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Farmers' control practices against the invasive red spider mite, *Tetranychus evansi* Baker & Pritchard in Benin

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ABSTRACT

In 2008, the invasive tomato red spider mite Tetranychus evansi (Acari: Tetranychidae), a pest of solanaceous crops, was identified for the first time as the cause of serious damage on tomato (*Solanum lycopersicum* L.; Solanaceae) crops in Benin. Since then, frequent outbreaks have been observed on Solanaceae and other leafy vegetables such as purple amaranth (*Amaranthus cruentus* L.; Amaranthaceae) and bitter leaf (*Vernonia amygdalina* D.; Asteraceae) in all growing areas in southern Benin. The objective of this study was to evaluate the intensity of damage by this invasive pest and the impact of farmers' control practices on purple amaranth, African eggplant *(Solanum macrocarpon L.*; Solanaceae) and tomato crops. A survey was carried out in January 2013 among 150 farmers in the three major growing areas in southern Benin: Sèmè-Kpodji, Grand-Popo and Pahou. *Tetranychus evansi* was the only mite observed, causing production losses estimated at 65% for African eggplant, 56% for tomato and 25% for purple amaranth. Previously encountered species such as *Tetranychus urticae* Koch, *Tetranychus ludeni* Zacher (Acari: Tetranychidae) and *Polyphagotarsonemus latus* Banks (Acari: Tarsonemidae) were not observed in any of the 45 samples. To protect the infested crops, growers sprayed various synthetic pesticides at high frequencies according to crop phenology 3, 6 and 12 times per month, respectively, on purple amaranth, African eggplant and on tomato, on average. The most frequently used pesticides were pyrethroids and organophosphate compounds. Farmers reported that these compounds were largely ineffective against *T. evansi*. The risks posed to human and environmental health, as well as existing alternatives to chemical pesticide use, are discussed.

1. Introduction

In Benin, vegetable production is increasing due to demand and consumption of vegetables by urban populations. Vegetable production helps to improve the living conditions of producers because it is an important source of income (Sounkoura et al., 2011). Vegetable crops are produced in all regions of Benin but especially in the South (Adorgloh-Hessou, 2006). Tomato is one of the most important vegetable crops produced in Benin, both in terms of area (27,800 ha) and production volume (154,600 tonnes) in 2010 (FAO, 2012). It is the vegetable most consumed and used daily as an ingredient in food (Naika et al., 2005).

The two indigenous leafy vegetables, purple amaranth and African eggplant or "gboma" in the local language, are also the most cultivated and the most consumed in Benin (Assogba-Komlan et al., 2007). However, these vegetable crops, and particularly tomato, are often attacked by many pests and pathogens (Schippers, 2004). Until recently, the main phytophagous mites reported on these crops were *Tetranychus urticae* Koch, *Tetranychus ludeni* Zacher and the broad mite *Polyphagotarsonemus latus* Banks (Adango et al., 2007; Martin et al., 2010). However, in 2008, outbreaks of *Tetranychus evansi* were observed on tomato and eggplant in the

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vegetable growing area of Sèmè-Podji (Martin, personal communication). Since then, frequent outbreaks have been observed during the dry season in all growing areas of southern Benin causing severe damage to tomato and African eggplant crops. *T. evansi* is an important invasive pest species of solanaceous plants in East Africa (Knapp et al., 2003), in Europe (Tsagkarakou et al., 2007) as well as in Asia (Gotoh et al., 2009). It originated from South America (Moutia, 1958) and was first reported in continental Africa in 1979 on tobacco in Zimbabwe (Blair, 1983) from where it spread to other parts of the continent. It has been reported as more prolific pest on tomato compared to *T. urticae*. This species is characterized by a high reproductive capacity and a gregarious behavior compared to *T. urticae* (Azandémè-Hounmalon et al., 2014). Besides its invasive nature, recent reports have indicated that *T. evansi* has replaced native spider mite species, hence presenting new pest management challenges (Ferragut et al., 2013).

The objective of this study was to evaluate the impact of this new pest on the production of the African eggplant, purple amaranth and tomato. We also investigated farmer practices to control *T. evansi* outbreaks.

