Acta
Entomology and Zoology

E-ISSN: 2708-0021
P-ISSN: 2708-0013
www.actajournal.com
AEZ 2025; 6(1): 07-16
Received: 08-11-2024
Accepted: 12-12-2024

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Knowledge, perceptions and management practices for *Tuta absoluta* (lepidoptera: Gelechiidae) on tomato in Botswana

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DOI: https://doi.org/10.33545/27080013.2025.v6.i1a.183

Abstract
A survey was conducted to investigate farmer's knowledge, perceptions and management practices for the tomato leaf miner, *Tuta absoluta* on tomato. 200 active tomato farmers were interviewed using a structured questionnaire from October 2023 to March 2024. The study revealed that tomato growers considered *T. absoluta* among the most economically devastating tomato pests in Botswana. The respondents demonstrated good knowledge of the pest and the type of damage it inflicts. The farmers reported that the moth pest reduces yields, affects the quality of tomatoes and increases their cost overruns. Infested fruits are rejected at the market leading to intolerable financial losses. Synthetic insecticides are favoured over all other control measures to manage invertebrate pests on their crops, and their action is not based on any threshold levels. Excessive amounts are applied in desperation to control the pest. The farmers lamented that *T. absoluta* is becoming increasingly difficult and expensive to control with conventional insecticides which they attribute to resistance development. There is a need for strict regulation on the importation and use of insecticides. Farmers should be trained on appropriate application of insecticides. Integrated pest management for the control of vegetable pests should be inculcated into farming systems. Pest control strategies should involve monitoring through the use of pheromone traps to delay resistance development and evade the undesirable consequences posed by insecticides.

Keywords: *T. absoluta*, tomato leaf miner, knowledge, perceptions, insecticides, tomato.

Introduction

Tomato, *Solanum lycopersicum* L. (Solanales: Solanaceae) is a leading commercial vegetable crop worldwide (Mojeremane *et al*. 2016) [1]. It is an important vegetable crop in Botswana (Materu *et al*. 2016; Baliyan and Rao, 2013) [2, 3] with numerous health benefits which are attributed to its phytochemical composition (Perkins-Veazie, 2006) [4]. It is a rich source of vitamins, minerals, and fibre, and a dietary source of antioxidants therefore playing an essential role in ensuring nutrition security (FAO, 2020; Hedges and Lister, 2015) [5, 6]. Tomato is produced by smallholder growers and commercial farmers for the market, serving mainly as a commercial crop. Commercial production of tomatoes is undertaken in open fields, shade nets, and tunnels in many parts of Botswana. Estimated at 60-100 tonnes per hectare, tomato production and productivity in Botswana is very low when compared to major tomato-producing countries in Africa (Badimo, 2020; Dube *et al*. 2020) [7, 8]. In an attempt to increase tomato production, the government of Botswana introduced a vegetable import ban on 1st January 2022. However, tomato production persistently remains low due to attacks by many invertebrate pests which include the African bollworm (*Helicoverpa armigera*), spider mites (*Tetranychus spp.*), whitefly (*Bemisia tabaci*), cutworm (*Agrotis* spp.), tomato semi-looper (*Chrysodeixis acuta*) and tomato leaf miner *(T. absoluta)* (Leungo *et al*. 2012; Madisa *et al*. 2010; Munthali 2009; Obopile *et al*. 2008) [9-12].

The tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is a major invasive lepidopteran pest of tomato (Machekano *et al*. 2018; Brévault *et al*. 2014) [13, 14]. It is considered to be among the most important and devastating pests of tomato in the world (Rwomushana *et al*. 2019; Mutamiswa *et al*. 2017) [15, 16]. *Tuta absoluta* originates in South America and was first documented in Spain in 2006 (Desneux *et al*. 2011) [17] before rapidly spreading to the rest of the world (Visser *et al*. 2017; Brévault *et al*. 2014) [18, 19]. *Tuta absoluta* was first reported in Botswana in 2017 (Mutamiswa *et al*. 2017) [16].

When it caused an acute shortage of tomatoes in the market (Seepi, 2017) [20]. At high infestations, *T. absoluta* is very destructive to tomato plants and fruits often causing up to 100% yield losses in the absence of control interventions (Ogutu, 2021) [21]. *T. absoluta* has an extensive host plant range and has been documented to infest solanaceous plants including potato (*Solanum tuberosum* L.), eggplant (*Solanum melongena* L.), pepper (*Capsicum annuum* L.) and tobacco (*Nicotiana tabacum* L.) (Mutamiswa *et al*. 2017; Ferracini *et al*. 2012) [16; 22].

