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MANAGEMENT OF AN EMERGING PEST, *Tetranychus urticae* Koch (Acari: Tetranychidae), WITH PESTICIDES IN EASTERN ETHIOPIA

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ABSTRACT

Outbreak of two-spotted spider mite, *Tetranychus urticae* Koch*,* happened on potato (*Solanum tuberosum* L.) in eastern Ethiopia in 2014 and effective pesticides as part of IPM practice were sought from greenhouse and laboratory experiments at Haramaya University, Ethiopia. The objective of the study was to identify pesticides with the highest efficacy against the mite. Potatoes infested with mites were used in the efficacy trial. Treatments, 9 pesticides and a control, were applied 2 times at weekly intervals. Mites per leaf before and after each spray were counted. Promising pesticides were further screened with leaf-disc spray, and dip methods. Adult mortality was recorded after 24 and 48 hours. Chlorantrniliprole + Lambda-cyhalothrin, Amitraz, Profenofos, Profenofos "Q" 720 g l^{-1}, and Paraffin oil showed superior efficacy on eggs and mobile stages; though Paraffin's efficacy became clear 14 days later. Paraffin had the lowest mortality in leaf-disc sprays, but better mortality in the leaf-disc dip. This was attributed to complete wetting by the latter. Chlorantrniliprole + lambda-cyhalothrin, Profenofos, Profenofos "Q" and Paraffin were identified as promising pesticides for the two spotted spider mite management on potato.

Key Words: Pesticides, potato, two spotted spider mite

RÉSUMÉ

L'explosion de tétranyque à deux points, *Tetranychus urticae* Koch, s'est produite sur la patate (*Solanum tuberosum* L.) dans l'Est de l'Ethiopie en 2014 et des pesticides effectifs comme une partie de de pratique IPM a été recherchée à partir des expérimentations sous serre et au laboratoire à l'Université de Haramaya, Ethiopie. L'objectif de l'étude était d'identifier les pesticides avec de très grande efficacité contre le tétranyque. Les patates infestées avec les tétranyques ont été utilisées dans un essai d'efficacité. Les traitements, 9 pesticides et un contrôle, étaient appliqués deux fois à des intervalles d'une semaine. Les tétranyques par feuille ont été comptés avant et après chaque traitement. Des pesticidesprometteurs ont été égalementévalués avec le pulvériseur à disque sur les feuilles, et les méthodes d'immersion. La mortalité de l'adulteétait evaluée après 24 et 48 heures. Chlorantrniliprole + Lambda-cyhalothrin, Amitraz, Profenofos, Profenofos "Q" 720 g l^{-1}, et l'huile du Paraffine ont montré une efficacité supérieure sur les œufs, stages mobiles ; quoique l'efficacité de paraffine est devenue claire à 14 jours après. Paraffine a eu la plus faible mortalité avec le pulvériseur à disque sur la feuille, mais meilleure mortalité avec l'immersion de la feuille. Ceci a été attribué à la mouillure complète de la deuxième méthode. Chlorantrniliprole + lambda-cyhalothrin, Profenofos, profenofos "Q" et Paraffine ont été identifiés comme pesticide prometteurs, pour la gestion du tétranyque à deux points sur la tomate.

Mots Clés: Pesticides, patate, tétranyque à deux points

INTRODUCTION

Potato (*Solanum tuberosum* L.) is an important crop in eastern Africa, and is currently grown on about 179,159.27 ha, with an average yield of 8.9 t ha^{-1} (CSA, 2014) in Ethiopia. Higher potato yields in Eastern Ethiopia than the national average is testament to the potential of high potato yields in the area. Potato production in Ethiopia is constrained by unfavourable climatic and edaphic conditions, in addition to a range of biotic factors. Poor quality seed tuber (Bezabih and Mengistu, 2011; Labarto, 2013), low yielding potato varieties, and insect pests and diseases (Ferdu *et al*., 2009) are among the biotic factors.

Potato germplasm are often imported from external sources to improve the genetic potentials in the country, and presently 25 to 40 potato materials are imported every year (Dereje and Gebremedhin, 2013). Recent pest risk analysis on imported potato germplasm from Netherlands, Peru, Uganda and Kenya identified 61 arthropods, 48 nematodes, 41 fungi, 14 bacteria, 24 viruses and 59 weeds as quarantine pest species for Ethiopia (Dereje and Gebremedhin, 2013). *Orthezia insignis,* for example, recognised as a quarantine insect of potato by Dereje and Gebremedhin (2013), is now present on *Lantana camara* in many parts of Ethiopia. It might be possible that *O. insignis* crossed borders from neighbouring Kenya, or might have been introduced with planting materials, thus making the threat of introduced pests and diseases certain, if precautions are not taken and a robust surveillance system put in place.

