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ORIGINAL RESEARCH ARTICLE

Comparative efficacy of three pesticides against the tomato red spider mite *Tetranychus evansi* Baker & Pritchard under laboratory conditions

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Abstract
Tetranychus evansi is an important pest of solanaceous crops in Africa, causing important economic damage. Control of *T. evansi* is mainly achieved chemically. In search for alternative measures, the efficiency of Neem Oil in suppressing eggs and adult females of *T. evansi* was tested in laboratory in comparison to Acarius and Sunpyrifos, two chemical acaricides commonly used in vegetable farms. The mean egg hatching rates varied significantly among treatments, ranging from 3.60 ± 0.54% to 60.3 ± 0.16% ($P < 0.0001$). The highest hatching rate was recorded with the Control whereas the lowest ones were recorded with Neem Oil. Mortality of adult female *T. evansi* also varied significantly among treatments, ranging from 48 ± 3% to 100% ($P < 0.0001$). The highest mortality rates were recorded with Neem Oil at D1 whereas the lowest rate was recorded with the Control treatment. Comparison between pesticide showed Neem Oil as the most efficient (100%) followed by Acarius (93%) and Sunpyrifos (78%). Fecundity of pesticide-treated females *T. evansi* and proportion of eggs that hatched revealed significant differences between Acarius and Sunpyrifos ($P < 0.0001$), while none of the female survived after being in contact with the Neem Oil. Consequently, Neem Oil could seldom induce pesticide resistance in *T. evansi* populations. It appears from the study that Neem Oil at D1 or D2 was very effective against *T. evansi* and could therefore be an alternative to synthetic acaricides for an effective control of *T. evansi* on nightshade or tomato.

Keywords *Solanum macrocarpon* · *Azadirachta indica* · Acaricide · Tetranychidae · Mite pests · Vegetable crops

Introduction

The tomato red spider mite, *Tetranychus evansi* Baker & Pritchard, is an important invasive pest of solanaceous plants in Africa (Varela et al. 2003; Knapp et al. 2003), but also in parts of Europe (Ferreira and Carmona 1995; Ferragut and Escudero 1999; Migeon 2005; Castagnoli et al. 2006; Tsagkarakou et al. 2007; Azandémè-Hounmalon et al. 2015), as well as Asia (Ho et al. 2004; Gotoh et al. 2009). Probably native to South America (Migeon et al. 2009; Boubou et al. 2011), *T. evansi* causes severe damage to many tropical vegetable crops and constitutes the most serious constraint to the growth and development of tomato plants (Saunyama and Knapp 2003; Duverney and Gueye-Ndiaye 2005; Martin et al. 2010; Migeon et al. 2014; Azandémè-Hounmalon et al. 2015).

Since 2008, *T. evansi* has become the key mite pest of first importance in Benin (West Africa), not only of tomato (*Lycopersicon esculentum* Mill.), but also of other solanaceous crops such as the nightshade *Solanum macrocarpon* L. (Azandémè-Hounmalon et al. 2014, 2015). This pest has a very high reproductive capacity therefore, it can quickly reach outstanding population densities on its host-plants. Besides its invasive nature, recent reports indicate that *T. evansi* may be displacing native spider mite species, hence posing new pest management challenges (Ferragut et al. 2013).

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While there are efforts to control *T. evansi* using cultural practices (Saunyama and Knapp 2003; Savi et al. 2019a, b; Djossou et al. 2020), application of chemical pesticides remains the method preferred by farmers (Azandémè-Hounmalon et al. 2015).