The damaging larval stage of *T. absoluta* feeds on the foliage causing a disruption in the photosynthetic efficiency of the plants, stunting the growth, and reducing yields (Mahlangu *et al*. 2022; Sperdouli *et al*. 2021) [23, 24]. *T. absoluta* attacks tomato plants in all their developmental stages, however, severe damage is inflicted on young seedlings often leading to death (Mkonyi *et al*. 2020; Zekeya *et al*. 2017; Guimapi *et al*. 2016) [25-27]. In addition, open wounds on the tissues caused by feeding larvae serve as entry points for pathogens. The larvae also cause irreversible damage to fruits leading to a reduction in marketability of tomatoes, often causing rejection of entire tomato produce and consequently severe financial losses. The movement of infested tomato produce, during import and export, is possibly one of the major reasons for its global invasion. *T. absoluta* has been documented to spread over extensive geographical distances in a short space of time (Desneux *et al*. 2011) [17].

The mine feeding behaviour of *T. absoluta* makes its control very difficult with synthetic insecticides, since most cannot penetrate through the leaf epidermis. The unjustified and excessive application of insecticides has accelerated its development of resistance to most synthetics developed for its control all over the world (Ongónge *et al*. 2023; Guedes *et al*. 2019; Roditakis *et al*. 2015; Bu *et al*. 2015) [28-31]. Although insecticides are considered an irreplaceable tool for achieving nutrition security for a growing world population, their unselective application has negative environmental and human health consequences (Rani *et al*. 2021; Bernardes *et al*. 2015) [32, 33].

Although *T. absoluta* causes serious damage to tomatoes, reduces production levels, and affects the profit margins of farmers, there has not been any comprehensive study in Botswana to assess the knowledge, perceptions, and management practices of farmers for this important pest. Farmers' experiences, attitudes, and knowledge should inform the basis on which innovative and sustainable pest management strategies are made (Khan and Damalas, 2015; Olaniran *et al*. 2015) [34, 35]. The objective of the present study was to assess farmers' knowledge, perceptions and management of *T. absoluta* on tomato in Botswana.

Materials and Methods

Farmers' knowledge and management practices were assessed through face-to-face interviews using semi-structured open and close ended questionnaires. The objectives were to collect data on farmers' knowledge of *T. absoluta* and to identify existing control measures and their perceived effectiveness. The questionnaires were administered to 200 farmers who had been selected by systematic random sampling from six (6) districts. The number of respondents interviewed per district was proportional to the number of active tomato farms in that district with the highest number of respondents being from the South East (N=46) followed by Kgatleng (N=35), Southern (N=30), Central (N=30), North East (N=26), Ngamiland (N=18) and Gantsi (N=15). The study selected only farms that had a tomato crop at the time of the enquiry. In the absence of the farm owner, the interview was conducted on farm managers or farm workers so long as they had extensive on-farm experience. The interviews were conducted in English and Setswana. The information collected included farmers' demographic background, farm characteristics, knowledge, and perceptions of *T. absoluta*. Farmers were also requested to outline their management actions for *T. absoluta*. Respondents who mentioned that they apply synthetic insecticides were asked to name them and/or provide their container labels for corroboration. They were also asked what motivated their resolve to apply insecticides their frequency of application and whether their measures were effective. Some of the respondents did not respond to certain questions and were therefore excluded from the analysis. For each question, the proportion of farmers who gave similar responses was calculated and percentages were computed based on the aggregate number of farmers who responded to each question. Some of the respondents selected more than one option per question, therefore percentages were calculated for each group of like responses.

Data Analysis

Data was analysed using MS Excel (2010) and IBM SPSS predictive analytics software (version 28) for Windows. Some of the respondents gave multiple answers to the same questions, therefore percentages may not add up to 100. One-way analysis of variance (ANOVA) were used to assess differences regarding socio-demographic and farm characteristics, knowledge, perceptions, and management practices for *T. absoluta*. All hypotheses were converted to the null and tested at an alpha level of 0.05.

Results

Socio-economic profile of farmers and farm characteristics

The socio-economic profile included gender, age, education level, and marital status of the respondents are indicated in Table 1. Most respondents (82.5%) surveyed were male; with 17.5% being females. The respondents' ages ranged from 20 as a minimum to over 60 years. Most farmers (29%) were aged 41-50 years and 51.0% were married. All the respondents had formal education. 51% of the farmers interviewed had completed their secondary education while 45% had been through tertiary school (either undergraduate or graduate school) showing that majority of the respondents could read and follow instructions from various agro-input suppliers and extension services. Majority (70.5%) of the farmers were Batswana and 29.5% were expatriates mainly of Zimbabwean descent. A large proportion 64.5% of the farms were owner-managed and 21.5% employed a farm manager. 75.5% of the interviewees had more than 10 years' experience growing vegetables and 78% had the same amount of experience growing tomatoes. Most (88.5%) of the tomatoes were grown for sale to large supermarkets while 8.5% were for street vendors and only 3% for domestic utilisation. Majority (64%) of the tomatoes were produced in open fields, while fewer (24%) were grown in greenhouses, 9% in tunnels, and 3% in hydroponics. The farmers who produced tomatoes in greenhouses and tunnels were mostly in the greater Gaborone and southern district. Majority (94.5%) of farmers grew tomatoes in fields of less than 5 ha, and 5.5% for 6-10 ha.