The two-spotted spider mite (TSSM)*, Tetranychus urticae*, is a serious pest on roses (Belder *et al*., 2009), tomato (Gashawbeza *et al*., 2009), and was earlier reported on pigeon pea in central Ethiopia (Tsedeke, 1987). Outbreaks of TSSM infestation on potato occurred in the main season of 2014, on farmers' fields, in limited localities of eastern Ethiopia (Muluken *et al*., 2016).

By 2015, the pest expanded its geographic distribution and covered the main potato growing districts of eastern Ethiopia and caused significant yield losses on farmers' fields, experimental plots and seed multiplication sites (Muluken *et al.,* 2016). It was not, however, confirmed whether it was a new introduction, or if the previously reported colony of *T. urticae* by Tsedeke (1987) spread to eastern and northern Ethiopia. Infestation was also evident on wild host plants, *viz.,* wild Solanaceous plants like *Datura stramonium* L. and *Solanum elaeagnifolium* Cav. (Muluken *et al*., 2016).

The list of attacked plant species may increase as TSSM is known for being polyphagous and feeds on over 1,100 plant species, belonging to more than 140 plant families (Grbic *et al*., 2011). The two-spotted spider mite problem became serious in the 2015 meher season, when there was shortage of rain. Many researchers believe that detrimental effects of spider mites in agriculture increases with intensifying global warming (Migeon *et al.,* 2009).

Pesticide use has become the first line of defense against insect pests in eastern Ethiopia. Vegetable growers in the central rift valley of Ethiopia observed a decline in efficacy of pesticides used against TSSM on crops such as tomato (Belete and Getahun, 2015). Following the first outbreak of TSSM in the major potato belt of eastern Ethiopia, farmers used insecticides available in the market; though, with limited success. This led to a complete failure of the crop in the area in 2014 and 2015 (Muluken *et al*., 2016). In Ethiopia, most of the insecticides available in the market for managing vegetable insect pests are broad-spectrum organo-phosphates, carbamates and pyrethroids (Anon, 2015). The population of TSSM in eastern Ethiopia is believed to have developed resistance to these groups of insecticides (Muluken *et al*., 2016), yet globally *T. urticae* is known for its ability to develop rapid resistance to pesticides (Van Leeuwen *et al*., 2010). Rapid population development, high fecundity and haplo-diploid sex determination were the factors that facilitated rapid evolution of pesticide resistance in two-spotted spider mite (Grbic *et al.*, 2011). Nevertheless, although chemical use constitutes one of the components of an integrated pest management, miticides/ insecticides that can effectively control TSSM need to be identified and used in a way that decelerate resistance development.

In Ethiopia, there are registered miticides for mite control in flowers, tomatoes, strawberry and cotton (Anon, 2014). Many insecticides also have acaricidal properties, and some are even more toxic to mites than to insects (Hoy, 2008). In India, mineral oils suppressed mite populations within short periods of time (Prasad *et al.*, 2008). However, in Ethiopia, none of the registered miticides were tested on potato, as it was only recently that TSSM was observed on this crop. The objective of this study was to screen the available miticides, insecticides and mineral oils against the TSSM, to identify those with the high efficacy and available to farmers so that they use the right product for controlling the mite pest.

MATERIALS AND METHODS

Study environment. The study was conducted at the Plant Protection Research Laboratory and greenhouse of Haramaya University in Ethiopia.

Source of *Tetranychus urticae.* A population of TSSM, *T. urticae,* was obtained from wild solanaceous plants and was maintained on young haricot bean plants (*Phaseolus vulgaris* L) grown indoors. Young bean plants were provided at weekly intervals to maintain the populations of TSSM.

Pesticides. Nine pesticide treatments, along with water as the control, were used (Table 1). One miticide (Amitraz), six insecticides (Chlorantroniliprole, Chlorantrniliprole + l-cyhalothrin, Spinosad, Flubendiamide, Profenofos, and Profenofos "Q" 720 g L^{-1}), Paraffin oil (pharmaceutical grade), Liquid detergent (Bright Becas) and water were

TABLE 1. Pesticide treatments and their application rates.