In Benin, Acarius 18EC (Abamectin 18 g / L, EC) and Sunpyrifos 48% EC (Chlorpyrifos-ethyl 480 g, EC) are the two chemical insecticide-acaricide widely used by farmers in major vegetable production, to control mite and other insect pests (Adjovi et al. 2020; Azandémè-Hounmalon GY. unpublished data). The active ingredient of Acarius 18 EC is Abamectin that has been enriched with oil to facilitate its penetration into the plant tissue. It acts by ingestion and, to a lesser extent, by contact on mobile forms of mites and on biting-sucking insects (Réseau National des Chambres d'Agriculture du Niger 2013). As for Sunpyrifos 48% EC, it's active ingredient is Chlorpyriphos-ethyl that acts by contact, ingestion and inhalation on a large number of arthropod pests. It has a neurotoxic effect and manifests a long persistence of action, and is generally used to control many pests such as caterpillars and biting-sucking insects (www.darboucosa.net; Réseau National des Chambres d'Agriculture du Niger 2013). Those two chemicals are not specifically recommended on vegetables; however, they are the chemical insecticides generally applied by farmers on tomato and other vegetable crops to control *T. evansi* (Azandémè-Hounmalon et al. 2015). More often, the applied doses of those pesticides are far beyond the threshold allowed for the products, thereby, creating environmental hazards with well-known consequences (Picanço et al. 2007; Maniania et al. 2008; Damalas 2009; Carvalho 2017).

To avoid or prevent these drawbacks associated with the use of synthetic chemicals in the management of vegetable crop pests such as *T. evansi*, it urges therefore, to search for alternative methods that can efficiently control the mite pest without harming the environment. In that respect, biopesticides such as plant extracts and essential oils have been acknowledged to be effective in addition to be biodegradable and thus, with no hazardous effects on the environment (Sanon et al. 2005; Rochefort et al. 2006; Salma and Jogen 2011; Sarwar 2015). Nowadays, several studies have evaluated the efficacy of plant extracts in the control of agricultural and crop pests including vegetable mite pests (Adango et al. 2020), and insect pests (Gnago et al. 2010; Fayalo et al. 2014; Sane et al. 2018), as well as other arthropod pests associated with bees and bee products (Gbedomon et al. 2012).

In Africa, several plant species are known and used for their biocidal activities (toxic, repellent, anti-appetite) against pests (Baidoo et al. 2012). Neem (*Azadirachta indica* A. Juss) is one of such plant whose extracts (leaf, seed oil etc..), are being extensively used as biopesticides, fungicides and organic fertilizers, an alternative to chemical pesticides to control mites, whiteflies, aphids and other types of soft-bodied insects (Fayalo et al. 2014; Traoré et al. 2019a; Adango et al. 2020). The main advantages of using Neem extracts are their insecticidal and acaricidal activities, their low toxicity towards mammals and birds, and their fast degradation in the soil and animals (Isman 2006;Normas tecnicas específicas para a produc 2008). The major active ingredient of Neem extracts is azadirachtin that can cause several negative effects on arthropods, such as feeding inhibition, repellency, fertility and fecundity reduction, behavioral changes and increased mortality (Schumutterer 1990; Dimetry et al. 1993; Mordue and Nisbet 2000; Musabyimana et al. 2001). Whereas Neem-based products have been shown to cause deleterious effects on several mite species (Mansour et al. 1997; Gonçalves et al. 2001; Makundi and Kashenge 2002; Venzon et al. 2005, 2008; Brito et al. 2006a, b; Adango et al. 2020), no quantitative studies have yet been carried out to evaluate their effects on *T. evansi*. The present study aims, therefore at comparing the effectiveness Neem Oil to that of Acarius 18EC, Sunpyrifos 48% EC in controlling the tomato red spider mite *T. evansi* as a first step for its possible use as alternative to chemical pesticides on vegetable farms.

Materials and methods

Study site

The study was conducted in a laboratory at the International Institute of Tropical Agriculture (IITA), Benin-Station located at 12 km NW Cotonou (6°25'N; 2°19′E; 15 m asl). The experimental conditions were 25 ± 2 °C, 60–70% RH and 12:12 h (L:D) photoperiod.