2. Materials and methods

2.1. Survey design and data description

The study was conducted in southern Benin in January 2013 in three coastal vegetable growing areas (Assogba-Komlan et al., 2001, 2007; PADAP/MAEP, 2003): Sèmè-Kpodji, Pahou and Grand-Popo. Sèmè-Kpodji is located in the department of Ouémé and covers an area of 250 km^2. The city of Grand-Popo is located in the southwest of the department of Mono covering an area of 289 km^2, extending over 20 km along the shoreline towards the Togo border. Pahou is located in the district of Ouidah, one of Benin city. Southern Benin is subject to a bimodal climate pattern with two rainy and two dry seasons, with maximum temperatures ranging between 30 and 39 °C, and minimum around 23 °C (Simon et al., 2014). The monthly relative humidity ranges from a minimum of 44–76% to a maximum of 99%. The survey was conducted among 150 subjects. The choice of farmers was mainly based on the production of tomato, African eggplant and purple amaranth. A total of 21 questions were asked and the interviews took on average 30 min per farmer. After obtaining information on the social situation, each farmer was asked about the production of the three crops and the mains pests causing damage on them. They were also asked the local name of *T. evansi*, how they distinguish it from other pest, its damage on crop production, the first time they observed *T. evansi*'s damage in the field, the main crops affected, the main season in which damages are abundant and the control practices of farmers. Other questions about the severity and evolution of damage were also asked. Farmers were asked also to classify the level of damage using the leaf mean damage index (LMD) classification of Hussey and Scopes (1985), ranking on a scale from 0 (no damage) to 5 (the leaf begins to shrivel). In the mite sampling, we targeted both prey and predators which were collected in each vegetable growing area presenting mite damage. Three leaves of each crop were randomly selected per bed and removed from the plant. Mites were brushed directly in polypropylene plastic tubes containing 70% alcohol using a fine brush. A total of 45 samples were collected from various host crops in the three areas. Mites were thereafter identified at UMR CBGP (Centre Biologique de Gestion des populations) in Montpellier, France with assistance of Philippe Auger.

2.2. Data treatment and analysis of the results

Analysis of variance followed by Bonferroni test was used to discriminate the crops according to the losses in production estimated by the farmers. Analysis of variance was done using STATA version 12 (StataCorp, 2011) to compare means at 5% level.

3. Results

3.1. Socio-economic characteristics of farmers

Horticultural production was the main activity for the majority of farmers (99%) in all three areas. On average farmers were older than 37 years: the youngest was 18 years and the oldest was 71 years. (Table 1). Horticultural production was more a male activity (84%) than a female one (16%); only 10% were old farmers (>65) and retired people. Youthful farmers interviewed (17%) were mostly secondary school students and casual laborers. The majority of farmers (84%) had at least primary education. Among them, 48% had a secondary school level of education (9–13 years of study), 33% had a primary school level of education (1–6 years of study), only 3% had reached the university level (14–17 years of study) and 16% of farmers had not received any formal education (Table 2).

3.2. Vegetable production

Tomato, African eggplant and purple amaranth were most commonly grown leafy vegetables in the targeted zones. These crops were produced, respectively, by 95%, 100% and 94% of farmers surveyed. Considering all growers surveyed, the mean area cultivated per farmer was, respectively, 4128, 724 and 406 m^2 for tomato, African eggplant and purple amaranth.

3.3. Mite species

Practically all the mites in our samples were identified as *T. evansi*, with only one individual collected on purple amaranth identified as *Tetranychus lombardinii* (Meyer). No mites belonging to the *T. urticae*, *T. ludeni* or *P. latus* species and no predatory mites were found in our samples.

3.4. Farmers' perception about T. evansi

According to 91% of farmers, *T. evansi* (commonly called red spider mite in the area) did not have a local name. The majority of farmers (95%) were able to identify *T. evansi* and recognize its damage. Over 90% said they had observed *T. evansi* damage symptoms on their crops. All farmers (100%) characterized the damage as very serious (100%) in Sèmè-Kpodji, 97% in Pahou and 78% in Grand-Popo (Table 3).

They reported that *T. evansi* damage could reach level 5 in one week (classification of Hussey and Scopes (1985)). Almost all farmers (91%) said that *T. evansi* damage had increased each year up to 2012, and was more important during the dry season (Table 3). Farmers also said that *T. evansi* could destroy the entire field in less than a week if no treatment was applied on the first day of its appearance. Thus, production losses, according to the farmers, could be assessed, respectively at 65, 56 and 25% on African

Table 1
Age and sex ratio of farmer's growing African eggplant, purple amaranth and tomato in southern Benin.

Variable	Description	Observation	Mean	Std.Dev.	Minimum	Maximum
Sex ratio	Male	126	37	10	19	71
	Female	24	35	13	18	70
Age		150	37	11	18	71

Std.Dev. = Standard deviation.

Table 2
Education level of farmer's growing African eggplant, purple amaranth and tomato in southern Benin.

Variables	Description	Frequency	Percentage	Cumul
Level of education	No education	24	16	16
	Primary	50	33	49
	Secondary	72	48	97
	University	4	3	100

Table 4
Percentage of production loss estimated by farmers on African eggplant, tomato and purple amaranth in 2012 in southern Benin.

Variables	Means (SD)	Frequency	df
Gboma	65% (18) a	150	98
Tomato	56% (25) b	150	149
Purple amaranth	25% (19) c	100	98

df = degree of freedom; SD = Standard deviation.

eggplant, tomato and purple amaranth in 2012 (Table 4).

