure 1A-B). Other cultivated host plants included eggplant, *S. melongena* L. (Figure 1C and Figure 2D); Potato, *S. tuberosum* L. (Figure 1D); alfalfa, *Medicago sativa* L.; Physic nut, *Jatropha curcas*; Broad bean, *Vicia faba* and Water melon, *Citrullus lanatus*. Also the pest was recorded attacking several wild plants that serve as represented alternative hosts. These include: Gubbain, *S. dubium* L.; Jimson weed, *Datura stramonium* L.; Common cocklebur (*ramtouk*), *Xanthium brasiliicum* Vell and spiny amaranth, *Amaranthus spinosus* L. (Mohamed et al. 2015). *T. absoluta* infests all aerial parts of tomato plant with specific preference to leaves and fruits (Figure 2A-C).

Table 1. *T. Absoluta* Sampling Sites across Sudan States using *Tuta Optima* (Male Attractant)

Area	State	Longitude	Latitude
Faki Hashim	Khartoum	15 50 00.4	32 32 24.0
Elsaggay	Khartoum	15 56 22.5	32 33 49.9
Elgailly 1	Khartoum	16 00 56.6	32 34 14.3
Elgailly 2	Khartoum	16 01 21.3	32 35 10.9
Wad Ramli	Khartoum	16 06 28.9	32 34 30.3
Shambat	Khartoum	15 39 49.0	32 53 19.0
Abudelou Omdurman	Khartoum	16 03 30.7	32 01 57.0
Kilo 7 Omdurman	Khartoum	15 44 13.3	32 20 56.0
Bagairailafoon	Khartoum	15 25 18.8	32 45 43.7
Wad Medani	Gezira	14 41 00.0	33 05 00.0
Um barouna	Gezira	14 25 49.3	33 33 28.2
Karaiba	Gezira	14 24 57.6	33 27 15.4
Shaygab	Gezira	14 25 56.6	33 27 26.4
DaimElmashaikha 1	Gezira	13 41 49.0	33 36 01.0
DaimElmashaikha 2	Gezira	13 41 44.8	33 36 15.0
Duffofa 1	Northern	19 33 01.4	30 27 17.6
Duffofa2	Northern	19 31 44.2	30 28 18.3
Artadi	Northern	19 09 40.4	30 28 18.2
Garada	Northern	19 16 18.5	30 36 59.2
Zaourat Middle	Northern	19 09 29.9	30 26 11.4
Zaourat north	Northern	19 20 02.4	30 25 03.0
Sennar	Sennar	13 56 00.0	33 06 00.0
Singa	Sennar	13 15 00.0	33 93 33.0
Kassala	Kassala	15 25 59.5	36 21 17.6
Takroof	Kassala	15 29 49.2	36 20 43.4
Kosti	White Nile	13 02 00.0	37 07 00.0
Shendi	River Nile	16 41 26.8	33 24 82.6
Shagalwa	River Nile	16 43 59.3	33 28 17.7
Ketiab	River Nile	16 43 53.8	33 28 25.8
Zeidab	River Nile	17 24 87.9	33 51 35.7
Singa	Blue Nile	13 09 08.4	33 56 44.7
Azazah 2	Blue Nile	13 06 56.3	33 57 53.9
Elhawata	Gedarif	13 25 10.6	34 37 56.1
Bazoura	Gedarif	13 06 32.8	34 55 91.2
Gadoura 2	Gedarif	13 00 12.2	34 58 00.3
Elgazira aba	White Nile	13 20 36.6	32 36 38.5
Almakhaleef	White Nile	12 29 37.9	32 49 13.3
Eldiuem	White Nile	12 49 58.0	32 47 25.0
Nyala	S. Darfur	12 01 55.4	24 55 48.9
Elgenaina	W. Darfur	13 26 46.6	22 27 49.1
Zalenji	C. Darfur	12 04 21.6	23 08 08.7

Figure 1. Infestation Symptoms of *T. Absoluta* on: A-top left) Tomato in Open Field, B-top right) Tomato in Glass House, C-bottom left) Eggplant Field, D-bottom right) Potato Field

Figure 2. Infestation Symptoms of *T. Absoluta* on: A-top left) Leaves of Tomato, B-top right) Flower and Buds of Tomato, C-bottom left) Fruit of Tomato, D-bottom right) Fruit of Eggplant

Seasonal Abundance of T. Absoluta on Tomato

For both sowing times, the population of insect increased gradually during vegetative growth of the plant coincided with the increase of temperature up to 30 C° and flared up during the fruiting time and increased steadily to reach the crest during the second and third picking of fruits (Figures 3-5). The pest was found all around the year which is coincided with the information provided by Elhaj et al. (2015) who reported that *T. absoluta* can be found all the year round in greenhouses and in locations with mild winters.

