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Nesidiocoris tenuis in Burkina Faso: Distribution, predatory capacity and insecticide sensibility

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Abstract

Tuta absoluta (Lepidoptera: Gelechiidae) is a worldwide invasive insect species, considered a major pest of tomato. It has recently established in Burkina Faso, where chemical control remains the only affordable option to limit damages. *Nesidiocoris tenuis* (Hemiptera: Miridae) is commercialized as a biological agent to control this pest in other parts of the world. But very limited information exists on this predator in Burkina Faso. In this study, we first performed an insect survey in all agricultural regions areas of the country, and we found *N. tenuis* to be widely observed in all of them. Then, we performed two laboratory bioassays and demonstrated that all instars preyed on *T. absoluta* eggs, whether they were fed ad libitum or they had to actively forage for their prey. Because insecticide tolerant populations of *T. absoluta* were recently identified, we finally aimed at identifying agrochemicals that do not harm *N. tenuis*. We evaluated the toxicity of two synthetic insecticides, three bio-bacterial insecticides and eight plant extracts, all being active ingredients available on the local market. Most of them (i.e., abamectin, emamectin benzoate, spinosad, spinetoram) were highly toxic for both *T. absoluta* and *N. tenuis*. In contrast, *Bacillus thuringiensis* var. Kurstaki, neem oil, *Cleome viscosa* (Asian spiderflower), *Ocimum basilicum* (Basil) and *Cassia occidentalis* (Coffee senna) were compatible with *N. tenuis* while still controlling *T. absoluta*. Based on our results, we recommend the application of *Bacillus thuringiensis* to both control *T. absoluta* and which does not compromise the maintenance of *N. tenuis* populations.

KEYWORDS
biological control, insecticide, IPM, *Nesidiocoris tenuis*, tomato, *Tuta absoluta*

INTRODUCTION

Tuta absoluta (Meyrick, 1917) (Lepidoptera: Gelechiidae) is a species of leaf miner native to South America infesting tomato plants and other Solanaceae. It became a worldwide insect pest after invading Europe and Africa (Biondi et al., 2018; Urbaneja et al., 2007). *T. absoluta* was first observed in Northern Burkina Faso in 2016 (Son et al., 2017). Since then, it has spread to all regions of the country (Sawadogo et al., 2020a). By undermining the vegetative and reproductive organs, the larvae cause losses of 45%–70% to tomato production, the equivalent of 1650–3300 US$ ha^{-1} (Sawadogo et al., 2020a). Considering that 167,400 tons of tomato were produced in 2018–2019, representing 20% of the country's vegetables production, the economic damage caused by this pest are potentially huge (MAAH, 2019).

The use of agrochemicals remains the most popular control method. But several cases of treatment failures were recently described, often resulting in the abandonment of farms (Sawadogo et al., 2020b). This could be explained by the existence of populations resistant to several families of insecticides (Guedes et al., 2019). As there was no difference in susceptibility between the collected populations of *T. absoluta* in Burkina Faso, it was found that all these populations were tolerant to various active molecules belonging to the neonicotinoids, acetamiprids and the pyrethroids (Sawadogo et al., 2020b). As a consequence, farmers increased dosages and frequencies of insecticide applications, reaching up to 40 treatments per crop season (Sawadogo et al., 2020a). In addition to the damage to human health and environment, these practices can devastate the populations of insect beneficials that naturally regulate *T. absoluta* populations in the field.

Several beneficials, including *Nesidiocoris tenuis* (Reuter, 1895) (Hemiptera: Miridae), were observed in tomato fields (Garba et al., 2020; Sawadogo et al., 2020b). *N. tenuis* preferred preys include whiteflies, aphids, thrips and moths, among which important pests like *Spodoptera exigua* Hubner (Lepidoptera: Noctuidae) and *T. absoluta* (Calvo et al., 2009; Gavkare & Sharma, 2019; Urbaneja et al., 2008; Yano et al., 2019). Unlike other members of its family, this zoophytophagous species can hardly survive on tomato in the absence of prey (Molla et al., 2014). And in that case, it feeds on the plant and causes significant damages (Biondi et al., 2016; Calvo et al., 2009; J. G. Kim et al., 2016). In Burkina Faso, *N. tenuis* has been found on various Solanaceae, as well as vegetables of other families including Cucurbitaceae, Asteraceae and Pedaliaceae (Sawadogo et al., 2020b).