Trade name	Common name	Chemical group	Rate per ha	Rate per (µL) plant
Mitac 20 EC	Amitraz	Amidine	2.5 L	60
Coragen 200 Sc	Chlorantroniliprole	Diamides	250 mL	5
Ampligo 150 ZC	Chlorantrniliprole+λ-cyhalothrin	Diamides+pyrethroid	300 mL	7
Tracer 480 SC	Spinosad	Spinosyn	300 mL	7
Belt SC 480	Flubendiamide	P.A.diamides*	120 mL	5
Profit 72 EC	Profenofos	Organophosphate	1.0 L	25
Selecron	Profenofos "Q" 720 g l^{-1}	Organophosphate	1.0 L	25
Paraffinic oil	Paraffin	Petroleum oil	2.5%	2.5
Liquid detergent	Bright Bekas	—	2.0%	2.0
Control	Water	—	Untreated	Untreated

*P.A. = Phthalic Acid

included. The manufacturer's rates were employed for the registered pesticides; while 2.5% of paraffin oil and 2.0% liquid detergent were used.

Efficacy of pesticides in greenhouse. Sprouted potato tubers of variety Gudene, were planted individually in pots of dimensions18 cm long, 20 cm and 14 cm diameter at top and bottom, respectively. Standard nursery soil composed of silt, sand and manure in a 2:1:1 ratio was used. Ten treatments (Table 1) considered in this experiment were replicated three times, in completely randomised design.

Three weeks after emergence, potato plants were inoculated with TSSM infested potato leaves. To ensure uniform and quick infestation of the experimental potato plants in the greenhouse, two successive inoculations using three infested leaves at daily intervals were made. Treatments were mixed with tap water to a volume of 100 ml for application onto individual plants.

Mite and egg counts, under a stereomicroscope, were performed on three leaf samples taken from different parts of the plant, before and after the first, second and third sprays were administered at weekly intervals.

Evaluation of pesticides with leaf dip bioassay. Aqueous dispersions of commercial pesticide formulations (Amitraz, Chlorantrniliprole+λ-cyhalothrin, Profenofos, Profenofos "Q" 720 g L^{-1}, Paraffin oil and control) were used in a leaf dip bioassay (Cahill *et al.*, 1995). A 4 cm x 4 cm sized bean leaf disc (Recep, 2005), with 20 TSSM adults, was dipped for 5 seconds in 100 ml aqueous solution of the pesticide on petri-dishes; while the control was dipped in 100 ml of tap water.

Treated leaves were placed on wet cotton wool, surrounded by moistened tissue paper inside Petri-dishes; and then placed at room temperature. Treatments were arranged in a completely randomised design, with four replications. Toilet tissue paper was moistened with distilled water whenever it dried. Mortality of TSSM was recorded at 24 and 48 hr after treatment. Mites were considered dead when appendages did not move when probed with a fine paint brush.

Evaluation of pesticides with leaf disc spray. Aqueous dispersions of the five pesticides (five pesticides) were used in a leaf disc spray method to evaluate pesticides efficacy (Helle and Overmeer, 1985). Twenty adult TSSM were placed onto each 4 cm x 4 cm sized leaf disc (Roopa, 2005) on wet cotton wool, surrounded by moistened tissue paper in petri-dishes. Toilet tissue paper was moistened with water when dried. Leaf discs containing twenty adult TSSM were treated with five compressions (0.5 mL) of the pesticide in a spray bottle, from a distance of 20 cm and an angle of 90 degrees. The sprayed leaf discs inside the petri-dishes were kept at room temperature (25 °C) in the laboratory.

Treatments were also arranged in a completely randomised design, with four replications. Numbers of dead or alive adults were recorded under a dissecting microscope at 24 and 48 hr after treatment. Again, mites were considered dead when appendages did not move when probed with a fine brush.

Data collection. The numbers of dead adults and immatures recorded from the greenhouse and at the laboratory experiments were converted into percentage mortality. Pre- and post-spray counts of eggs, immatures and adults per leaf were also recorded from the greenhouse experiment, and the reduction in infestation (efficacy %) was computed following Henderson and Tilton (1955) equation. Any change in colour and texture of leaves due to probable phytotoxicity of the pesticides and plant mortality, due to the tested pesticides, were recorded. Percent mortality was corrected using Abbott's formula (Abbott, 1925) as follows:

% Corrected Mortality =

$$\frac{(\%\ \text{mortality in the treatment} - \%\ \text{control mortality})}{(100 - \%\ \text{control mortality})} \times 100$$

Percent reduction in infestation (% efficacy) of mites was calculated using Henderson and Tilton, 1955 Equation:

Reduction (%) =

$$\left(1 - \frac{n \text{ in Co before treatment} \times n \text{ in T after treatment}}{n \text{ in Co after treatment} \times n \text{ in T before treatment}}\right) \times 100$$

Where:

n = number, Co = Control and T = Treatment

Data analysis. Efficacy expressed as a percentage of the pesticides generated using Henderson and Tilton (1955) formula, was neglog transformed (Whittaker *et al.*, 2005) and subjected to analysis of variance GLM procedure, using IBM SPSS Statistics version 20 (IBM SPSS, 2011). Mite counts before and after sprays were analysed using the repeated measurement procedure of GenStat 12.1 (GenStat, 2009). Mite mortality values from the laboratory experiments were adjusted with logistic transformation (Johnson, 1949) and subjected to analysis of variance (ANOVA).