3.5. Control of *T. evansi*

Based on the invasive and destructive nature of *T. evansi*, farmers had no other choice than using chemical control. All farmers (100%) reported spraying chemical insecticides to control *T. evansi*. Sixteen synthetic formulations were identified (Table 5). The frequently used pesticides belonged to the synthetic pyrethroid (SP) family (54%) alone or associated with an organophosphate (OP) (25%). The result showed that a significant number of farmers (65%) used Cotalm P (lambdacyhalothrin + profenofos) at different doses. Some used high doses to get a better efficacy to control the mites. Other farmers combined several formulations such as Cotalm P and Decis (deltamethrin) without any respect to recommended doses. The number of treatments performed also varied according to grower and crop. Thus, purple amaranth, African eggplant and tomato, respectively, received an average 3, 9 and 12 treatments per month to control *T. evansi*.

4. Discussion

Almost all of the mites in our samples belonged to *T. evansi*, while those reported as major horticultural pests in Benin (Adango et al., 2007; Martin et al., 2010), i.e. *T. urticae*, *T. ludeni* and *P. latus*, were not found in any of the samples. It thus appears that in just a few years, *T. evansi* had outcompeted and replaced the native phytophagous mites on the host plants investigated. Adango et al. (2006) reported predatory mites including *Typhlodromalus saltus* (Denmark and Matthysse), *Iphiseius degenerans* (Berlese) and *Amblyseius tamatavensis* (Blommers) on *Solanum macrocarpum* L. and *Amaranthus cruentus* L. in Benin. However, during the present survey no predatory mites were recorded. This could be due to the heavy reliance of synthetic pesticides for the control of *T. evansi*, thus completely wiping out the more vulnerable predators. These results confirm those of Adango et al. (2006) who did not find any predatory mites during their collections of mites on *Solanum* spp. and *Amaranthus* spp. in the horticultural production areas of southern Benin, but reported several species in untreated vegetable plots of the International Institute of Tropical Agriculture (IITA) in Abomey Calavi, Benin.

Farmers have reported that the red spider mite is a pest causing serious damage to their crops. According to them, the severity and extent of damage have increased since 2008. The outbreaks seem more important in the dry season than in the rainy season. *Tetranychus evansi* damage level can reach level 5 in one week according to the classification of Hussey and Scopes (1985). Indeed, the initial *T. evansi*-infested plants exhibit a few white spots. Level 5 damage is when the mites destroy the leaf parenchyma cells causing leaf drop and subsequently a reduction in productivity (Flechtmann and Knihinicki, 2002). The rapid multiplication of *T. evansi* could explain the high losses (65, 56 and 25%, respectively, observed on African eggplant, tomato and purple amaranth). Similar results were found in the study carried out in Zimbabwe by Saunyama and Knapp (2003). In our case, the heaviest infestations were recorded on African eggplant and tomato, illustrating the real challenge of this pest for growers. Indeed, we found that the African eggplant and purple amaranth were the two most grown leafy vegetables in southern Benin. These crops were produced, respectively by 100 and 94% of farmers surveyed. This is mainly because tomatoes and leafy vegetables are used in the traditional sauce eaten at each meal with cereal grains by Beninese, and thus are an important source of income for households (Gerstl, 2001).

Based on the invasive and destructive nature of *T. evansi*, farmers seemed to have no other option than using chemical control. All farmers (100%) reported spraying synthetic insecticides to control *T. evansi*. The most frequently used pesticides belonged to the synthetic pyrethroid class and were used individually or mixed with an organophosphate. These binary formulations are registered against cotton pests and should not have been to be used against vegetable pests. The number of treatments performed varied according to grower and crop. Thus, purple amaranth, African eggplant and tomato, respectively received an average of 3, 9 and 12 treatments per month to control *T. evansi*. Among these synthetics products, profenofos is known to have acaricidal properties, but mainly against *P. latus* (Vaissayre et al., 1986). According to farmers this synthetic pesticide (OP) was not really effective against *T. evansi*. This could be due to frequent pesticide use that favors the resistance of mites as suggested by Nyoni et al. (2011) or by the poor quality of products. Recent studies conducted in southern Benin by James et al. (2006), showed that 90% of the production of African eggplant was destroyed by *P. latus* despite spraying on

Table 3
Responses of growers about the severity of damage due to *Tetranychus evansi*, the degree of damage and importance according to season in three areas in southern Benin.

Variables	Damage description	Grand-Popo (n = 50) %	Pahou (n = 50) %	Sèmè-Kpodji (n = 50) %	Total (%)
Gravity	Very serious	78	97	100	92
	Serious	6	3	0	3
	Moderate	6	0	0	2
	Not serious	10	0	0	3
Evolution	Increase	82	92	100	91
	Constant	8	4	0	4
	Decrease	10	4	0	5
Season	Rainy season	14	8	0	7
	Dry season	60	60	94	71
	Rainy and dry seasons	26	32	6	22

Table 5
Insecticides routinely sprayed by growers to control *Tetranychus evansi* on vegetables in southern Benin.