Figure 3. Average Number of *T. Absoluta* of the Early Sown Tomato from December to February (2012/2013) for Three Locations in Kassala State

Figure 4. Average Number of *T. absoluta* Trapped Males for the Late Sown Tomato from February to June 2013, Khartoum State Natural Enemies of *T. Absoluta* in Sudan

Figure 5. Average Number of *T. Absoluta* Trapped Males of Three Season for the Early Sown Tomato from December to March, Season 2013/2014 (Senna State)

The survey for natural enemies across different states in Sudan revealed the form of new association between five hymenopteran parasitoids with *T. absoluta*. These parasitoids are *Bracon* (*Habrobracon*) sp. *Concolorans* Marshall (Figure 6A), *Bracon* (*Habrobracon*) *hebetor* Say (Figure 6B); Tormidae *Ecdamuacadenati* (Risbec) all the three species belonging to the family Braconidae. Also *Neochrysocharisformosa* (Westwood) of the family Eulophidae was reported as parasitoid of *T. absoluta*. Also, *Macrolophu* ssp. (Figure 6C) and *Nesidiocoris tenuis* (Figure 6D) are found as very efficient predatory bugs preying on eggs and larvae of the pest.

Figure 6. Natural Enemies of *T. Absoluta* A-top left) *Bracon* (*Habrobracon*) *hebetor*, B-top right) *Bracon* *Nigricans*, C-bottom left) *Macrolophu* ssp., D-bottom right) *Nesidiocoris* *Tenuis*

Trapping of *T. Absoluta*

Evaluation of the Effectiveness of Male Pheromones for Trapping of T. Absoluta

The results of evaluation of the performance of the three lures for trapping males of *T. absoluta* showed that, the three lures are potent attractants to the males of *T. absoluta*. TUA-Optima[®] loaded with 0.8 mg had the higher captures of males at both study sites followed by Tuta Long life[®] and TUA-100N[®], (Figure 7). TUA-100N[®] and Tuta long life are new slow release pheromone system that can last up to 100 days. These two products are designed for open field tomato cultivations in the hot climates. The use of the three pheromones reduced the level of infestation to 18%, 22%, 28% for Tuta optima[®], Tua 100N[®], Tuta long life[®] respectively, while the infestation level for the control plots was 55%. The results of males mass trapping resulted in yield increase and enrichment of tomato fruits quality.

Role of Male Pheromones in Mass Trapping of T. absoluta

The experiment of mass trapping of males of *T. absoluta* which was conducted in two states using pheromone traps resulted in capturing of high numbers of males during vegetative growth which reflected positively in reducing the number of catches during the fruiting season and lowered the infestation levels of tomato fruits in the two states to 5 ± 0.5 % and to 3.5 ± 0.3 % in Sennar State sites. The obtained results in this trial is in accordance with the findings of Benvenga et al. (2007) and Mohamed and Mahmoud (2013) who stated the possibilities of using pheromone traps in mitigating the population of *T. absoluta*.

It was obviously recorded that, the use of pheromone in trapping males of *T. absoluta* increased the population of natural enemies especially the predatory bugs *Macrolophus* and *Nesibug* (Figure 8).

Figure 7. Catchability of Pheromones to Males of *T. Absoluta* in Tomato Field, Sudan

Figure 8. Effect of Using Pheromones for Trapping Males of *T. Absoluta* on the Population of Natural Enemies

Evaluation of the Efficacy of Some Insecticides to Control *T. Absoluta*

After consecutive trials some insecticides were registered and released to be applied by farmers to control tomato leafminer among them are Spinosad, Belt Extra (Spirotetramat + flubendiamide), Indoxcarb, Acetamiprid products, Abamectin and Emamectin benzoate products. Study regarding the effect of insecticides on the population of *T. absoluta* and natural enemies reflected that, most of insecticides reduced the population of the pest and at same time affect negatively the population of natural enemies of *T. absoluta* (Figure 9).