As control mortality was less than 10%, there was no need to correct the values with Abott's formula (Abbott, 1925). Mean separation was done using the Least Significant Difference (Snedecor and Cochran, 1980).

Logistic $p = \log(p / (100 - p))$ for percents,

Where:

p is a proportion or percent (Johnson, 1949)
Neglog = sign (x) ln (|x| + 1) (Whittacker *et al.*, 2005)

RESULTS

Greenhouse. The efficacy of pesticides against adults and eggs of TSSM in the greenhouse was highly significant (Table 2).

Efficacies of above 97% on adults recorded for Amitraz, Chlorantrniliprole+λ-cyhalothrin, Profenofos, Profenofos"Q" 720g l^{-1}, and Paraffin oil, were significantly different from the control, Chlorantroniliprole and Flubendiamide (Table 2). Negative efficacy and eventual plant death, similar to the control, was noted in Flubendiamide. Spinosad and liquid detergent had fair efficacy, though could not protect potato plants from TSSM. Potato leaves were, however, killed by liquid detergent, indicating phyto-toxicity of this material. Illustrations depicting the effect of the pesticides on the mites and growth of the potato plants are presented in Figure 3.

Differential efficacy among pesticides against eggs of TSSM were also recorded (Table 2). Chlorantrniliprole+λ-cyhalothrin, Profenofos, Profenofos"Q" 720g l^{-1}, and Paraffin oil showed greater than 99% efficacy, which was significantly different from control and liquid detergent. Chlorantroniliprole, Spinosad and Flubendiamide, on the other hand, had efficacy in the range of 86.7-91.7%; while Amitraz had low efficacy, not significantly different from the control and liquid detergent. As for the combined effects of the pesticides against the adults and eggs of the TSSM, four pesticides (Chlorantrniliprole+ λ-cyhalothrin, Profenofos, Profenofos"Q" 720g l^{-1}, and Paraffin oil) had high and consistent efficacies against the mobile stages and eggs of TSSM. Amitraz was effective in killing the mobile stages while having lower efficacy against egg. Liquid detergent acted similar to Amitraz. Although chlorantroniliprole, had very good action against the eggs, it was ineffective against the adults and the nymphs. Spinosad had a similar tendency to that of Chlorantroniliprole. Negative efficacy was noted for Flubendiamide.

Data for number of TSSM adults and nymphs were also monitored over a three weeks period before and after the application of pesticides, and are presented in Figure 1. Mite populations during the three time periods

TABLE 2. Efficacy of the pesticides against eggs, immature and adults of TSSM in a greenhouse

Treatments	Percent efficacy against	
	Adults and immature*	Eggs*
Amitraz	97.7 (4.6)	30.0(1.5)
Chlorantroniliprole	5.9 (1.1)	91.7(4.5)
Chlorantrniliprole+ λ-cyhalothrin	100.0 (4.6)	100.0 (4.6)
Spinosad	60.1 (3.3)	86.7(4.5)
Flubendiamide	-59.3 (-1.7)	91.7(4.5)
Profenofos	99.8 (4.6)	100.0(4.6)
Profenofos"Q" 720 g l^{-1}	99.9 (4.6)	99.3(4.)
Paraffin oil	99.9 (4.6)	100.0 (4.6)
Liquid detergent	78.2 (4.3)	-10.0 (-1.1)
Control	0.0 (0.0)	0.0(0.0)
CV (%)	80.3	59.8
LSD (0.05)	4.1	3.3

Numbers in parenthesis are the Neglog transformed values, CV = coefficient of variation; LSD = least significant difference.