Plants and mites rearing

The potted *S. macrocarpon* plants used in the study were kept on metallic benches (Length: 350 cm; Width: 80 cm; Height: 78 cm) in a screenhouse at IITA-Benin (27 ± 1 °C, 70–80% RH and 12:12 h (L:D) photoperiod) on *S. macrocarpon* plants, for about 45 days until they bear at least four completely developed leaves. The leaves were subsequently picked, either for producing the leaf discs or for rearing *T. evansi*. For these experiments, leaves of *S. macrocarpon* were preferred to tomato leaves because they are large enough to allow for standardized size of the leaf discs. Using *S. macrocarpon* leaves is, however, not a problem since the nightshade *S. macrocarpon*, is among the main host-plants of the mite pest *T. evansi*; and the results accrued on the nightshade are assumed to be applicable to tomato especially as both plants belong to the same family.

The population of *T. evansi* used in this study was originally collected from a vegetable farm at Sèmè-Kpodji in

Southern-Benin (6°22'N; 2°37E) in March 2016, and maintained in a screenhouse on *S. macrocarpon* plants for ca. 18 months prior to starting the experiments. Vegetable farms in southern-Benin are generally treated with pesticides (Azandémè-Hounmalon et al. 2015); however, how their effects persist within the *T. evansi* populations after this long period of rearing has not been investigated.

Pesticides tested

The experiments were started in September 2017. The pesticides used in the study included two chemical acaricides, Acarius 18 EC, Sunpyrifos 48% EC and one biopesticide, Neem Oil.

Neem Oil is obtained from *Azadirachta Indica* A. Juss. (Meliaceae) seeds and is used as an insecticide whose active ingredient is Azadirachtin. It is a 100% natural oil that is non-toxic to humans and animals. It doesn't act by contact but prevents insects from feeding thereby disturbing their development and their ability to oviposit (Karnavar 1987; Belanger and Musabyimanan 2005). The Neem Oil used in this study was purchased from Biophyto at Allada, Republic of Benin.

The chemical pesticide Acarius 18 EC (Abamectin 18 g/L, EC), miticide-insecticide is manufactured by Savana www.Savanna-France.Com. The application doses recommended were 0.5L/ha. Abamectin acts by ingestion and, to a lesser extent, by contact on biting-sucking mites and insects (Réseau National des Chambres d'Agriculture du Niger 2013; http://terra.mg/agricom/agriculture/fr/produit/acarius-018-ec/, June 2022).

Sunpyrifos (Chlorpyrifos-ethyl 480 g, EC) a chemical pesticide is produced by Zhejlang Xinan Chemical Industrial Group Co.Ltd in China and distributed by Wynca Sunshine Agric Products and Trading Co., (Gh) Ltd, Based in Accra Ghana. It acts by contact, ingestion and inhalation on a large number of pests. It has a Neurotoxic effect and manifests a long persistence of action. This is a broad-spectrum active ingredient, used to control many pests such as caterpillars and biting-sucking insects. The application doses recommended were 1.5L/ha (Réseau National des Chambres d'Agriculture du Niger 2013; www.Darboucosa.Net, Nov. 2017).

The two chemical pesticides used in this study were purchased at SODECO at Cotonou, Republic of Benin.

Experimental design

The experiment consisted of the application of two chemical acaricides: Acarius and Sunpyrifos; the bio-pesticide: Neem Oil and the Control treatment (without any pesticide). Three doses, respectively, of Neem Oil, Acarius and Sunpyrifos were tested. For each pesticide, the half of the recommended dose (D1), the recommended dose itself (D2) and twice the recommended dose (D3) were tested together with the Control (application of tap water alone). The different doses of Sunpyrifos, Acarius and Neem were based on formulated products or active ingredients. According to the recommandations by Réseau National des Chambres d'Agriculture du Niger (2013), 60 ml of Sunpyrifos and 25 ml of Acarius should be mixed with 15 L of water while 80 mL of Neem Oil are requested for 16 L of water (https://www.biophyto-benin.com). For each pesiticide, the solution used in the experiments was prepared as presented in Table 1