The role of *N. tenuis* in controlling *T. absoluta* in Burkina Faso is not documented. Neither is its distribution in the country, despite its potential important role as a biological control agent. In this work, we have (i) surveyed its occurrence in 24 of the 45 provinces of the country (with at least one province in each of the 13 agricultural regions), (ii) evaluated its predation abilities on eggs using insect populations originating from Burkina Faso and (iii) evaluated its level of sensitivity to chemical pesticides and biopesticides, and compared them with those of the pest *T. absoluta* in order to identify chemical products that are compatible with an integrated pest management strategy.

MATERIALS AND METHODS

Nesidiocoris distribution in the country

During two tomato growing periods, ranging from October 2018 to April 2019 and from October 2019 to May 2020, we travelled through all 13 regions of the country to verify the presence of *N. tenuis* in tomato fields. In each visited province (24 of the 45 provinces of the country, including at least one province in each region), a minimum of 6 tomato fields were surveyed, for a total of 165 fields visited. These fields were planted with tomato, belonging to one of the following varieties: Cobra 26 F1, Mongal, Petomech, Tropimech and Rossol. Mature plants only were inspected (i.e., experiencing the development of their inflorescence or their fruits). All visited fields received repeated chemical treatments, involving various active ingredients, for the control of *T. absoluta* (Sawadogo et al., 2020a). In each field, we randomly placed 4 quadra of 1 m^2 each (made of four wood sticks) and visually inspected all included plants. For a given comparison, if all the elements to be compared follow the normal distribution, then an analysis of variance (1-factor analysis of variance [ANOVA]) was carried out, otherwise a nonparametric Kruskal–Wallis analysis was performed. *Insects and plants*—About 1000 *T. absoluta* larvae were collected from a tomato field in Kuinima (Bobo-Dioulasso) in March 2020. They were reared in the laboratory, inside cages (80 cm long, 40 cm wide and 40 cm high) placed under a photoperiod of 12:12 (light: dark), $26 \pm 2°C$ and $71 \pm 14\%$ of relative humidity. About 500 *N. tenuis* nymphs and adults were collected from a tomato field in Kibi (Bobo-Dioulasso), located at 5 km from the *T. absoluta* collection site, in April 2020 and brought back to the same laboratory (www.irac-online.org). They were placed in similar cages and were left to reproduce in presence of tomato plants (v. Tropimech) infested by *T. absoluta*. Those plants originated from a greenhouse tomato production.

Predation capacity

We evaluated the ability of *N. tenuis* to predate on *T. absoluta* eggs in laboratory conditions ($26 \pm 2°C$, $50 \pm 15\%$ RH and 12:12 photoperiod) through two experiments: (i) Predation of eggs performed in Petri dishes (no foraging behaviour needed, ad libitum feeding) and (ii) predation of eggs placed on tomato plants, in net cages (foraging behaviour required).

i. To expose *T. absoluta* eggs to *N. tenuis*, we introduced 60 *T. absoluta* eggs in a 8.9 cm diameter Petri dish containing a slightly moistened piece of blotting paper and a single *N. tenuis* individual (previously starved for 24 h). The number of *T. absoluta* eggs was determined during a preliminary experiment during which a single predator never ate more than 55 eggs. After 24 h, the predator was removed, and the number of emptied *T. absoluta* eggs was counted using a magnifying glass. The test was repeated five times for each nymph stage of *N. tenuis*, including N1, N2, N3, N4, N5 as well as adults. The test was validated if no ecdysis was observed in the Petri dish and if the predator was still alive. Petri dishes containing no *N. tenuis* nymph were used as a control.
ii. To expose plants bearing *T. absoluta* eggs to *N. tenuis*, we used one-month-old tomato plants (about 25–30 cm high, 5–6 leaves). They were introduced into the *T. absoluta* rearing cages to collect eggs. After 24 h, the plants were removed from the cages. Each plant was carefully examined and *T. absoluta* eggs were counted by two operators to ensure that errors in the counting are reduced at a minimum. If more than 60 eggs were found, the plant was used in this experiment. To simulate the field conditions (a density of 6 tomato plants m^{-2}), we introduced six tomato plants at random location in a net cage (80 cm long, 40 cm wide and 40 cm high). Two of them were covered with *T. absoluta* eggs, whereas the other four were 'clean' tomato plants (i.e., no insect egg on them). The leaves of all six plants were in contact with each other to allow access to all plants by *N. tenuis* nymphs. A cage also containing six plants with *T. absoluta* eggs but without *N. tenuis* was used as a control. A starved predator was introduced at a random location into the