Table 1: Socio-economic profile of farmers and farm characteristics

Demographic characteristics	Frequency	Percent (%)	Cum. %
1. Gender			
Male	165	82.5	82.5
Female	35	17.5	100.0
2. Age of respondent (years)			
20-30	26	13	13
31-40	37	18.5	31.5
41-50	58	29	60.5
51-60	49	24.5	85
Above 60 years	30	15	100.0
3. Marital status			
Single	74	37	37
Married	102	51	88
Divorced	19	9.5	97.5
Widowed	5	2.5	100.0
4. Educational level			
Primary education	8	4	4
Secondary education	102	51	55
Diploma	42	21	76
Bachelor's degree	36	18	94
Master's degree	8	4	98
Doctorate	4	2	100.0
5. Nationality			
Motswana	141	70.5	70.5
Expatriate	59	29.5	100
6. Management of the farm			
Farm Manager	43	21.5	121.5
Owner managed	129	64.5	186
Employee	28	14	100.0
7. Responsibilities			
Farm hand	28	14	14
Gardener	29	14.5	28.5
Manager	133	66.5	95
Labourer	10	5	100.0
8. Experience growing vegetables			
Less than 10 years	30	15	15
10-20years	151	75.5	90.5
21-30 years	19	9.5	100.0
9. Experience growing tomatoes			
Less than 10 years	42	21	21
10-20years	156	78	99
21-30 years	2	1	100.0
10. Purpose for growing tomatoes			
Domestic utilisation	6	3	3
Sale to supermarkets	177	88.5	91.5
Street vending	17	8.5	100.0
11. Production system for tomatoes			
Greenhouse	48	24	24
Open field	128	64	88
Tunnels	18	9	97
Hydroponics	6	3	100.0
13. Field area planted with tomatoes			
1-5ha	189	94.5	94.5
6-10 ha	11	5.5	100.0

Farmers' awareness and perceived seriousness of tomato infesting insect pests

To determine the awareness level of tomato infesting insects, farmers were asked to identify the major insect pests affecting their production. The farmers were then requested to rank the most serious insect pest based on the impact of those pest on their production (Table 2). The majority (84%) of the farmers mentioned *T. absoluta* as the most serious pest affecting tomato production in Botswana. Spider mites of the genus Tetranychus (72%) were also identified as very serious pests of tomato followed by aphids (45%), *Bemisia tabaci* (35%). Agrotis spp. (23%) and *Helicoverpa armigera* (20%). Other less mentioned pests of economic importance were *Thrips tabaci* (19%), Spodoptera spp. (17%), *Chrysodeixis acuta* (13%), Liriomyza spp. (12%), *Zoonocerus variegatus* (10%), and *Acanthoplus discoidalis* (7%).

Table 2: Tomato infesting insect pests reported by farmers

Pest	Proportion of farmers (%)
Tomato Leaf miner (*Tuta absoluta*)	84
Spider mites (*Tetranychus* spp.)	72
Whiteflies (*Bemisia tabaci*)	35
Thrips (*Thrips tabaci*)	19
Cutworm (*Agrotis* sp.)	23
Aphids **(***Myzus persicae*)	45
Bollworm (*Helicoverpa armigera*)	20
Semi-looper (*Chrysodeixes acuta*)	13
Variegated grasshopper (*Zoonocerus variegatus*)	10
Armoured corn cricket (*Acanthoplus discoidalis*)	7
Armyworm (*Spodoptera* spp.)	17
American Leaf Miner (*Liriomyza trifolii*)	12

Farmers' awareness of the moth problem and its impact

The results of the study showed that all the farmers interviewed had erstwhile knowledge of *T. absoluta* (Table 3). Agro-inputs suppliers (78%) and other farmers (66.5%) were mentioned as the most important sources of pest information. The agricultural television programme on Botswana Television (BTV) was repeatedly mentioned by 70% of farmers as an important contributor to farmers' pest awareness. Extension services (24%) were mentioned as a less important source of pest information for farmers. All the farmers reported having been previously affected by *T. absoluta* in their farms. When asked about the time when *T. absoluta* was first encountered in the field 62.5% of the farmers mentioned; a few cropping seasons ago, 23% in the previous cropping season and 12.5% mentioned several cropping seasons ago**.** The farmers categorised *T. absoluta* infestations as very serious (54%), serious (31%), moderate (12.5%), and not serious (2.5%). The farmers mentioned that the proportion of the tomato crop infested by *T. absoluta* was less than 10% (%), 10-40% (%), 41-60% (%), 61-90% (%) and above 90% (%).