Trade name	Frequency (%)	Active ingredient	Concentration	Chemical familly[a]	Class[b]
COTALM P 218 EC	98 (65)	Lambdacyhalothrin	18 g/L	PY	II
		Profenofos	200 g/L	OP	II
ALPHACAL P 318 EC	84 (56)	Alphacypermethrin	18 g/L	PY	II
		Profenofos	200 g/L	OP	
LAMBDA	41 (27)	Lambdacyhalothrin		PY	II
CYPERCAL 50 EC	28 (19)	Cypermethrin	50 g/L	PY	II
PACHA 25 EC	26 (17)	Acetamiprid	10 g/L	NE	II
		Lambdacyhalothrin	15 g/L	PY	
K-OPTIMAL	22 (15)	Lambdacyhalothrin	15 g/L	PY	II
		Acetamiprid	10 g/L	NE	
CYDIM C 50	18 (12)	Cypermethrin	50 g/L	PY	II
CAPT 88 EC	17 (11)	Acetamiprid	16 g/L	NE	II
		Cypermethrin	72 g/L	PY	
COTOFAN 350 EC	9 (6)	Endosulfan	350 g/L	CY	II[c]
DECIS 12.5 EC	7 (5)	Deltamethrin	12,5 g/L	PY	II
CYPER D	3 (2)	Cypermethrin	10 g/L	PY	II
DIMEX 400 EC	3 (2)	Dimethoate	400 g/L	OP	II
SUNPYRIFOS 48% EC	3 (2)	Chlopyrifos ethyl	480 g/L	OP	II
DURSBAN	3 (2)	Chlopyrifos ethyl	300 g/L	OP	II
CYPADEM	2 (1)	Cypermethrin	36 g//L	PY	II
		Dimethoate	400 g/L	OP	
ORTHEN 50 SP	2 (1)	Acephate	500 g/kg	OP	III

[a] PY: pyrethroid; OP: organophosphorus; NE: neonicotinoid; CY: cyclodien.
[b] Class II: moderately hazardous; Class III: slightly hazardous.
[c] Because of its threats to human health and the environment, a global ban on the manufacture and use of endosulfan was negotiated under the Stockholm Convention in April 2011.

average 7 insecticide applications of deltamethrin or bifenthrin. Such insecticide overuse could be explained by the ineffectiveness of pyrethroids to control broad mites (Vaissayre, 1986) whilst adversely affecting their predators (Phytoseiidae) and maybe the lack of efficient acaricidal products available in the country. Our results corroborate numerous studies in Africa showing that pesticides are used incorrectly with inappropriate products, incorrect dosage, timing and targeting of application, non-calibrated that impact negatively the environment (Ngowi et al., 2007; Gomgnimbou et al., 2009; Fianko et al., 2011; Ahouangninou et al., 2011, 2012; De Bon et al., 2014). Moreover, the arrival of this new pest has increased the bad use of synthetic pesticide dramatically. Inappropriate use has consequences not only for the effectiveness of the intended pest control but also for operator and consumer health, farm livestock, soil organisms, wildlife and vegetation, and contamination of soil, water and air (Conway and Pretty, 1991; Kishi, 2005; Pretty and Hine, 2005; Williamson et al., 2008; Tomenson and Matthews, 2009; Fianko et al., 2011). In their study, among smallholder farmers in Benin, Ethiopia, Ghana and Senegal, growing cotton, vegetables, pineapple, cowpea, and mixed cereals and legumes, Williamson et al. (2008) described the hospitalization cases and health problems due to incorrect and inappropriate use of pesticides by smallholder farmers. Pesticide residues were already found in apple and locally produced fruit in the Accra Metropolis (Bempah and Donkor, 2011); different species of fish were found to be contaminated with pesticides in the Ouémé River in Benin and the Densu River in Ghana (Pazou et al., 2006; Fianko et al., 2011). Recent study carried out by Ippolito et al. (2015) on insecticide runoff through modeling showed that 40% of water bodies in global land surface may be at risk due to the adverse effects of insecticides. Ahouangninou et al. (2012), in their study of plant protection practices of farmers in southern Benin, showed high Index Risk of Environment (IRE) and Health (IRH) with the frequent use of carbofuran, chlorpyrifos ethyl and endosulfan. To overcome serious public health and environmental pollution problems, urgency is needed to bring an effective solution to these small-scale growers to help fight this pest. Previous studies have shown the effectiveness of some agricultural acaricides such as dicofol, propargite, abamectin, milbemectin and cyenopyrafen that could be recommended to farmers (Gotoh et al., 2011; Toroitich et al., 2014; Bugeme et al., 2014). However, farmers need to be aware of strategies such as rotation and alternation of these miticides to reduce the risk of selecting resistant populations. The use of a biopesticide based on isolates of the entomopathogenic fungus *Metarhizium anisopliae* (Metsch) could also be an alternative method of control (Bugeme et al., 2008). In the long term, in collaboration with the International Institute of Tropical Agriculture (IITA), the predator *Phytoseiulus longipes* Evans could be introduce as a biological control agent against *T. evansi* (Ferrero et al., 2011). Multiple natural enemy releases have been employed as a way to improve pest suppression (Yaninek et al., 1998; Hanna and Toko, 2001; Onzo et al., 2003; Yaninek and Hanna, 2003; Rhodes et al., 2006; Cakmak et al., 2009; Rahman et al., 2011; Azandémè-Hounmalon, pers. com.). For example, the simultaneous use of *P. longipes* and *M. anisopliae* could enhance the biological control against *T. evansi*. Recently, the entomopathogenic fungi *M. anisopliae* and the predatory mites *P. longipes* have shown successful control in both laboratory, greenhouse and field conditions against *T. evansi* (Wekesa et al., 2005; Ferrero et al., 2007, 2011; Furtado et al., 2007a, b; Bugeme et al., 2009, 2014). Moreover, *P. longipes* and *M. anisopliae* were compatibles (Maniania and Kungu, 2011). The combination of acaricide-treated nets with the release of the predator *P. longipes* (Martin et al., 2010; Kungu, pers. com.) could also help farmers to protect their vegetable crops against the red spider mite. The development of these approaches held much promise in the controlling of *T. evansi.*