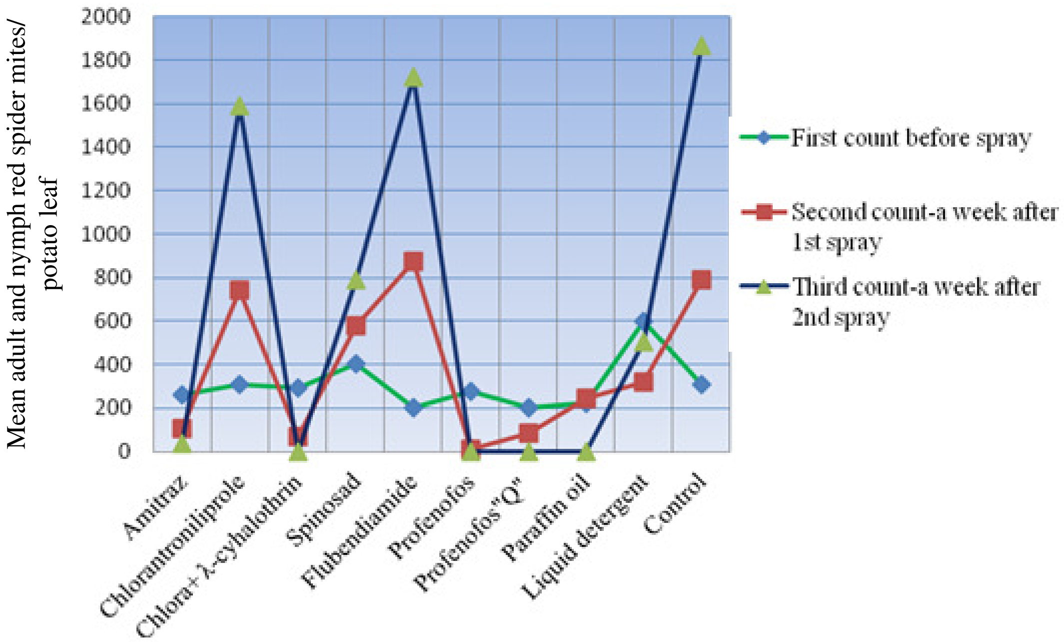

Figure 1. Adult mite population dynamics after treatment with pesticides over a three week.

(1st count before spray, 2nd count after 1st spray and 3rd count after second spray) and the interactions of the three periods with the treatments were significantly different (P<0.05). The TSSM adult and nymph population was suppressed one week after the application of Amitraz, Chlorantrniliprole+ λ-cyhalothrin, Profenofos and Profenofos"Q".

The population of the mobile stages were however, not suppressed and instead remained constant with Paraffin oil one week after the first spray. The effect of paraffin oil became equaled to that of Amitraz, Chlorantrniliprole+ λ-cyhalothrin, Profenofos and Profenofos"Q" 720 g l^{-1} after the second spray as they all suppressed the mite population. The mite population, however, was not checked in the second and third weeks after applications of Chlorantroniliprole, Spinosad, Flubendiamide and Liquid detergent.

The eggs of TSSM monitored over a three week period, at a weekly intervals, following the application of the pesticides revealed variable responses (Fig. 2). Mite egg counts during the three time periods (1st count before spray, 2nd count after 1st spray and 3rd count after second spray) and the interactions of the three periods with treatments were significantly different (P<0.001). Chlorantrniliprole +λ-cyhalothrin, Spinosad, Profenfos, Profenfos "Q", and Paraffin oil decimated red spider mite eggs considerably a week after the first spray, and had their final impact following the second spray. Amitraz and Chlorantroniliprole had reduced the number of TSSM eggs to some extent. Mite eggs at Flubendiamide, treated plants were comparable to that of the control a week after the first spray. After the second spray, however, a number of pesticides reduced mite eggs drastically.

Laboratory

Evaluations of pesticides with leaf dip bioassay. Mortality of TSSM adults in a leaf disc dip method due to the selected pesticides in the laboratory yielded highly significant differences (Table 3). All pesticides had high mortalities on TSSM adults (24 hr later) that were significantly higher than the control