cage for 24 h. It was then removed, and nonpredated and predated (i.e., emptied) *T. absoluta* eggs were counted. The experiment was repeated five times for each developmental stage of *N. tenuis*, including N1, N2, N3, N4, N5 and adults.

After checking for normality (Shapiro–Wilk's test), an analysis of variance (1 factor ANOVA) was performed to compare the means. A Student Newman–Keuls test at the 5% significance level was also used identify the differences in mean numbers of consumed prey.

Insecticide sensibility

In this assay, we aimed at evaluating the susceptibility of *N. tenuis* to the insecticide formulations mainly used against *T. absoluta*, as well as biological alternatives available on the local market. Two synthetic insecticides and three bacterial-based insecticides have been tested, which have shown effectiveness against *T. absoluta* (Sawadogo et al., 2020b). Also, eight plant extracts available on the markets have been included in the assay. We purchased on the local market the following organic and synthetic insecticides (RD = supplier recommended dose): abamectin 18 g L^{-1} EC (Abalone 18 EC, Arysta Lifescience, RD = 1 L ha^{-1}), emamectin benzoate 19 g L^{-1} EC (Emacot 019 EC, Savana, RD = 0.5 L ha^{-1}), spinosad 480 g L^{-1} SC (Laser 480 SC Dow Agrosciences Export S. A.S, RD = 100 ml ha^{-1}), spinetoram 120 g L^{-1} SC (Radiant 120 SC Dow Agrosciences Export S.A.S, RD = 100 ml ha^{-1}), *Bacillus thuringiensis* var. Kurstaki 16,000 IU mg^{-1} (Bio K 16, Savana, RD = 1.5 kg ha^{-1}), neem oil (Bioprotect, RD = 5 L ha^{-1}), *Jatropha curcas* oil (RD = 5 L ha^{-1}) and botanical extracts of Asian spiderflower, *Cleome viscosa* L. (Cleomaceae), African Locust Bean, *Parkia biglobosa* Jacq R. Br. ex G. Don f (Fabaceae), Heb eddbae, *Cassia nigricans* Vahl (Fabaceae), Basil, *Ocimum basilicum* L. (Lamiaceae), Agbal, *Mitragyna inermis* (W.) Kuntze (Rubiaceae) and Coffee senna, *Cassia occidentalis* L. (Fabaceae) (Kambou et al., 2008; Mano et al., 2019).

The IRAC 022 method was followed (detailed on https://irac-online.org/methods/). We used *T. absoluta* L2 larvae and *N. tenuis* L5 nymphs, which are the offspring of the individuals collected in the field. The test consisted of soaking young tender tomato leaves for 3 s in one concentration of one insecticide containing Triton X100 wetting agent (0.2 g L^{-1}) and letting them dry up in the open air. A control treatment without insecticide (distilled water + Triton X100) is used to record natural mortalities. Four to six different concentrations per product were considered, including at least one below and one above the supplier recommended concentration. After drying, leaves were placed in Petri dishes covered with slightly dampened blotting paper. Each box received five to six larvae of *T. absoluta* or four nymphs of *N. tenuis*, reaching a total of 20 *N. tenuis* nymphs and 32 *T. absoluta* larvae per concentration of each insecticide. These boxes were then sealed with parafilm. During the following 72 h, larvae were observed and considered dead when they failed to perform a coordinated movement with the stimulus of a fine tweezer. Insect mortalities were corrected according to Abbott's (1925) formula and the bioassays selected were those where the mortality of the controls did not exceed 10%–15%. Probit dose–response analyses were then performed to achieve estimates of lethal concentrations of each insecticide. Control failures likelihood using the Guedes (2017) formula were finally calculated.

$$\mathrm{CFL} = 100 - \frac{\mathrm{Mo}\,(\%)}{\mathrm{Ho}\,(80\%)} * 100$$

Control failure likelihood (CFL) is the probability of treatment failure; Mo is the percentage of individuals that die when the recommended dose is applied; Ho is the minimum efficacy threshold required to allow registration of a conventional insecticide and is generally estimated at 80%.