5. Conclusions

In conclusion, the study showed the extent of damage caused by *T. evansi* infestation in southern Benin. For some years now outbreaks of *T. evansi* have spread to all growing areas. This situation has left farmers with no other recourse than to use synthetic pesticides that they can find on the local market, even if these are ineffective against this pest. Further, farmers often increase the dosage and the frequency of applications. Given the toxicity of the chemicals sprayed, the household consumption of tomato and leafy vegetables, and the unsafe phytosanitary practices used by growers to fight the pest, red spider mite outbreaks are a very serious threat to public health and environmental safety in Benin.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.cropro.2015.06.007.

References

Adango, E., Onzo, A., Hanna, R., Atachi, P., Braima, J., 2006. Inventaire de la faune des acariens sur *Amaranthus cruentus* (Amaranthaceae), *Solanum macrocarpon* et *Solanum aethiopicum* (Solanaceae) dans le Sud Bénin. Int. J. Trop. Insect Sci. 26, 155–165. http://dx.doi.org/10.1079/IJT2006115.

Adango, E., Onzo, A., Hanna, R., Atachi, P., James, B., 2007. Mite pests of major importance on indigenous leafy vegetables in Benin: the search for appropriate control strategies. Acta Hort. 311–317 (ISHS) 752. http://www.actahort.org/books/752/752_53.htm.

Adorgloh-Hessou, R., 2006. Guide pour le développement de l'entreprise de production et de commercialisation de légumes de qualité dans les régions urbaines et périurbaines du Sud-Bénin. Rapport de consultation. IITA, Bénin, p. 86.

Ahouangninou, C., Fayomi, B.E., Martin, T., 2011. Évaluation des risques sanitaires et environnementaux des pratiques phytosanitaires des producteurs maraîchers dans la commune rurale de Tori-Bossito (Sud-Bénin). Cah. Agric. 20, 216–222.

Ahouangninou, C.A., Martin, T., Edorh, P., Siddick, I.A., Bio-Bangana, S., Dion, S., Onil, S., St-Laurent, L., Boko, M., Simon, S., Fayomi, B.E., 2012. Characterization of health and environmental risks of pesticide use in market-gardening in the rural city of Tori-Bossito in Benin,West Africa. J. Env. Prot. 3, 241–248. http://dx.doi.org/10.4236/jep.2012.33030.

Assogba-Komlan, F., Anihouvi, P., Achigan, E., Sikirou, R., Boko, A., Adjé, C., Ahlè, V., Vodouhe, R.S., Assa, A., 2007. Pratiques culturales et teneur en éléments anti nutritionnels (nitrates et pesticides) du *Solanum macrocarpum* au sud du Bénin. Afr. J. Food. Agric. Nutr. Dev. 7, 1–21.

Assogba-Komlan, F., Singbo, A., Ahlé, V., Azagba, J., 2001. Résultats préliminaires sur la valorisation de quelques déchets agroindustiels en maraîchage, Cas de la ville de Cotonou. In: Actes de l'Atelier Scientifique 2, Programme Régional Sud-Centre du Bénin, pp. 16–26.

Azandémè-Hounmalon, G.Y., Fellous, S., Kreiter, S., Fiaboe, K.K.M., Subramanian, S., Kungu, M., Martin, T., 2014. Dispersal behavior of *Tetranychus evansi* and *T. urticae* on tomato at several spatial scales and densities: implications for integrated pest management. PLoS ONE 9 (4), e95071. http://dx.doi.org/10.1371/journal.pone.0095071.