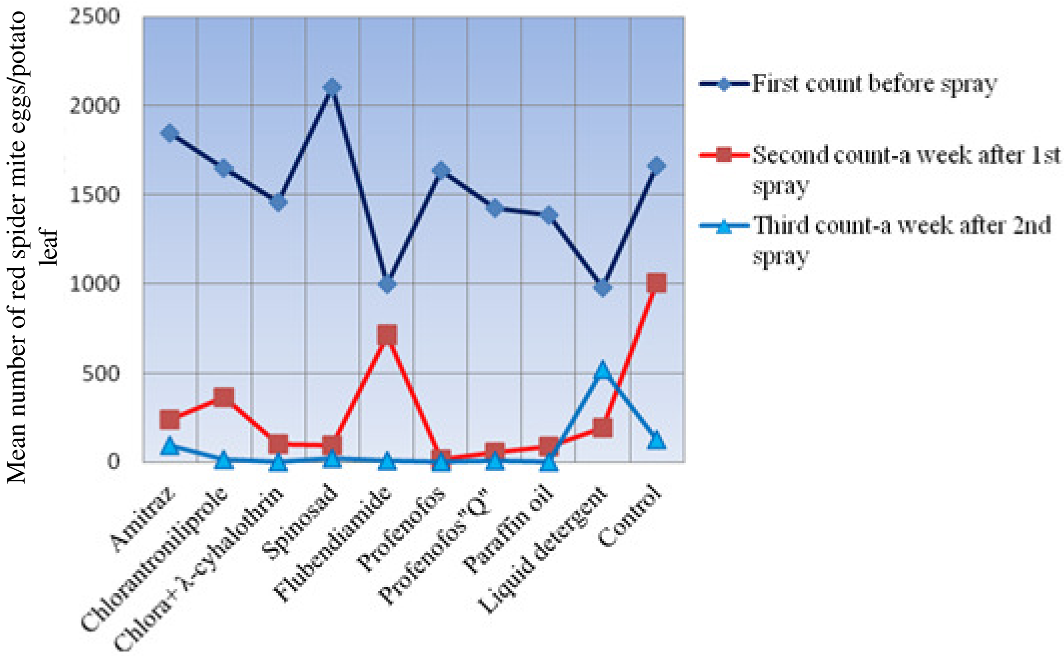

Figure 2. Red spider mite egg counts in treated plots over a three week period.

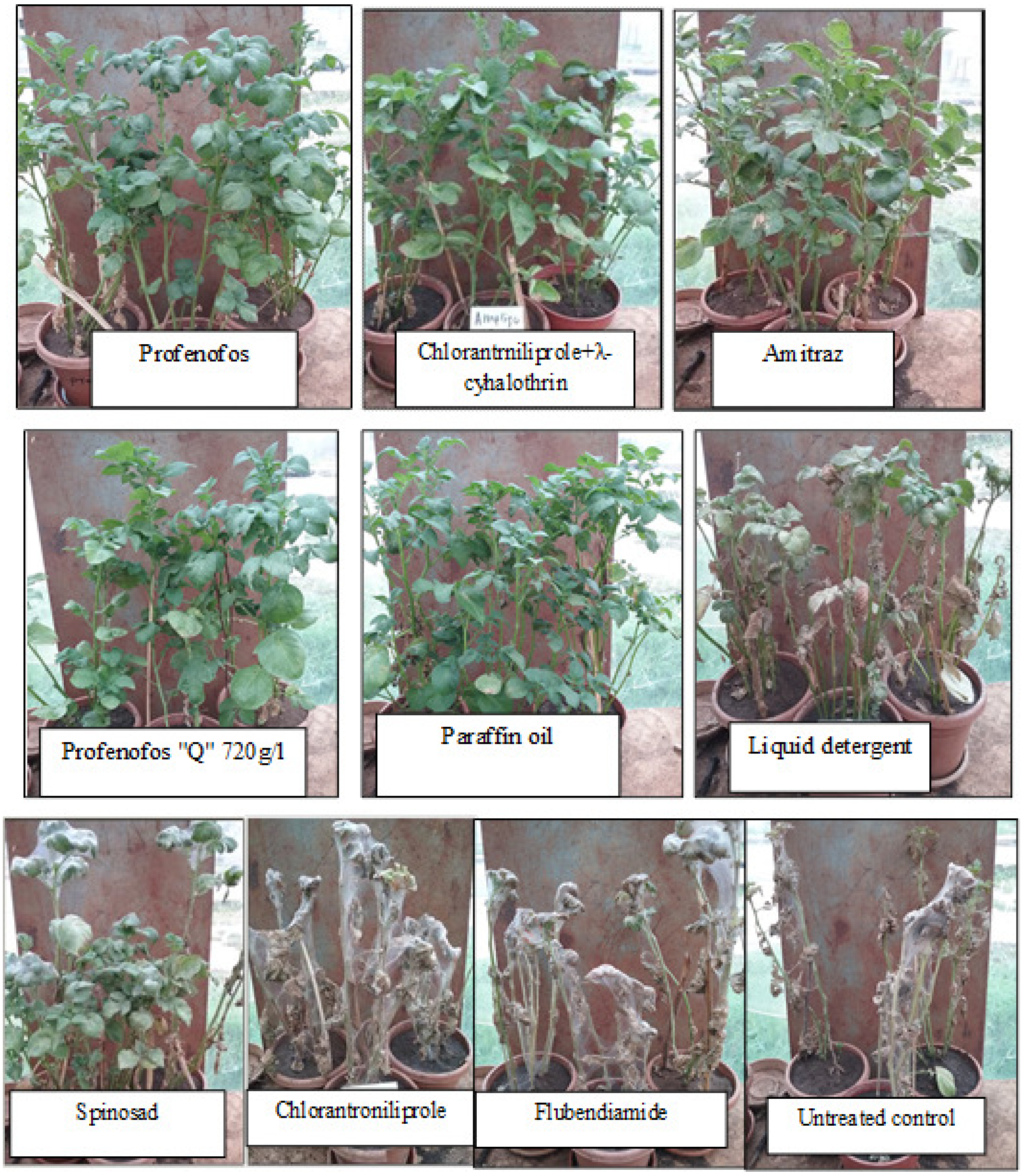

Figure 3. Pictorial efficacy of treatments after three weeks.