Figure 9. Effect of Insecticides used to Control *T. Absoluta* on the Population of Natural Enemies

Insecticidal Potency of Water Extracts of Some Botanicals on Tomato Leafminer Management

Regarding the use of water extracts of botanicals to control Tomato leafminer, all tested aqueous extracts of the test plants reduced the number of infested leaflets of tomato plants, the number of mines on tomato plants and the number of infested fruits/plants compared to the untreated control. Aqueous extract of Neem 5% was significantly better than Biotrne 1.8% EC and other botanicals in all above mentioned insect parameters. On other hand the use of Neem reflected positively

in reduction of yield loss in tomato fruits due to the infestation of *T. absoluta* to less than 10% followed by Biotrue 1.8% EC (Figure 10).

Figure 10. Effect of Using Water Extract of Some Botanicals to Control *T. Absoluta* in no of Infested Leaflets/Plant, no of Mines/Plant, no of Infested Fruits/Plant and Percentages of Yield Loss

Intercropping of Tomato with Coriander or Fenugreek for Controlling T. Absoluta

The intercropping experiment indicated that, the use of coriander or fenugreek intercropped with tomato lowered the number of infested fruits when compared to mono-cropped tomato.

Capacity Building and Public Awareness

Within the program of IPM of *T. absoluta*, six training of trainers (TOTs) were conducted in 6 states of Sudan for 240 trainers. The trained persons were staff of Plant Protection Directorate, Universities teaching staff, extension officers, Agricultural Research staff and pioneer farmers (Figure 11). The gender issue was considered where 40% of the participants were females. Ten field days attended by more than 1,200 farmers were conducted. In the field days, the farmers were acquainted with knowledge on the pest biology, host range, natural enemies and eco-friendly control tactics to reduce the damage caused by *T. absoluta*.

Also, public awareness was raised through several radio and T.V programs at national and state levels giving information about the pest, prospects of its integrated management and safe use of insecticides.

Figure 11. Activities of Capacity Building Include TOT, Farmers Field Schools and Field Days

Conclusions

Tomato leafminer is well established in Sudan and become the main constrain that reduce tomato productivity all over the country. Successfully, strenuous efforts resulted in adding *T. absoluta* to the list of the national pests which are managed by the federal government authorities to reduce the reliance of farmers on insecticides and help the poorest farmers by offering pheromone traps in free of charge basis.

The results obtained in the first phase of this project highlighted the promising role which natural enemies can play especially the predatory bugs (Nesibug and mirid bug) and braconid parasitoids. Further studies regarding their efficacy and suitability as indigenous parasitoids should be well studied in order to be mass reared and released to suppress the population of *T. absoluta*.

From the results obtained also Use of pheromone/s in mass trapping of *T. absoluta* was found a key control measure that should be considered as a corner stone in any IPM program for the quick action it cause in the tremendous reduction of the population of *T. absoluta*, indirect increase of the population of natural enemies and maximization of the produce and alleviating it to the standards of organic product. Time of application is considered as the most important factor for the successful of mass trapping operations. It is preferred to start monitoring the population of *T. absoluta* from the sowing date or transplanting of seedlings and start mass trapping after the population reach 30 males/trap/week.

The registration of some insecticides from different chemical groups will help particularly in providing alternatives to reduce the chances of generation of

resistance of *T. absoluta* to the action of insecticides as the pest known to show resistance to most of insecticides especially that belonging to organophosphate and pyrethroid groups.

According to the obtained results of the efficacy of water extract of Neem on controlling *T. absoluta*. Using different extracts of neem tree for the purpose of controlling this pest should be given more attention by the scientists for the abundance of neem tree all around the year.

Intercropping of tomato with coriander and/or fenugreek which gave good performance in controlling *T. absoluta* is one of the techniques that can be adopted by farmers as push and pull strategy, in Sudan spices such as coriander and fenugreek are of high economic value, where they can regenerate money for farmers and compensate the loss of tomato yield.

Due to the ravage damage it causes and quick movement and invasive behavior, integration of all control options is the key role to the management of *T. absoluta*. Screening of different tomato genotypes for resistance to tomato leafminer, identification and introduction of endophyte/s and entomopathogens and assess the role of natural enemies and develop procedure for mass rearing of the most promising one/s to be applied in bio-control program will play the utmost role to management of the best, secure and safe food.

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