Blair, B.W., 1983. *Tetranychus evansi* Baker & Pritchard (Acari; Tetranychidae), a New Pest of Tobacco in Zimbabwe. CORESTA. -Phytopathology and Agronomy Study Group, Bergerac, France, pp. 1–6.

Bempah, C.K., Donkor, A.K., 2011. Pesticide residues in fruits at the market level in Accra Metropolis, Ghana, a preliminary study. Env. Monit. Assess. 175 (1–4), 551–561.

Bugeme, D.M., Knapp, M., Ekesi, S., Chabi-Olaye, A., Boga, H.I., Maniania, N.K., 2014. Efficacy of *Metarhizium anisopliae* in controlling the two-spotted spider mite *Tetranychus urticae* on common bean in screenhouse and field experiments. Ins. Sci. 1–8. http://dx.doi.org/10.1111/1744-7917.12111.

Bugeme, D.M., Knapp, M., Boga, H.I., Wanjoya, A.K., Maniania, N.K., 2009. Influence of temperature on virulence of fungal isolates of *Metarhizium anisopliae* and *Beauveria bassiana* to the two-spotted spider mite *Tetranychus urticae*. Mycopathol 167 (4), 221–227.

Bugeme, D.M., Maniania, N.K., Knapp, M., Boga, H.I., 2008. Effect of temperature on virulence of *Beauveria bassiana* and *Metarhizium anisopliae* isolates to *Tetranychus evansi*. Exp. Appl. Acarol. 46, 275–285. http://dx.doi.org/10.1007/s10493-008-9179-1.

Cakmak, I., Janssen, A., Sabelis, M.W., Baspinar, H., 2009. Biological control of an acarine pest by single and multiple natural enemies. Biol. Cont. 50 (1), 60–65.

Conway, G.R., Pretty, J.N., 1991. Unwelcome Harvest: Agriculture and Pollution. Earthscan, London.

De Bon, H., Huat, J., Parrot, L., Sinzogan, A., Martin, T., Malézieux, E., Vayssières, J.F., 2014. Pesticide risks from fruit and vegetable pest management by small farmers in sub-Saharan Africa. A review. Agro. Sustain. Dev. 34, 723–736. http://dx.doi.org/10.1007/s13593-014-0216-7.

FAO [Food and Agriculture Organization of the United Nations], 2012. FAOSTAT Database on Agriculture. Food and Agriculture Organization of the United Nations. FAOSTAT, Rome, Italy is available online at: http://faostat3.fao.org/.

Ferragut, F., Garzón-Luque, E., Pekas, A., 2013. The invasive spider mite *Tetranychus evansi* (Acari: Tetranychidae) alters community composition and host-plant use of native relatives. Exp. Appl. Acarol. 60, 321–341. http://dx.doi.org/10.1007/s10493-012-9645-7.

Ferrero, M., Calvo, F.J., Atuahiva, T., Tixier, M.S., Kreiter, S., 2011. Biological control of *Tetranychus evansi* Baker & Pritchard and *Tetranychus urticae* Koch by *Phytoseiulus longipes* Evans in tomato greenhouses in Spain [Acari: Tetranychidae, Phytoseiidae]. Biol. Cont. 58, 30–35.

Ferrero, M., de Moraes, G.J., Kreiter, S., Tixier, M.S., Knapp, M., 2007. Life tables of the predatory mite *Phytoseiulus longipes* feeding on *Tetranychus evansi* at four temperatures (Acari: Phytoseiidae, Tetranychidae). Exp. Appl. Acarol. 41, 45–53.

Fianko, J.R., Donkor, A., Lowor, S.T., Yeboah, P.O., Glover, E.T., Adom, T., Faanu, A., 2011. Health risk associated with pesticide contamination of fish from the Densu River Basin in Ghana. J. Env. Prot. 2 (02), 115.

Flechtmann, C.H.W., Knihinicki, D.K., 2002. New species and new record of *Tetranychus* Dufour from Australia, with a key to the major groups in this genus based on females (Acari: Prostigmata: Tetranychidae). Aust. J. Entomol. 41, 118–127. http://dx.doi.org/10.1046/j.1440-6055.2002.00289.x.

Furtado, I.P., de Moraes, G.J., Kreiter, S., Tixier, M.S., Knapp, M., 2007a. Potential of a Brazilian population of the predatory mite *Phytoseiulus longipes* as a biological control agent of *Tetranychus evansi* (Acari: Phytoseiidae, Tetranychidae). Biol. Cont. 42, 139–147.

Furtado, I.P., Toledo, S., de Moraes, G.J., Kreiter, S., Knapp, M., 2007b. Search for effective natural enemies of *Tetranychus evansi* (Acari: Tetranychidae) in northwest Argentina. Exp. Appl. Acarol. 43, 121–127.