(Table 3). The mortality due to Paraffin oil was lower than Amitraz, Chlorantrniliprole+λ-cyhalothrin, Profenofos, and Profenofos”Q”. At 48 hr, however, all pesticides had mortalities significantly different from the control, though the magnitude was slightly lower for paraffin oil. Comparing the suitability of the leaf disc spray and dip as methods of testing effectiveness of pesticides against the TSSM, it was found that the leaf disc dip method was more robust in showing quick results though there was the possibility that mites could get dislodged and fall in the solution during dipping.

TABLE 3. Mortality of TSSM adults due to the pesticides in the leaf disc dip method

Pesticide	Mortality after 24 hr	Mortality after 48 hr
Amitraz	99.90 (3.00)	99.90 (3.00)
Chlorantrniliprole+ λ-cyhalothrin	99.90 (3.00)	99.90 (3.00)
Paraffin oil	89.50 (1.30)	96.46 (2.21)
Profenofos	99.90 (3.00)	99.90 (3.00)
Profenofos"Q" 720g l^{-1}	99.90 (3.00)	99.90 (3.00)
Control	2.54 (-2.29)	4.87 (-1.87)
CV (%)	30.9%	30.0
LSD (0.05)	0.742	0.804

TABLE 4. Mortality of red spider mite due to the pesticides from a leaf disc spray

Pesticide	Mortality after 24 hrs	Mortality after 48 hrs*
Amitraz	98.92 (2.66)	99.90 (3.0)
Chlorantrniliprole+ ë-cyhalothrin	98.92 (2.66)	99.90 (3.0)
Paraffin oil	8.00 (-1.08)	16.00 (-0.8)
Profenofos	99.90 (3.00)	99.90 (3.0)
Profenofos"Q" 720 g l^{-1}	98.92 (2.66)	99.90 (3.0)
Control	5.02 (-1.56)	7.00 (-1.2)
CV (%)	46.3	9.50
LSD (0.05)	0.839	0.21

Numbers in parenthesis are the logistic transformed values, CV = coefficient of variation; LSD = least significant difference

Evaluation of pesticides with leaf disc spray. Mortality of TSSM adults in a leaf disc spray method due to the selected pesticides yielded highly significant differences (Table 4). Amitraz, Chlorantrniliprole+ λ-cyhalothrin, Profenofos, and Profenofos"Q" produced mortality of above 98% 24 hr after treatment that was significantly different from Paraffin oil and the control (Table 4). Paraffin oil was at par with the control.

For the effective pesticides, mortality was raised to 99.9% 48 hr later. Though significantly lower than the best pesticides, mortality by paraffin oil was doubled 48 hrs later.

DISCUSSION

Greenhouse. The results obtained from the efficacy test in the greenhouse (Table 2) showed that Amitraz, Chlorantrniliprole+ λ-cyhalothrin, Profenfos, Profenfos "Q" and Parrafin oil gave excellent control of the TSSM adults and nymphal stages. All the treatments listed above, except Amitraz, also demonstrated superb control effect on the TSSM eggs. Poor efficacy of Amitraz against eggs of the TSSM (Table 2) obtained in this study might imply that the eggs of TSSM are less susceptible to Amitraz and the finding seems to agree with Aveyard *et al*. (1986) who reported eggs of

Tetrananycus becoming less susceptible to an acaricide as they mature though in this study we did not consider the age of the TSSM eggs.

Disparity in efficacy against the mobile stages (adult and immature) of TSSM between Chlorantrniliprole and Chlorantrniliprole+λ-cyhalothrin might also be due to synergistic effects because a separate treatment with Chlorantrniliprole proved not effective. Mite outbreaks are often implicated with use of pyrethroids due to resistance development (Zhan *et al*., 2013). Similarly, field populations of *Tetranychus urticae* became resistant to λ-cyhalothrin while being susceptible to other products (Eziah *et al*., 2016). On the other hand, Chlorantrniliprole+λ-cyhalothrin registered for the management of *Tuta absoluta* in Ethiopia gave excellent control of TSSM and it might have been tried on a mite pest for the first time. We found neither literature on studies that tried this product on mite pest nor were mite pests listed on the product information sheet for Chlorantrniliprole + λ-cyhalothrin (Anon, 2017).