Effects on *T. evansi* eggs

Per treatment, 10 leaf discs (2 cm diameter) were cut from fresh *S. macrocarpon* leaves and on each of them, 10 newly laid *T. evansi* eggs (24 h-old) were deposited. The 10 leaf discs for each treatment were then placed, lower side up, on water-soaked cotton wool in a Petri dish (9 cm diameter) and sprayed with the pesticide solution at its appropriate dose for 5 s. The leaf discs were then dried out at ambient air for 1 h. The leaf discs contained in a Petri dish (15 cm diameter) represent the 10 replicates for each treatment. The leaves were monitored daily for four consecutive days to record the number of eggs that hatched per treatment and per dose.

Effects on adult females *T. evansi*

Per treatment, 10 leaf discs cut from fresh *S. macrocarpon* leaves were dipped for 5 s into the pesticide solution tested. We then placed the leaf discs with the lower side up on water-soaked cotton wool in Petri dishes (9 cm diameter), and allowed to dry for 30 min (Toroitich et al. 2014). Thereafter, 10 adult females *T. evansi* (24 to 48 h-old) were transferred from the rearing unit to each leaf disc. We started the monitoring 24 h later for six consecutive days during which the mortality of females, the number of eggs laid and those that hatched were recorded daily. Escaped mites were excluded from the analyses. The mortality rates of adult females were used to calculate the toxicity of each solution following Hassan (1992) and Sterk et al. (1999)

Table 1 Different doses used for acaricide treatment

	Doses (ml/l) of water		
Treatments	D1	D2	D3
Acarius	0.83	1.66	3.34
Sunprifos	2	4	8
Neem oil	2.5	5	10

D1 Half recommended-dose, *D2* Recommended dose, *D3* Double recommended dose

classification, ranking on a scale from 0 to 30% (=effective), 30 to 79% (=slightly effective), 80 to 99% (=moderately effective) and 99–100% (highly effective). We used in the experiments only the recommended-doses of the different pesticide solutions.

Data analysis

The mortality data on ovicidal tests were corrected in relation to the control (water) by Abbott's formula (Abbott 1925), while actual uncorrected figures were used for adult mortality. Data on egg and adult mortalities were corrected using arcsine square root-transformed. The corrected data were then subjected to a one-way analysis of variance (Proc GLM). The means were separated using the Student–Newman–Keuls test (SAS 9.1 2009). The efficacy of the different pesticide products on adult females *T. evansi* was determined based on Schneider-Orelli's formula as follows:

$$\text{Efficacy\%} = \left(\frac{\text{Mortality on treated leaf disc(\%)} - \text{Mortality on control leaf disc(\%)}}{100 - \text{Mortality on control leaf disc(\%)}}\right) \times 100$$

Results

Effects on viability of *T. evansi* eggs

Among all the three pesticides tested (all doses pooled together), the average hatch rate of *T. evansi* eggs ranged from 3.6 ± 0.5% (Neem Oil) to 60.3 ± 0.2% (Control) (Fig. 1). Results of the analysis of variance showed significant differences in the viability of *T. evansi* eggs among the three products tested (df = 6; F = 44.5; P < 0.0001). Within each pesticide product tested, there were significant differences among the three doses (P < 0.0001), with generally the lowest egg viability on the double recommended doses, followed by the recommended doses and the highest egg viability of the half-doses (Table 2).