Demographic characteristics (area planted and production system) did not have a significant effect on the seriousness of the moth problem. However, the seriousness of the *T. absoluta* problem differed significantly ($p<0.001$) across districts. The moth was more prevalent in the southern parts of Botswana; Gaborone (23%) and the Southern district (12.5%), followed by Central district (12%), Francistown (8%), Maun (2.5%), and Gantsi (2%). 56% of the farmers revealed that they mainly depended on the mining symptoms on the leaf to know the identity of the pest. However, the key features they used to identify *T. absoluta* were small greenish larvae (47%), grey brown speckled wings (43%), 6-7mm long moths (38%), light brown pupae (23%), long legs and antennae of moths (12%), small yellowish eggs (10%), brown and black bands on legs and antennae of moths (5%). Respondents measured the severity of the *T. absoluta* infestations by the amount of damage inflicted on the crop (83%), the population levels (78%), amount of yield loss (80%), amount of pesticide used to arrest the infestation (68%) and cost overruns as a result of control interventions (75%). They attributed the severity of the infestations to high temperatures (68%), pesticide resistance (60%), high population (53%) and high reproductive rate (40%).

Table 3: Farmers' knowledge and perceptions of *T. absoluta* (NB. %s may not add up to 100)

	Frequency	Percent (%)
1. Prior knowledge about *T. absoluta*?		
Yes	200	100.0
No	0	0
2. Important Agro-information sources		
First-hand experience	180	90
Fellow farmers	133	66.5
Agro-input traders	156	78
Agricultural extension officers	48	24
Researchers	10	5
Radio/television	140	70
3. Time when *T. absoluta* was first encountered in the field		
This (current) cropping season	4	2.0
The previous cropping season	46	23
A few cropping season ago	125	62.5
Many cropping seasons ago	25	12.5
4. Severity of *T. absoluta* infestations		
Very serious	108	54
Serious	62	31
Moderate	25	12.5
Not serious	5	2.5
5. Proportion of tomato crop infested by *T. absoluta*		
Less than 10%	20	10
10-40%	56	28
41-60%	98	49
61-90%	126	63
Above 90%	56	28
6. Some identification features mentioned by farmers		
6-7mm long moths	76	38
Grey brown speckled wings	86	43
Long legs and antennae	24	12
Brown and black bands on legs and antennae	10	5
Small yellowish eggs	20	10
Greenish larvae	94	47
Light brown pupae	46	23
Mining symptoms on leaves	112	56
7. Judging the severity of infestations		
Amount of damage inflicted on the crop	166	83
Pest population levels	156	78
Yield loss levels	160	80
Pesticide application levels	136	68
Cost overruns	150	75
8. Cause of severity of *T. absoluta* infestations		
High temperatures	136	68
High reproductive rate	80	40
Pesticide resistance	120	60
High population	106	53

Farmer's knowledge of symptoms of *T. absoluta* infestation

Farmers were asked to identify *T. absoluta* from a photographic catalogue of local vegetable insect pests. 58.3% of farmers correctly identified *T. absoluta*. The farmers who correctly identified *T. absoluta* were then tested on their ability to identify (on the catalogue) its damage symptoms. Farmers observed that *T. absoluta* moths lay their eggs on all plant parts but have a high preference for leaves. 88% identified that the hatching larvae creates mines on the tomato leaves; and 80% suggested that young larvae penetrate the leaves for feeding and development. Most (90%) of the respondents mentioned that heavy infestations lead to excessive defoliation and eventually death of the plant.

Table 4: Farmer's knowledge of symptoms of *T. absoluta* infestation.

***Symptoms of T. absoluta* infestation**	**Proportion of farmers (%)**
T. absoluta creates mines/galleries on tomato leaves	88
T. absoluta larvae mine the leaves for feeding and development	80
T. absoluta create exit holes on tomatoes	90
T. absoluta infested fruits develop an abnormal shape	87
Female moths prefer tomato leaves for oviposition	83
Moths can oviposit on all plant parts	43
The moth attacks all parts of the plant	95
Larvae can attack stem, young shoots, flowers, apical buds, and fruits	81
Larvae produce frass (waste material) on plants.	83
Tuta infested fruits are prone to rot due to secondary agents.	79
Heavy infestation leads to leaf necrosis, defoliation and death of the plant	90