Excellent control of TSSM mobile and egg stages with Profenofos and Profenofos "Q", registered as insecticides in Ethiopia for the control of pea aphids on field pea and maize stalk borer on maize, respectively, achieved from this study suggest their significance for mite management. In fact Profenofos and Profenofos "Q" are known for their acaricidal effects (Venugopal *et al.,* 2003; Rabea, 2009).

Efficacy of paraffin oil against the mobile and egg stages of TSSM was at par with the commercial grade pesticides, such as Chlorantrniliprole+ λ-cyhalothrin, Profenofos and Profenofos "Q" (Table 2). The population of mobile stages of TSSM, however, remained stagnant a week after the first paraffin oil spray and was only decimated with the second paraffin oil spray (Fig. 1).

The impact of paraffin oil spray on the eggs of TSSM was observed a week after the first spray (Fig. 2) and this indicates that paraffin oil had a greater and quicker impact on the eggs than on the mobile stages. It also meant that TSSM eggs fixed on potato leaves with webs can be easily wet with the first paraffin oil spray than the mobile stages that required a second spray to see its impact. Complete wetting of the target pest is required for the paraffin oil spray to take effect as it is associated with its modes of action (hypoxia). Paraffin oil was not tried in Ethiopia against TSSM, but in other parts of the world it is commonly used against soft scales on citrus (Muegge and Merchant, 2000) and is also known for having miticidal effects (Prasad *et al.,* 2008). In fact, medopaz (80% paraffin oil) is the only closely related product to paraffin oil registered in Ethiopia for the control of red, Orange, Purple and Black scale on citrus (Anon, 2015).

As paraffin oil belongs to a category of mineral oils, there are no reported cases of resistance and that was associated with their mode of action (Willett and Westigard, 1988) and/or their relatively low selection pressure against pests (Fernandez *et al*., 2005). Paraffin oil, therefore, holds the potential for integration with other methods like its inclusion in a pesticide rotation scheme, provided that its application is correctly timed.

Negative efficacy against the mobile stages recorded for Flubendiamide (Table 2) indicated that the insecticide favoured increase of mite population that eventually led to whole plant death. Elevated TSSM population might have resulted from Flubendiamide-induced fecundity increase. Several studies indicated a significant increase in fecundity of TSSM, after application of neonicotinoids such as imidacloprid (James and Prince, 2002) and thiamethoxam (Smith *et al*., 2013).

These results are in agreement with our findings. The mechanisms related to increase in fecundity of TSSM under pesticide pressure are due to hormolygosis (James and Price, 2002; Castagnoli *et al*., 2005), changes in mite physiology such as increase in production of vitellin (eggs) (Zeng and Wang, 2010) or changes in physiology of host plants that favor increased mite reproduction (Hardin *et al*., 1995)

The relative effectiveness of Chlorantrniliprole and Flubendiamide on eggs than on the adults (Table 2) observed in this study will not make these insecticides suitable components of TSSM management on potato. But both insecticides are recommended for tomato leaf miner (*Tuta absoluta*) control (Anon, 2015) and as TSSM can also attack tomato, these insecticides applied against tomato leaf miner might have some impact on the eggs of TSSM. Moderate efficacy of Spinosad, especially against the eggs might also indicate its benefit when applied for tomato leaf miner control on tomato or potato.

Laboratory. TSSM mortality results for the pesticides obtained from the leaf disc spray and dip methods were comparable except with paraffin oil. Significant mortality of TSSM adults obtained with the pesticides following leaf disc spray and dip methods, except paraffin, indicated that these pesticides can become components of an integrated mite management system.

Effect of paraffin oil on TSSM adults was only observed with the leaf disc dip method and that meant paraffin oil needs complete wetting of the target pest. Higher mortality of TSSM with leaf disc dip method than in the leaf disc spray could be related to mode of action of oils. Oils kill insects and mites by blocking spiracles, thus reducing availability of oxygen and interfering with various metabolic processes (Flint, 2014).

Delayed effects of paraffin oil on the adults in the greenhouse trial might also be because of attainment of complete coverage of the target with the second spray. Leaf disc dip method ensured more complete wetting of the leaf and the mites on it compared to the leaf disc spray and might be the reason for the elevated mortalities in the leaf dip.

CONCLUSION

From this study, Amitraz, Profenofos, Profenfos"Q", Chlorantrniliprole+ λ-cyhalothrin and paraffin oil are identified as promising pesticides for the management of TSSM on potato. No phytotoxic effects are displayed by those pesticides. The leaf disc dip method guarantees the real effects of certain pesticides better than the leaf disc spray. Amitraz, Profenofos, Profenofos"Q", Chlorantrniliprole+ λ-cyhalothrin and paraffin oil need to be included in future field investigations before their large scale use.

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