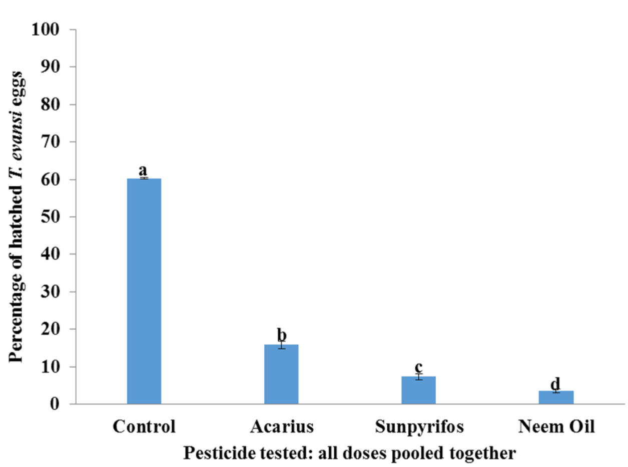

Fig. 1 Eggs hatching of *T. evansi* after application of pesticide products Columns followed by the different letters indicate significant differences (SNK test, P < 0.05)

Effect on mortality of adult female *T. evansi*

The temporal evolution of the effect of the different pesticide products on the mortality of adult female *T. evansi* is presented on Fig. 2. Irrespective of the doses, the lowest mortality rate was recorded in the Control (47.9 ± 2.8%) whereas the highest was recorded with the Neem Oil (100.0%). At day 1 (i.e. 24 h) after application, the highest mortality rate of *T. evansi* females (100%) was reached at half-doses (D1) with Neem Oil while these rates were reached 3 days (72 h) and 6 days (148 h) after application, respectively for Acarius (96.9 ± 2.2%) and Sunpyrifos (100.0%) (Fig. 2). The analysis of variance showed significant differences in the effects of treatments on the mortality of adult female *T. evansi* (df = 9; F = 12.4; P < 0.0001; Table 3). The Student–Newman–Keuls multiple range test revealed that the half-dose (D1), the recommended dose (D2) and the double recommended dose (D3) of Neem Oil as well as the recommended dose (D2) and the double recommended dose (D3) of Acarius had statistically similar effects, by inducing the highest adult mortality of *T. evansi* (Table 3). They were followed by the half dose of Acarius

Table 2 Within-treatments effects of doses on hatchability of *T. evansi* eggs

Treatments	N	Mean ± SE (%)	Df	*F*	*P*
Acarius (D1)	40	27.5 ± 12.95 b			
Acarius (D2)	40	22.0 ± 9.39 b			
Acarius (D3)	40	4.00 ± 4.96 c			
Neem Oil (D1)	40	6.0 ± 6.71 c			
Neem Oil (D2)	40	4.5 ± 6.38 c	2	70.52	< 0.0001
Neem Oil (D3)	40	0.25 ± 1.58 d			
Sunpyrifos (D1)	40	16.25 ± 14.44 b			
Sunpyrifos (D2)	40	5.7 ± 6.35 c			
Sunpyrifos (D3)	40	0.0 ± 0.0 d			
Control	40	60.25 ± 2.78 a			

Values represent % ± SE. Percentages followed by the same letter in a column are not significantly different (SNK test, P < 0.05)