Farmers' knowledge and perceptions of *T. absoluta* damage and economic impact

Results in Table 5 suggest that all the farmers interviewed agreed that *T. absoluta* causes severe leaf damage to host plants. Majority (98%) of the farmers agree that the moth larvae cause damage to plants by mining into the leaf and feeding on the mesophyll tissues. 98% agree that the moth reproduces and multiplies quickly. The farmers (80%) concur that outbreaks are common during the hot summer months. The farmers unanimously (100%) agree that *T. absoluta* negatively affects farmers' income levels. Majority (96%) of the respondents perceive the invasive moth as a serious threat to the growing local tomato industry. 73% of the farmers submitted that infested tomato plants usually bear less fruit, which are usually of low quality (92%); and attract poor market (95%). 50% believe that *T. absoluta* can transmit plant diseases while 50% disagree. 90% of the respondents informed the researcher that *T. absoluta* has become very difficult to control with insecticides. 85% of them lament that these insecticides are very expensive to acquire; and 94% state that this increases their cost of production. Most (99%) of the farmers are of the view that money that could otherwise be used for other activities is spent on procurement of insecticides. Majority (94%) of the farmers are aware of the harmful effects of insecticides on human health and the environment.

Table 5: Farmers' knowledge and perceptions towards *T. absoluta* damage and economic impact

Statement	**Rating scale**					
	SD	**D**	**SLD**	**SLA**	**A**	**SA**
1. *T. absoluta* causes severe leaf damage	0 (0%)	0 (0%)	0 (0%)	32 (16%)	66 (33%)	102 (51%)
2. *T. absoluta* damage plants by mining and chewing the leaf mesophyll.	0 (0%)	0 (0%)	4 (2%)	38 (19%)	72 (36%)	86 (43%)
3. *T. absoluta* reproduces and multiplies quickly.	0 (0%)	2 (1%)	2 (1%)	30 (15%)	66 (33%)	100 (50%)
4. *T. absoluta* outbreaks occur during summer months.	8 (4%)	8 (4%)	24 (12%)	14 (7%)	28 (14%)	118 (59%)
5. *T. absoluta* reduce farmers' income.	0 (0%)	0 (0%)	0 (0%)	24 (12%)	20 (10%)	156 (78%)
6. *T. absoluta* are a threat to the local tomato industry.	0 (0%)	0 (0%)	8 (4%)	24 (12%)	26 (13%)	142 (71%)
7. *T. absoluta* reduces fruit quality.	4 (2%)	6 (3%)	6 (3%)	28 (14%)	34 (17%)	122 (61%)
8. *T. absoluta* infested tomatoes attract poor market.	2 (1%)	4 (2%)	4 (2%)	16 (8%)	54 (27%)	118 (60%)
9. *T. absoluta* Infested plants usually bear less fruit.	16 (8%)	14 (7%)	24 (12%)	26 (13%)	24 (12%)	96 (48%)
10. *T. absoluta* can transmit plant diseases.	34 (17%)	26 (13%)	40 (20%)	30 (15%)	40 (20%)	30 (15%)
11. *T. absoluta* are difficult to control with insecticides.	10 (5%)	8 (4%)	2 (1%)	24 (12%)	26 (13%)	130 (65%)
12. Insecticides for *Tuta* control are expensive to buy	12 (6%)	8 (4%)	10 (5%)	10 (5%)	30 (15%)	130 (65%)
13. *T. absoluta* increases the cost of production.	4 (2%)	4 (2%)	4 (2%)	20 (10%)	26 (13%)	142 (71%)
14. Money that could otherwise be used for other activities are spent on procurement of insecticides	0 (0%)	2 (1%)	0 (0%)	16 (8%)	24 (12%)	156 (79%)
15. Manpower that could be used for other field operations are diverted to insecticide applications.	6 (3%)	6 (3%)	6 (3%)	14 (7%)	18 (9%)	150 (75%)
16. Insecticides are harmful to humans and the environment	2 (1%)	6 (3%)	4 (2%)	26 (13%)	24 (12%)	138 (69%)

Farmers' management practices against *T. absoluta* on tomato

Farmers were requested to outline the *T. absoluta* management actions they practiced in their farms. The use of chemical insecticides was by far the most commonly mentioned (95%) method of controlling *T. absoluta*. 90% of the farmers were aware of non-chemical pest control practices. The majority (86%) of farmers were aware of the cultural management practices, which included: crop rotation (28%), planting resistant varieties (33%), weeding (23%), and destroying infested plants or plant parts (43%), controlled entry (14%), and water sprinkling (9%). Other management tactics mentioned but were perceived as less important were hand picking, use of bio-insecticides (5%), sanitation (12%) and organic insecticides (2%). Observed. Farmers did not mention the use of parasitoids, which lead to the conclusion that they were not aware of their use to control insect vegetable pests. Knowledge of pheromone traps for scouting, monitoring, and mass trapping and sticky traps were also little known to farmers.