All the different analyses were carried out with the IBM SPSS Statistics 25 software.

RESULTS

Nesidiocoris distribution and density in the country

N. tenuis was found in all surveyed areas of Burkina Faso (Figure 1). Their density varied from one field or site to another. Despite the high frequency of low densities encountered (less than 10 individuals m^{-2}), we noted that densities of up to 79.8 ± 9.9 individuals m^{-2} (Tolotama, Bobo-Dioulasso) have been recorded in some fields.

Predation capacity of *N. tenuis* on *T. absoluta* eggs

All *N. tenuis* developmental stages consumed *T. absoluta* eggs (Table 1). In the Petri dish experiments, the number of *T. absoluta* eggs consumed per day by a single *N. tenuis* was statistically similar for all stages (ranging from 18.4 ± 12.7 to 32.40 ± 7.63). Similarly, there were no differences in egg consumption between the N2, N3, N4, N5 nymphs and adults (30.20 ± 8.13 to 45.0 ± 9.9). When the predator had to search for eggs on the plants, only N5 nymphs and adults (20.40 ± 7.82–21.00 ± 11.07) managed to predate more eggs than N1 nymphs (4.60 ± 5.07).

Sensitivity of *T. absoluta* to insecticides

For all tested chemicals, the values (responses) predicted by the log (dose)/probit (mortality) model did not differ significantly from the values observed in the bioassays (low values from χ^2 and *p* value >0.05). Therefore, we conclude that the probit model is suitable, and its results can be interpreted (Table 2).

i. Avermectin/milbemycin: The LC80s of abamectin and emamectin benzoate were 0.22 and 0.05 mg L^{-1}, respectively. The confidence limits of the LC80 were 0.157–0.44 and 0.04–0.07, respectively. Since they do not overlap, emamectin benzoate has