N Number of observations

D1 Half recommended-dose, *D2* Recommended dose, *D3* Double recommended dose

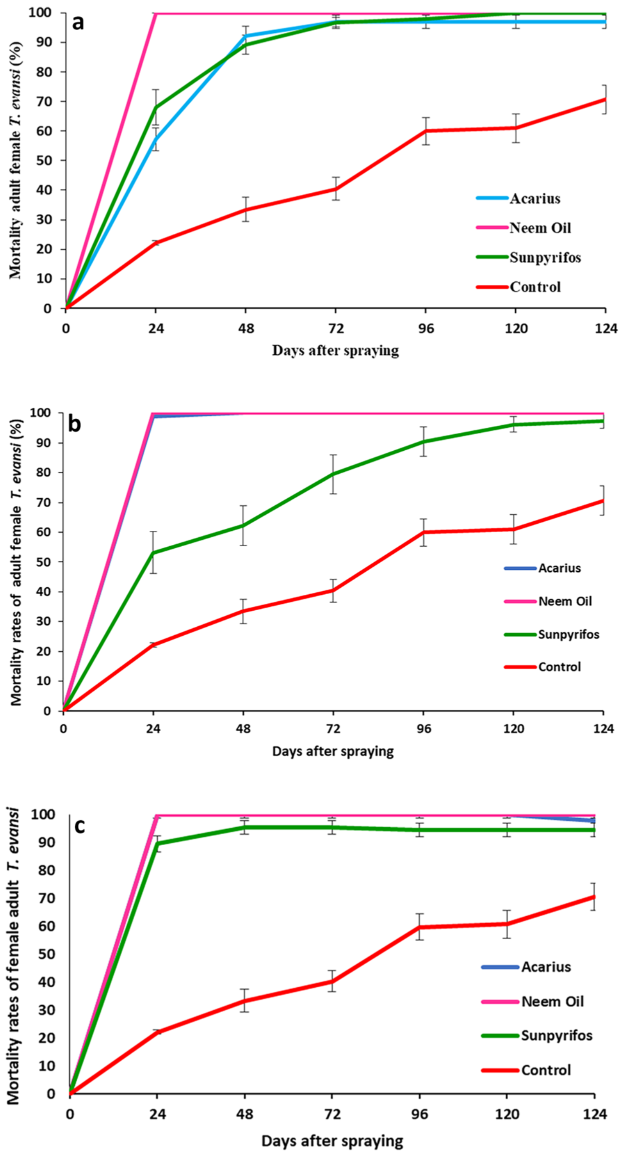

Fig. 2 Adult mortality of *T. evansi* at half-dose D1 (**a**), recommended dose D2 (**b**) and double recommended dose D3 (**c**) of different pesticide products

and Sunpyrifos (D1), the double recommended dose (D3) and the recommended dose (D2) of Sunpyrifos.

The efficacy of the different pesticide products was 78.2% for Sunpyrifos, 92.9% for Acarius and 100.0% for Neem Oil.

Fecundity of adult females *T. evansi* that survived pesticide applications

The mean number of eggs laid by an adult female *T. evansi* that survived the pesticide applications ranged between 0.0 (Acarius) and 6.8 ± 1.2 (Control). The results of the analysis of variance showed significant differences among treatments in *T. evansi* fecundity (df = 2; F = 7.40; P < 0.05) (Table 4). With those acaricides, the fecundity of the surviving *T. evansi* females was gradually reduced when the dose increased. However, there were no surviving *T. evansi* females with Neem Oil applications. For all the products, the lowest fecundity rate for the surviving *T. evansi* females was recorded with Acarius (0.0%).

Table 3 Effects of treatments on mortality of adult female *T. evansi*

Treatments	N	Mean ± SE (%)	Df	F	P
Neem Oil (D1)	60	100.0 ± 0.0 a			
Neem Oil (D2)	60	100.0 ± 0.0 a			
Neem Oil (D3)	60	100.0 ± 0.0 a			
Acarius (D2)	60	99.8 ± 0.2 a	9	12.4	< 0.001
Acarius (D3)	60	99.7 ± 0.2 a			
Acarius (D1)	60	89.5 ± 2.2 b			
Sunpyrifos (D1)	60	92.0 ± 1.9 b			
Sunpyrifos (D3)	60	94.2 ± 1.0 b			
Sunpyrifos (D2)	60	79.9 ± 3.1 c			
Control	60	47.9 ± 2.8 d			

Values represent % ± SE. Percentages followed by the same letter in a column are not significantly different (SNK test, P < 0.05)

N Number of observations

D1 Half recommended-dose, *D2* Recommended dose, *D3* Double recommended dose

Table 4 Fecundity of adult females *T. evansi* after application of pesticide products