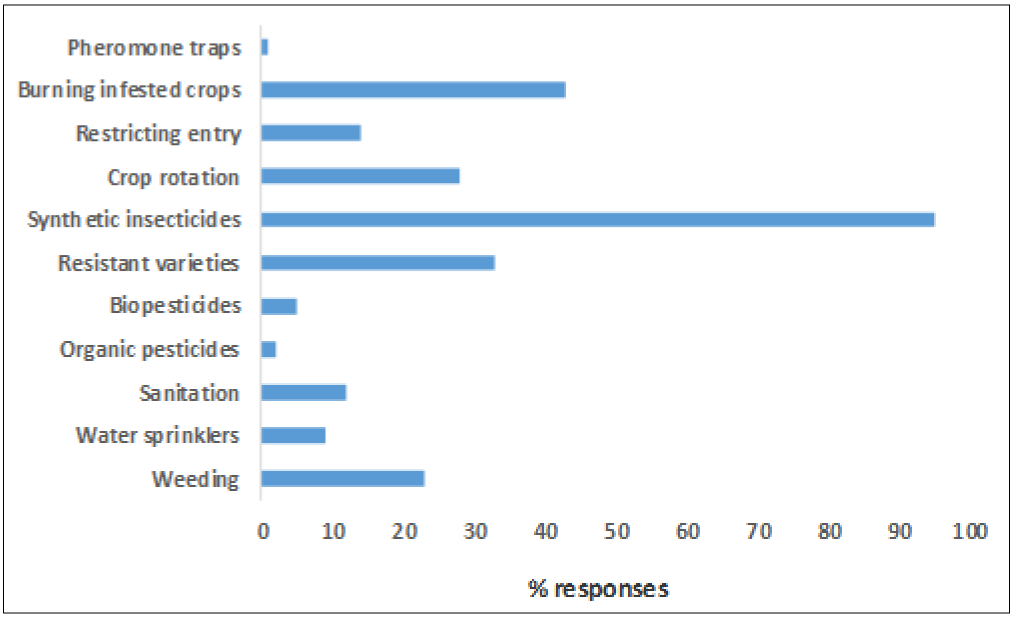

Fig 1: Most common *T. absoluta* management actions

Insecticides routinely sprayed by growers to control *T. absoluta* in Botswana

During the survey, farmers provided trade names, and in some instances active ingredients, for the products they were using, which we converted to active ingredients. A total of twenty four (24) insecticide active ingredients were being applied the control *T. absoluta* (Table 6). The study also found that the active ingredients constituted several chemical groups namely the organophosphates (4), pyrethroids (2), spinosyns (2), oxadiazine (2), diamides (2), avermectins (1), carbamate (1), anthranilic pyrrole (1), diacylhydrazine (1), nereistoxin analogue (1), neonocotinoids (1), oxadiazine, diamide (1) and phenylpyrazole (1).

Some of the insecticides mentioned were combinations of two active ingredients from different chemical groups, namely; Ampligo™ (Diamide + Pyrethroid), Avermectin + Organophosphate, Denim fit™ (Avermectin + benzoylurea), Gate fast™ (Avermectin + Neonicotinoid), Belt™ (Phthalic acid diamide + Pyrethroid).

The most commonly used insecticide active ingredient was Emmamectin benzoate (78%) followed by, Lambda cyhalothrin (65), Spinosad (63%), Indoxacarb (54%), Chlorantriniliprole (45%), Spinetoram (47%), Indoxacarb (43%), Imidacloprid (38%), Methomyl (35%), Chlorfenapyr (33%), Alpha-cypermethrin (27%), Acephate (25%), Methoxyfenozide (23%) and Chlorpyrifos (18%). The list contains five (5) combination insecticides containing two active ingredients. Other insecticides mentioned are shown in Table 6.

Among the insecticide active ingredients mentioned four (4)m Abamectin, Dichlorvos, Methomyl and Monocrotophos are classified as highly hazardous (class 1b) by the World Health Organisation (WHO 2020) [36]. Most of the insecticides are classified as moderately hazardous (Class II) and slightly harzadous (class III).