Gerstl, S., 2001. The Economic Costs and Impact of Home Gardening in Ouagadougou, Burkina Faso. PhD Thesis. University of Basel, Germany. http://dx.doi.org/10.5451/unibas-002393646.

Gomgnimbou, A.P., Savadogo, P.W., Nianogo, A.J., Millogo-Rasolodimby, J., 2009. Usage des intrants chimiques dans un agrosystème tropical: diagnostic du risque de pollution environnementale dans la région cotonnière de l'est du Burkina Faso. Biotechnol. Agron. Soc. Environ. 13 (4), 499–507.

Gotoh, T., Araki, R., Boubou, A., Migeon, A., Ferragut, F., Navajas, M., 2009. Evidence of co-specificity between *Tetranychus evansi* and *Tetranychus takafujii* (Acari: Prostigmata, Tetranychidae): comments on taxonomic and agricultural aspects. Int. J. Acarol. 35, 485–501. http://dx.doi.org/10.1080/01647950903431156.

Gotoh, T., Fujiwara, S., Kitashima, Y., 2011. Susceptibility to acaricides in nine strains of the tomato red spider mite Tetranychus evansi (Acari: Tetranychidae). Int. J. Acarol 37 (2), 93–102.

Hanna, R., Toko, M., 2001. Cassava green mite biological control in Africa: project overview and summary of progress. In: Hanna, R., Toko, M. (Eds.), Proceedings of the Regional Meeting of the Cassava Green Mite Biocontrol Project, Dar Es Salaam, Tanzania, 15 _/17 November 2000. IITA, Cotonou, pp. 4–22.

Hussey, N.W., Scopes, N.E.A., 1985. Greenhouse vegetables (Britain). In: Helle, M., Sabelis, M.W. (Eds.), Spider Mites. Their Biology, Natural Enemies and Control, vol. 1B. Elsevier, Amsterdam, Oxford, New York, Tokyo, pp. 285–297.

Ippolito, A., Kattwinkel, M., Rasmussen, J.J., Schäfer, R.B., Fornaroli, R., Liess, M., 2015. Modeling global distribution of agricultural insecticides in surface waters. Environ. Pollut. 198, 54–60.

James, B., Godonou, I., Atcha, C., Baimey, H., Adango, E., Boulga, J., Goudegnon, E., 2006. Healthy Vegetables through Participatory IPM in Peri-urban Areas of Benin. Technical Report. IITA, Cotonou, p. 49.

Kishi, M., 2005. The health impacts of pesticides: what do we now know? In: Pretty, J. (Ed.), The Pesticide Detox. Towards a More Sustainable Agriculture. Earthscan, London, pp. 23–38.

Knapp, M., Wagener, B., Navajas, M., 2003. Molecular discrimination between the spider mite *Tetranychus evansi* Baker & Prichard, an important pest of tomatoes in southern Africa, and the closely related species *T. urticae* Koch (Acarina: Tetranychidae). Afr. Entomol. 11, 300–304.

Maniania, N.K., Kungu, M., 2011. Evaluation of of *Metarhizium anisopliae* and Predatory Mite *Phytoseiulus longipes* for the Control of *Tetranychus evansi*. In: Power Point Presentation, 40 Years Science for Africa.

Martin, T., Assogba-Komlan, F., Sidick, I., Ahle, V., Chandre, F., 2010. An acaricide-treated net to control phytophagous mites. Crop Prot. 29, 470–475.

Moutia, L.A., 1958. Contribution to the study of some phytophagous Acarina and their predators in Mauritius. Bull. Entomol. Res. 49, 59–75.

Naika, S., van Lidt de Jeude, J., de Goffau, M., Hilmi, M., van Dam, B., 2005. Agrodok 17—Cultivation of Tomato: Production, Processing and Marketing. Agromisa Foundation and CTA, Wageningen, Netherlands.

Ngowi, A.V.F., Mbise, T.J., Ijani, A.S.M., London, L., Ajayi, O.C., 2007. Smallholder vegetable farmers in Northern Tanzania: pesticides use practices, perceptions, cost and health effects. Crop Prot. 26 (11), 1617–1624.

Nyoni, B.N., Gorman, K., Mzilahowa, T., Williamson, M.S., Navajas, M., Field, L.M., Bass, C., 2011. Pyrethroid resistance in the tomato red spider mite, *Tetranychus evansi*, is associated with mutation of the para-type sodium channel. Pest