Treatments	N	Mean ± SE	Df	F	P
Acarius (D1)	23	1.08 ± 0.4c			
Acarius (D2)	1	0.00 ± 0.0d			
Acarius (D3)	2	0.00 ± 0.0d			
Neem Oil (D1)	-	-			
Neem Oil (D2)	-	-	2	7.40	< 0.05
Neem Oil (D3)	-	-			
Sunpyrifos (D1)	21	6.9 ± 1.7a			
Sunpyrifos (D2)	31	3.1 ± 0.6b			
Sunpyrifos (D3)	25	0.4 ± 0.2d			
Control	59	6.83 ± 1.2a			

Values represent Means ± SE. Means followed by the same letter in a column are not significantly different for the performance measurement (SNK test, P < 0.05)

N Number of observations

D1 Half recommended-dose, *D2* Recommended dose, *D3* Double recommended dose

Viability of eggs laid by pesticide-treated adult females *T. evansi*

The hatching rate of eggs laid by pesticide-treated female *T. evansi* was significantly the lowest on Acarius compared to Sunpyrifos. Comparison of the half-doses, the recommended doses and the double recommended doses for each product revealed differences among treatments in *T. evansi* viability of eggs (df = 2; F = 6.7; P < 0.05) (Table 5).

Discussion

The current study is the first in Benin to have focused on the management of the red spider mite *T. evansi,* thereby evaluating in the laboratory the effects of Acarius and Sunpyrifos, two chemical acaricides commonly used in Benin (Azandémè-Hounmalon GY. unpublished data) and that of the Neem Oil, which is a natural insecticide/acaricide. Our results showed that all the three pesticide products tested were efficient against this mite pest by both inducing mortality in the adult female populations and by reducing the viability of their eggs. However, the deleterious effects on *T. evansi* populations differed significantly among these products. In that respect, Neem Oil and Acarius exerted the most significant effects both on the viability of *T. evansi* eggs, as well as on the mortality and fecundity of adult females, compared with Sunpyrifos, irrespective of the applied doses. These results suggest that, beside acting by ingestion and to a lesser extent by contact on larvae and adults -as indicated by their respective manufacturers- Acarius and Sunpyrifos appeared having also ovicidal effects on *T. evansi*. Indeed, *T. evansi* egg has a slender chorion with airfoils (small holes related to embryonic respiration), that certainly facilitate its penetration by the toxic compounds (Bruce et al. 2004). Neem Oil is now well-known for its insecticidal but also ovicidal potentials (Yarou et al. 2017; Adango et al. 2020), because of the presence of Azadirachtin, a compound reported by several authors around the world as having fungicidal, insecticidal and/or acaricidal properties (Karnavar 1987; Bélanger and Musabyimana 2005; Yarou et al. 2017; Traoré et al. 2019a, b; Adango et al. 2020). The high mortality of *T. evansi* (adults and eggs) recorded with Neem Oil witnesses the sensitivity of all life stages of the mite pest to that azadirachtin. Moreover, Mouffok et al. (2008) reported the negative effects of azadirachtin on hormonal secretion, morphogenetic development, respiration of several insect species and on the development of insect tissues (i.e. muscular, nervous, glandular, etc.). They also reported that azadirachtin is an anorexic agent since once in contact with it, the insect no longer eats and finally dies. The insecticidal or acaricidal effects of Neem Oil have indeed been reported on several arthropods including *Atherigona soccota* Rondani (Zongo et al. 1993), *Clavigralla gibbosa* (Shukla and Kumar 2002), *Sesamia calamitis* Hampson (Bruce et al. 2004), *Amrasca devastans* (Haq 2006), *Bemisia tabacci* (Prabhat Kumar 2007), *Pieris brassicae* (Fazil and Ansari 2011), *Diatraea saccharlis* (Oliveira et al. 2013), *Clavigralla tomentosicollis* (Traoré et al. 2019a), *Maruca vitrata* (Traoré et al. 2019b), and the broad mite *Polyphagotarsonemus latus* Banks infesting the nightshade (Adango et al. 2020).