Table 6: Insecticides mentioned by farmers for the control of *T. absoluta*

Trade names	Active ingredient (s)	Chemical family	WHO hazard class*	Responses (%)
Alpha-thrin 100 SC, Fendona 6 SC	α-cypermethrin	Pyrethroid	II	27
Emma, Warlock 19.2EC, Proclaim, Promec 20EW. Wormex, Emaben Vitex 50, Lepidex	Emmamectin benzoate	Avermectin	II	78
Tracer 120SC, Entrust Naturalyte, Eco Insect Control	Spinosad	Spinosyn	III	63
Prevathon 5 SC, Coragen, Prevathon	Chlorantraniliprole	Anthranilic diamide	U	45
Steward 150 EC, Advance 150EC, Addition 150EC, Doxstar	Indoxacarb	Oxadiazine	II	54
Ampligo	Chlorantraniliprole + Lambda cyhalothrin	Diamide + Pyrethroid	U-II	70
Lambda 50 EC, Karate	Lambda-cyhalothrin	Pyrethroid	II	65
Abamectin + Diclorvos	Abamectin + Dichlorvos	Avermectin + Organophosphate	1b + 1b	29
Denim fit	Emmamectin benzoate + Lufenuron	Avermectin + benzoylurea	II + III	48
Savage 360 SC, Hunter 24 SC	Chlorfenapyr	Pyrrole	II	33
Runner 240 SC	Methoxyfenozide	Diacylhydrazine	U	23
Delegate™ 250 WG	Spinetoram	Spinosyn	U	47
Cartap 500SP	Cartap hydrochloride	Nereistoxin analogue	II	10
Acephate 750SP, Compete 75 SP; Lipat 75 SP; Conthene 75 SP	Acephate	Organophosphate	II	25
Lannate, Farmag Methomyl 90SP, Methomex 900SP, Methomate 200SL, Spitfire 900SP, Cyplamyl 90SP,Masta 900SP, Mylomex 900SP	Methomyl	Carbamate	1b	35
Avenue WG	Imidacloprid	Neonicotinoid	II	38
Avaunt, Steward 150EC, Advance, Addition, Doxstar Flo	Indoxacarb	Oxadiazine	II	43
Gate fast SC	Abamectin + thiamethoxam	Avermectin + Neonicotinoid	1b + II	9

Belt	Flubendiamide	Diamide	III	3
Belt SC + Decis forte EC	Flubendiamide+ Deltamethrin	Phthalic acid diamide + Pyrethroid	III + II	6
Avi-klorpirifos 480 EC, Agropyrifos, Pyrinex 480EC, Agropyrifos	Chlorpyrifos	Organophosphate	II	18
Lophos 36	Monocrotophos	Organophosphate	1b	7
Profenofos, Farmag Profenofos 500	Profenofos	Organophosphate	II	5
Coach SC	Fipronil	Phenylpyrazole	II	9
Avi-Merkaptothion, Avi-Merkaptotoks, Avi Gard Mecarptothion, Harrier 500 EC, Malasol, Malathion	Mercaptothion	Organophosphate	III	5

*WHO hazard classification: 1a = extremely hazardous; 1b = highly hazardous; II = moderately hazardous; III = slightly hazardous; U = unlikely to present acute hazard in normal use (WHO, 2020) [36].

The study revealed that farmers used different spray equipment to apply insecticides to tomato plants (Table 7). The knapsack hand sprayer (98%) was the most commonly used spray equipment in Botswana. The handheld sprayer (72%) was also cited as a common choice for smallholder farmers. Other less common methods of conveying insecticides to plants were the tractor boom sprayer (5%), the knapsack power sprayer (2%), and the drone sprayer (2%).

Table 7: Different spray equipment used by tomato farmers to control tomato pests

Spraying equipment	Frequency	%
Knapsack hand sprayer	196	98
Knapsack power sprayer	4	2
Hand held sprayer	144	72
Tractor boom sprayer	10	5
Trailer sprayer	0	0
Drone sprayer	4	2
Aircraft sprayer	0	0
Stirrup sprayer	0	0
Hand compression sprayer	0	0

Most (49.5%) of the farmers interviewed revealed that they initiated control measures when they noticed the moth, larvae or its eggs on the tomato plants, while 24% started spraying when they noticed damage symptoms on the crop, 21% followed an existing spray program, and 5.5% used economic thresholds (Table 8). Some farmers apply up to 10 insecticide sprays per cropping season. 68% of the farmers revealed that they applied 1-5 insecticide sprays per cropping season while 30% applied 6-10 insecticide sprays, and 2% over used over 10 sprays per cropping season. The frequency of spraying was not significantly (P=0.001) associated with the age of the farmer. The farmers, when asked about the perceived level of effectiveness of their management tactics, majority (40.5%) of the farmers indicated that they were fairly successful, very successful (21%) and not successful (38.5%). Most (64.5%) of the farmers believed that the moth had developed resistance to insecticides they used. They mentioned that they noticed the phenomenon a number of cropping season before (44%), the previous cropping season (32%), and the current cropping season (24%). When asked about the strategies they employ to evade *T. absoluta* resistance development, most (23%) mentioned that they would alternate different insecticides, increase dosage (21%), use integrated pest management (20%), increase spray frequency (16%), observe economic thresholds (14%), and reduce spray frequency (6%).