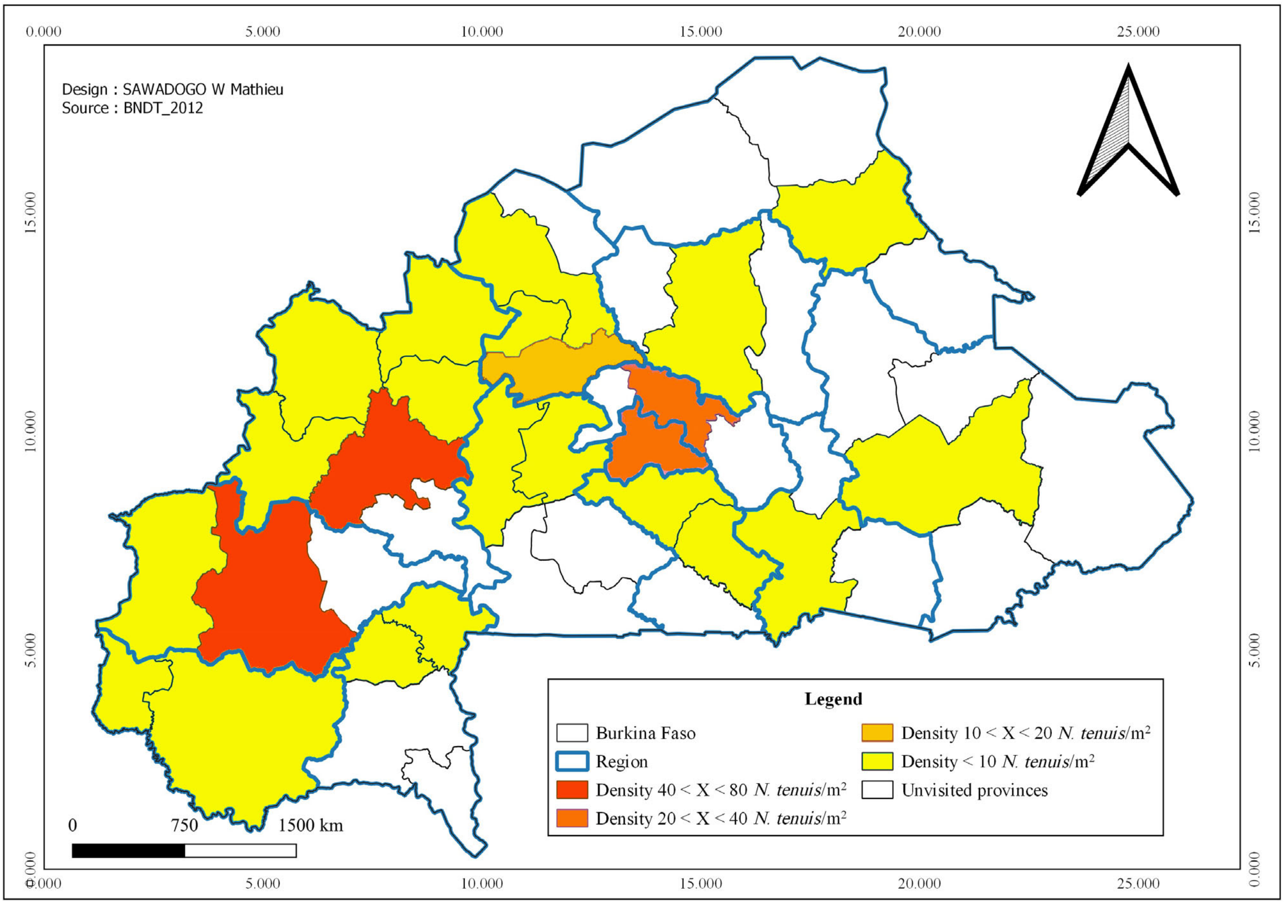

FIGURE 1 Geographical distribution and abundance of *Nesidiocoris tenuis* in Burkina Faso

TABLE 1 *Nesidiocoris tenuis* predation capacity on *Tuta absoluta* eggs (mean number of eggs ± SD)

Stages	Petri dish experiment	Cage experiment
N1	18.40 ± 12.68a	4.60 ± 5.07a
N2	30.20 ± 8.13ab	9.80 ± 6.49ab
N3	32.40 ± 7.63ab	8.80 ± 5.71ab
N4	39.60 ± 8.32b	13.80 ± 9.65ab
N5	39.60 ± 8.29b	21.00 ± 11.07b
Adults	45.00 ± 9.94b	20.40 ± 7.82b
F	5.098	3.46
Pr > *F*	0.003	0.017

Note: Numbers followed by the same letters in the same column are not significantly different (Student Newman–Keuls test, $\alpha = 0.05$).

a higher toxicity than abamectin. A CFL of −25 was recorded suggesting that at the dose recommended by the manufacturers of these insecticides, the treatment would be 100% effective.

ii. Spinosyns: The LC50s values of spinosad and spinetoram are 0.04 and 0.08 mg L^{-1}, respectively. The confidence limits of the LC80s do not overlap (0.05–0.08 and 0.23–0.51, respectively). Also, the slope of spinosad is higher than that of spinetoram (31.1 ± 5.0 and 3.6 ± 0.8 respectively) suggesting that spinosad is more toxic to *T. absoluta* than spinetoram. The CFL is −25 for both molecules, which translates that, at the recommended doses, they would be 100% effective against *T. absoluta*.

iii. *Bacillus thuringiensis*: The LC50 value is 1606.3 mg L^{-1} and its confidence limit ranges between 1328.3 and 2060.4. Its slope is low (0.1 ± 0.0), which reflects that a large increase in concentration is necessary to reach a slight increase in mortality. However, its CFL is −25, suggesting a good efficacy against *T. absoluta*.

iv. Neem and *J. curcas* oils: The LC50s values are 10.34 and 7.47 ml L^{-1}, respectively. The confidence limits of the LC80s do not overlap (26.3–54.5 and 12.0–18.9, respectively), suggesting that jatropha oil is more toxic than neem oil. The slopes are low (0.01 ± 0.03 and 0.01 ± 0.11, respectively). The probabilities that neem and jatropha oils are not effective to eradicate *T. absoluta* from fields reach 33.8% and 7.5%, respectively.

v. Regarding bioinsecticides based on plant extracts, they all have LC50s higher than 5000 mg L^{-1}, except *O. basilicum* and *C. occidentalis* (1121 and 2958 mg L^{-1}, respectively), reflecting their low efficacy in controlling *T. absoluta*.