Table 5 Viability of *Tetranychus evansi* eggs after application of pesticide products

Treatments	N	Mean ± SE	Df	F	P
Acarius (D1)	23	0.13 ± 0.1c			
Acarius (D2)	1	0.00 ± 0.0c			
Acarius (D3)	2	0.00 ± 0.0c			
Neem Oil (D1)	-	-			
Neem Oil (D2)	-	-	2	6.7	< 0.05
Neem Oil (D3)	-	-			
Sunpyrifos (D1)	21	4.90 ± 1.25a			
Sunpyrifos (D2)	31	0.96 ± 0.35b			
Sunpyrifos (D3)	25	0.08 ± 0.08c			
Control	59	5.20 ± 1.07a			

Values represent Means ± SE. Means followed by the same letter in a column are not significantly different for the performance measurement (SNK test, P < 0.05)

N Number of observations

D1 Half recommended-dose, *D2* Recommended dose, *D3* Double recommended dose

Comparing the effects of the three pesticide products, both on female mortality and on egg viability, it appears that Neem Oil ranked the first in reducing *T. evansi* populations. Our data clearly showed, indeed, that even with the half-dose, 100% mortality of adult female mites was achieved within only 24 h after applying Neem Oil. Several studies have reported that azadirachtin acts in several ways on insect populations by directly killing them or repelling them. Azadirachtin also has an anti-appetite effect, while it can affect egg-laying by females as well as molting and larval growth in certain arthropods (Stoll 2002; Bélanger and Musabyimana 2005; Guèye et al. 2011; Gbedomon et al. 2012; Bernardi et al. 2013).

While considering the fecundity and the viability of adult females *T. evansi* that survived pesticide applications, it appears that Acarius induced the lowest fecundity rate and the lowest viability of eggs laid compared with Sunpyrifos treatments, irrespective of the doses. In addition, it has been observed that irrespective of the doses, the survival of the progeny (i.e. larvae that hatched) was the lowest (not exceeding six days) with Acarius compared with Sunpyrifos. These interesting data suggest that *T. evansi* populations treated with Neem Oil could seldom develop pesticide resistance since none of the female survived after being in contact with the product. Therefore, no progeny could be expected and that could have survived to adulthood to initiate new populations (Osakabe et al. 2009; Fortin et al. 2012), while such risks are effectively present with both Acarius and Sunpyrifos. Caution has to be taken, however, since our conclusion based on laboratory experiments may not translate in the fields due to several biotic and abiotic factors. Unlike synthetic chemical pesticides, azadirachtin is a plant extract that is biodegradable therefore, harmless to the environment. In addition, Neem Oil is also thought to fertilize the soil (Traoré et al. 2019a, b; Adango et al. 2020), and is, therefore, interesting for integrated pest management (IPM) strategies since it would preserve existing natural enemy communities (Gerson 1992; Bélanger and Musabyimana 2005; Bernardi et al. 2013).

It, therefore, emerges from the present study that the use of Neem Oil on vegetable production areas would be a first choice in the search for means to control *T. evansi* populations on tomato plants and certainly on other crop species. Neem Oil is very effective against this mite pest, and since it is derived from a vegetal, it is expected to be less toxic to non-target organisms such as mammals, birds, aquatic fauna, and its use in biological or conventional agriculture is continuously increasing. It is a relatively low-cost acaricide while, instead of using the recommended dose, farmers could simply apply half of the recommended dose to get maximal effect within 24 h after application. Neem Oil is also acknowledged to be beneficial to human since it is widely used in traditional medicine in Benin (Onzo A. personal communication). Whereas, further studies are still needed in greenhouse and/or field conditions, Neem Oil may be recommended as an alternative to chemical acaricides for the control of *T. evansi* on vegetable farms as already suggested by Adango et al. 2020, for the control of the broad mite *Polyphagotarsonemus latus* (Banks) on Gboma plots in Southern Benin.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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