Manag. Sci. 67 (8), 891–897.
Onzo, A., Hanna, R., Zannou, I., Sabelis, M.W., Yaninek, J.S., 2003. Dynamics of Refuge Use: Diurnal, Vertical Migration by Predatory and Herbivorous Mites within Cassava Plants. Oikos 101, 59_/69.
PADAP/MAEP, 2003. Diagnostic, Demande, Offre et Marchés. Systèmes de production. In: Rapport définitif Etude de faisabilité, 2. Ministère de l'Agriculture, de l'Elevage et de la Pêche (MAEP), Bénin, Tome, p. 158.
Pazou, E.Y., Laléyé, P., Boko, M., van Gestel, C.A., Ahissou, H., Akpona, S., van Hattum, B., Swart, K., van Straalen, N.M., 2006. Contamination of fish by organochlorine pesticide residues in the Ouémé River catchment in the Republic of Bénin. Environ. Int. 32, 594–599.
Pretty, J., Waibel, H., 2005. Paying the price: the full cost of pesticides. In: Pretty, J. (Ed.), The Pesticide Detox. Towards a More Sustainable Agriculture. Earthscan, London, pp. 39–54.
Rahman, T., Spafford, H., Broughton, S., 2011. Single versus multiple releases of predatory mites combined with spinosad for the management of western flower thrips in strawberry. Crop Prot. 30 (4), 468–475.
Rhodes, E.M., Liburd, O.E., Kelts, C., Rondon, S.I., Francis, R.R., 2006. Comparison of single and combination treatments of *Phytoseiulus persimilis, Neoseiulus californicus* and Acramite (bifenazate) for control of two spotted spider mites in strawberries. Exp. Appl. Acarol. 39, 213–225.
Saunyama, I.G.M., Knapp, M., 2003. Effect of pruning and trellising of tomatoes on red spider mite incidence and crop yield in Zimbabwe. Afr. Crop Sci. J. 11, 269–277.
Schippers, R.R., 2004. Légumes Africains Indigènes: présentation des espèces cultivées. Margraf Publishers, Weikersheim, Germany & CTA, Wageningen, The Netherlands.
Simon, S., Assogba Komlan, F., Adjaïto, L., Mensah, A., Coffi, H.K., Ngouajio, M., Martin, T., 2014. Efficacy of insect nets for cabbage production and pest management depending on the net removal frequency and microclimate. Int. J. Pest Manage 60, 208–216. http://dx.doi.org/10.1080/09670874.2014.956844.
Sounkoura, A., Ousmane, C., Eric, S., Urbain, D., Soule, A., Sonia, P., Huat, J., 2011. Contribution of Rice and vegetable value chains to food security and incomes in the inland valleys of southern Benin and Mali: farmers' perceptions. In: Agricultural Innovations for Sustainable Development: Contributions from the Finalists of the 2009/2010 Africa-wide Women and Young Professionals in Science Competitions. FARA, Accra, pp. 51–56.
StataCorp, 2011. Stata Statistical Software: Release 12. StataCorp LP, College Station, TX.
Tomenson, J.A., Matthews, G.A., 2009. Causes and types of health effects during the use of crop protection chemicals: data from a survey of over 6,300 smallholder applicators in 24 different countries. Int. Arch. Occup. Environ. Health 82, 935–949.
Toroitich, F.J., Knapp, M., Nderitu, J.H., Olubayo, F.M., Obonyo, M., 2014. Susceptibility of geographically isolated populations of the tomato red spider mite (*Tetranychus evansi* Baker & Pritchard) to commonly used acaricides on tomato crops in Kenya. J. Entomol. Acarol. Res. 46, 18–23. http://dx.doi.org/10.4081/jear.2014.1469.
Tsagkarakou, A., Cross-Ateil, S., Navarro, M.N., 2007. First record of the invasive mite *Tetranychus* evansi (Acari: Tetranychidae) Baker and Pritchard in Greece. Phytoparasitica 35, 519–522.
Vaissayre, M., Crétenet, M., 1986. Modèle de décision appliqué à l'interaction entre fertilisation minérale et protection phytosanitaire en culture cotonnière. Coton. Fibres Trop. 41 (2), 89–96.
Wekesa, V.W., Maniania, N.K., Knapp, M., Boga, H.I., 2005. Pathogenicity of *Beauveria bassiana* and *Metarhizium anisopliae* to the tobacco spider mite *Tetranychus evansi*. Exp. Appl. Acarol. 36, 41–50.
Williamson, S., Ball, A., Pretty, J., 2008. Trends in pesticide use and drivers for safer pest management in four African countries. Crop Prot. 27 (10), 1327–1334.
Yaninek, J.S., Mé Gevand, B., Ojo, B., Cudjoe, A.R., Abole, E., Onzo, A., Zannou, I., 1998. Establishment and spread of *Typhlodromalus manihoti* (Acari; Phytoseiidae), an introduced phytoseiid predator of *Mononychellus tanajoa* (Acari: Tetranychidae) in Africa. Env. Entomol. 276, 1496–1505.
Yaninek, J.S., Hanna, R., 2003. Cassava green mite in Africa: a unique example of successful classical biological control of a mite pest on a continental scale. In: Neuenschwander, P., Borgemeister, C., Langewald, L. (Eds.), Biological Control in IPM Systems in Africa. CABI Publishing, pp. 61–75.