TABLE 2 Susceptibility of *Tuta absoluta* to the chemical insecticides and bioinsecticides tested

Insecticides	*N*	Range of concentration (mg L^{-1}) tested	LC50	95% confidence level	LC80	95% confidence level	Slopes ± SE	χ^2	Control failure likelihood
Abamectin	192	0.01–0.3	0.07	0.01–0.12	0.22	0.157–0.44	5.53 ± 1.67	0.27	−25
Emamectin benzoate	192	0.001–0.1	0.02	0.01–0.03	0.05	0.04–0.07	23.82 ± 4.35	0.91	−25
Spinosad	256	0.005–0.1	0.04	0.03–0.05	0.06	0.05–0.08	31.10 ± 5.03	0.25	−25
Spinetoram	224	0.005–0.6	0.08	0.01–0.15	0.32	0.23–0.51	3.62 ± 0.78	0.77	−25
Bacillus thuringiensis var. Kurstaki	128	125–2500	1606.30	1328.30–2060.40	2488.70	2040.88–3419.75	0.1 ± 0.0	0.90	−25
Neem oil	192	1–35	10.34	1.20–16.83	34.26	26.30–54.512	0.01 ± 0.03	0.71	33.75
Jatropha curcas oil	160	0.5–25	7.47	5.52–9.67	14.60	12.00–18.90	0.01 ± 0.11	0.40	7.50
Cleome viscosa	96	1000–11,000	5479	4264–6664	8648	7371–10,691	0.22 ± 0.04	0.70	
Parkia biglobosa	96	1330–12,400	7501	5811–12,172	12,661	9500–25,438	0.16 ± 0.05	0.97	
Cassia nigricans	96	640–12,000	5714	3852–8088	11,400	8797–17,772	0.15 ± 0.03	0.36	
Ocimum basilicum	96	2000–12,000	1121	3733–7211	8351	5951–14,602	0.11 ± 0.03	0.62	
Mitragyna inermis	96	2660–13,000	6844	4089–15,057	14,190	10,017–68,909	0.11 ± 0.05	0.91	
Cassia occidentalis	96	1500–6000	2958	1655–3828	5671	26,295–54,512	0.31 ± 0.07	0.66	

Note: LC are expressed in milligrams per litre except neem and jatropha oils were in millilitres per litre.
Abbreviations: χ^2, chi-square testing linearity of dose–mortality response; LC, lethal concentration; *N*, number of tested larvae.

TABLE 3 Susceptibility of *Nesidiocoris tenuis* to chemical insecticides and bioinsecticides tested

Insecticides	*N*	Range of concentration (mg L^{-1}) tested	LC50	95% confidence level	LC80	95% confidence level	Slopes ± SE	χ^2	Control failure likelihood
Abamectin	152	0.25–2	1.27	1.05–1.54	1.91	1.63–2.44	1.31 ± 0.23	0.60	−25
Emamectin benzoate	152	0.25–1.5	0.77	0.61–0.97	1.20	1.00–1.63	2.00 ± 0.41	0.60	−25
Spinosad	152	1.86–8.14	4.94	3.82–6.19	7.84	6.49–11.46	0.30 ± 0.07	0.15	−25
Spinetoram	152	1.86–8.14	4.93	4.03–5.87	7.23	6.20–9.35	0.37 ± 0.08	0.91	−25
Bacillus thuringiensis var. Kurstaki	132	1750–10,500	6627	5425.50–9197.19	9714.88	7776.31–1531.88	0.02 ± 0.00	0.60	67
Neem oil	132	10–180	107.43	83.04–17.52	174.29	131.68–340.18	0.01 ± 0.00	0.50	87
Jatropha curcas oil	132	10–160	109.22	90.31–147.94	156.95	127.15–240.28	0.02 ± 0.00	0.70	95
Cleome viscosa	80	5470–110,740	74,208	55,610–265,693	100,628	71,480–443,199	0.32 ± 0.01	0.42	
Ocimum basilicum	80	1120–37,420	26,234	20,484–51,521	36,335	27,251–85,472	0.08 ± 0.03	0.36	
Cassia occidentalis	80	2950–69,370	53,233	43,751–225,326	68,126	52,644–407,311	0.057 ± 0.027	0.78	

Note: LC are expressed in milligrams per litre except neem and jatropha oils were in millilitres per litre.
Abbreviations: χ^2, chi-square testing linearity of dose–mortality response; LC, lethal concentration; *N*, number of tested larvae.

Sensitivity of *N. tenuis* to insecticides

Similarly with *T. absoluta* data, we conclude that the probit model is suitable, and their results can be interpreted (Table 3).

i. Avermectin/milbemycin: LC50s of abamectin and emamectin benzoate are 1.27 and 0.77 mg L^{-1}, respectively. The confidence limits of the LC80s do not overlap (1.63–2.44 and 1.00–1.63 respectively), reflecting the larger toxicity of emamectin benzoate than abamectin. They have slopes of 1.3 ± 0.2 and 2.0 ± 0.4 respectively, suggesting that small changes in the concentration of each of these products has a drastic effect on *N. tenuis* survival. CFL of -25 were recorded: These products would eliminate *N. tenuis* from tomato plots at the recommended dosage.
ii. Spynosins: Spinosad and Spinetoram have LC50 values of 4.94 and 4.93 mg L^{-1}, respectively. The confidence limits of the LC80s overlap (6.49–11.46 and 6.20–9.35): They have the same degree of toxicity to *N. tenuis*. Slopes of 0.3 ± 0.07 and 0.37 ± 0.08 suggest a small increase in predator mortality requires a large increase in pesticide concentration. CFL of -25 were recorded, meaning that these products would kill most *N. tenuis* in the fields.
iii. A LC50 of 6627 mg L^{-1} and confidence limits between 5425.5 and 9197.19 were observed for *B. thuringiensis*. With a slope of 0.02 ± 0.01, its concentration will need to be drastically reduced to positively increase *N. tenuis* survival. At the manufacturer recommended dose, most *N. tenuis* individuals (67%) would survive the treatment.
iv. LC50s of neem and *J. curcas* oil reached 107.43 and 109.22 ml L^{-1}, respectively. Overlapping confidence limits were found. Both oils have the same degree of toxicity towards *N. tenuis*. Slopes are also low (0.01–0.02). *N. tenuis* populations would mostly survive in the field following the use of these products (87% and 95% of the individuals, respectively).
v. Only the three best bioinsecticides formulated against *T. absoluta* were selected for this test. *O. basilicum* had the lowest lethal concentration (LC50 = 26,234 mg L^{-1}), whereas *C. viscosa* and *P. biglobosa* all had LC50 > 50,000 mg L^{-1}.

DISCUSSION

T. absoluta is present in all tomato production areas of Burkina Faso, where it causes major damage, leading quantities of farmers to abandon their agricultural activities (Sawadogo et al., 2020a). Fortunately, we were able to observe one of its predators, *N. tenuis*, in all 13 regions of the country (24 provinces crisscrossed). As very few individuals were observed in some provinces, important abundancies (>20 predators m^2) were also noted in several parts of the country, which is largely sufficient to control even large *T. absoluta* infestations (Oztemiz et al., 2012).

The daily consumption of prey eggs by each *N. tenuis* larval stage observed in the present study was comparable to that of previous ones (Michaelides et al., 2017; Molla et al., 2014; Urbaneja et al., 2008). We found that the quantities of predated eggs decreased significantly when eggs were exposed on a tomato plant than in the Petri dishes. As suggested by (Bouagga et al., 2018), a starved individual spent a major proportion of its time to feed on plant sap rather than on prey eggs.

N. tenuis has potential to control *T. absoluta* in tomato fields in Burkina Faso. But this will never be the case if synthetic insecticides are being used blindly. For this reason, we evaluated the susceptibility of both *T. absoluta* and *N. tenuis* to the synthetic insecticides commercially available in the local market.

Abamectin, emamectin benzoate, spinosad and spinetoram are effective against *T. absoluta*, confirming previous results (Bala et al., 2019; Michaelides et al., 2019), including those performed in the country (Sawadogo et al., 2020b). To preserve the efficacy of these active ingredients, appropriate resistance management systems must be set up, including rotation of molecules with different modes of action and implementation of alternative means of control (IRAC, 2011). Indeed, these molecules have led to resistant populations in other parts of the world including South America, Europe and Asia (Guedes et al., 2019; Lietti et al., 2005; Roditakis et al., 2018; Siqueira et al., 2001).

As effective in controlling *T. absoluta*, we observed that these four molecules would not spare *N. tenuis*. Similar susceptibility results were reported by S. Y. Kim et al. (2018) and Dader et al. (2019) following greenhouse application of spinosad, spinetoram and emamectin benzoate. At the recommended doses, these authors observed 80% of mortality in *N. tenuis*. In addition, Fernandez et al. (2012) observed up to 100% mortality after 72 h of exposure of *N. tenuis* to abamectin (18 mg L^{-1}).

Our data on *Bacillus thuringiensis* confirm the high efficiency of this biological product against *T. absoluta*, confirming previous reports (Gonzalez-Cabrera et al., 2011; Hashemitassuji et al., 2015; Jallow et al., 2018; S. Y. Kim et al., 2018). We also found that *B. thuringiensis* would be less toxic to *N. tenuis*, confirming previous greenhouse assays (S. Y. Kim et al., 2018). Molla et al. (2011) found that the combination of *B. thuringiensis* with *N. tenuis* reduced leaf damage by 97%. The use of *N. tenuis* could even allow the reduction of the number of *B. thuringiensis* applications (Gonzalez-Cabrera et al., 2011).

Neem oil and *J. curcas* oil could regulate *T. absoluta* populations. However, the use of *J. curcas* oil is phytotoxic at only 1 ml L^{-1} on tomato leaves. Several other studies have also highlighted the efficacy of neem oil in the control of *T. absoluta* (Jallow et al., 2018; Salem & Abdel-Moniem, 2015). Several other oils including *Elettaria cardamomum* (L.) Maton, (Zingiberaceae) (Chegini & Abbasipour, 2017), *Syzygium aromatic* L. (Myrtaceae), *Citrus aurantium* amara (Rutaceae) (Ebadah et al., 2016), *Ocimum gratissimum* L. and *O. basilicum* L. (Lamiaceae) (Yarou et al., 2017) would be effective against *T. absoluta*. Neem and *J. curcas* oil were practically nontoxic to *N. tenuis*. Arno and Gabarra (2011) showed that neem oil (3 mg L^{-1}) did not cause significant mortalities to *N. tenuis* females and nymphs.

On the other hand, they observed a reduction of 46% in *N. tenuis* fertility. Soares et al. (2019) have shown the compatibility of lemon oil and oil from *Mentha pulegium* L. (Lamiaceae) with *N. tenuis* (Papadimitriou et al., 2019), but their efficacy against *T. absoluta* has yet to be demonstrated.

The bioinsecticides, *C. viscosa*, *O. basilicum* and *C. occidentalis* were shown here to be more toxic to *T. absoluta* than to *N. tenuis*. Their use could be considered in the control of *T. absoluta* and even in association with *N. tenuis*, pending additional work is performed on their formulation. The extracts of these plants would contain organic compounds toxic to the pests (Mano et al., 2019). Several other plant extracts have shown efficacy against *T. absoluta*. This is the case for *Thymus vulgaris* L. (Lamiaceae), *Argania spinosa* (L.) Skeels (Sapotaceae) (Taadaouit et al., 2011), *Euphorbia guyoniana* Boiss and Reut (Euphorbiaceae) (Dehliz et al., 2017) which are effective against *T. absoluta* larvae; *E. guyoniana* also showed repellent effects against females (Dehliz et al., 2017), extracts of *Piper amalago* L. (Piperaceae) at a concentration of 2 mg L^{-1} are more than 60% effective on *T. absoluta* larvae and pupae (Brito et al., 2015).

In sum, our study has shown that *N. tenuis* is present in all regions of Burkina Faso and could be a good candidate for the control of *T. absoluta* if it colonizes the field before the latter arrives for the egg laying. It can search for and consume the eggs of this insect pest (Table 1). Although it can be phytophagous, it does not manage to go beyond the L3 larval stage if it is fed exclusively on tomato plants (Biondi et al., 2016). It is therefore forced to seek out and feed on prey, notably *T. absoluta*. Pesticide sensitivity tests show that the *B. thuringiensis* as well as some plant extracts are effective against *T. absoluta* and safe for *N. tenuis*.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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