Table 8: Farmers' management tactics for *T. absoluta*

	Frequency	Percent (%)	Cum. %
2. What influences your decision to spray?			
Presence of pest on crop	99	49.5	49.5
Spray programme	42	21	70.5
Damage signs	48	24	94.5
Economic thresholds	11	5.5	100.0
1-5 insecticide sprays	136	68	68.0
6-10 insecticide sprays	60	30	98.0
>10 insecticide sprays	4	2	100.0
3. How effective are your current management tactics?			
Very successful	42	21	21.0
Fairly successful	81	40.5	61.5
Not successful	77	38.5	100.0
4. Does *T. absoluta* become resistant to insecticides?			
Yes	129	64.5	64.5
No	71	35.5	100.0
5. When did you notice?			
This (current) cropping season	48	24	24.0
The previous cropping season	64	32	56.0
A few cropping seasons ago	88	44	100.0
6. Strategies to evade resistance development			
Increase dosage	42	21	21.0
Alternate insecticides	46	23	44.0
Increase spray frequency	32	16	60.0
Reduce spray frequency	12	6	66.0
Integrated pest management	40	20	86.0
Observe economic thresholds	28	14	100.0

Discussion

The findings of this study indicate that several insect pests affect tomato production in Botswana. However, the invasive *T. absoluta* was the most problematic in both open and protected agro-systems (Kandil *et al*. 2020; CABI, 2019) [37, 38]. Farmers from the selected locations demonstrated knowledge of identification of the moth and its developmental stages. The *Tsa Temo Thuo* television programme on Botswana Television (BTV) was seen as an important source of agronomic information. As mentioned by Gaobolokwe and Hulela (2014) [39] and Nazari and Hasbullah (2010) [40], television and radio programmes have become popular in agricultural information dissemination. Nazari and Hassam (2011) [41] emphasize the importance of educational interventions transferred through a TV programme in knowledge enhancement. The farmers also demonstrated reasonable knowledge of the damage and economic impact of *T. absoluta* on tomato production. Farmers were able to describe the mining and feeding damage caused by the larvae on the plant, and emphasized that it was capable of causing serious crop damage. This is consistent with Shahini *et al*. (2021) [42] who found that *T. absoluta* was able to cause yield losses up to 100% in the absence of control measures. Furthermore, farmers lamented that infestations by *T. absoluta* were the cause of low productivity of tomato in Botswana. This also affected their levels of income from the crop. The farmers informed that *T. absoluta* larvae can attack all developmental stages of the tomato plant as reported in other studies (Braham and Hajji, 2012) [43] but most damage was inflicted on early growth stages of the plant. Consistent with findings of Materu *et al*. (2016) [2] and Silva *et al*. (2016) [44], the farmers reported that apart from seriously affecting yields levels, tomato produce with *T. absoluta* damage symptoms is often discarded. As with most insect pests (Kandil *et al*. 2020; Mansour *et al*. 2018) [37, 45], *Tuta absoluta* control was mainly dependent on synthetic insecticide applications. The findings that over 90% of farmers favoured synthetic insecticides over any other control measure were similar to those found in other African countries (Mrosso *et al*. 2023; Thovhogi *et al*. 2021) [46, 47]. The relative ease of application, quick killing activity, availability, and accessibility (Laizer *et al*. 2019) [48] coupled with the high commercial value of tomatoes make insecticides an obvious choice for tomato farmers in their quest to secure profitable yields. However, insecticides are very expensive and increase the cost of production. Farmers interviewed in this study indicate that they were continually noticing reduced effectiveness of insecticides which they attributed to resistance development. These views were in agreement with Kandil *et al*. (2020) [37] and Bala *et al*. (2019) [49] who found that *T. absoluta* populations were becoming resistant to several classes of insecticides. This prompts farmers to seek new, more lethal, and more expensive insecticides.

Since the larvae tunnel into tomato leaves soon after emerging from their protective egg capsules, (Shahini *et al*. 2021; Mutamiswa *et al*. 2017; Pfeiffer *et al*. 2013) [39, 16, 50] they easily evade contact insecticide applications which may be another reason for the unsatisfactory control results. Farmers apply insecticides at excessively high amounts which may inflict undesirable environmental and human health consequences. Furthermore, frequent applications result in poor sustainability of production and increased production costs (Barathi *et al*. 2024) [51]. Four insecticide compounds mentioned were on the list of highly hazardous (class 1b) technical grade active ingredients by the World Health Organisation (WHO, 2020) [36]. Most were classified as moderately to slightly hazardous (Class II and III). It was revealed that farmers were purchasing insecticides registered to control other pests and were using them to control *T. absoluta* on tomato. This underscored the farmers' desperation to control the devastating pest. Some of the insecticides mentioned were combination products containing two active ingredients (blended insecticides) from different chemical groups and modes of activity. These have a potential of causing more confusion to the farmers regarding their choice of appropriate insecticides for *T. absoluta* control. The findings that a greater variety of insecticides were recorded in the southern, south east and Kgatleng regions than other regions were similar to those of Obopile *et al*. (2008) [12].

Based on this information, the Registrar of agrochemicals should identify unregistered and/or highly hazardous products and regulate their countrywide distribution and usage. Early detection, accurate pest identification and the use of threshold levels are important for the successful control of *T. absoluta*. Extension services need to be improved in order to provide farmers with the most current pest information. They should encourage the use of pheromone based monitoring for *T. absoluta* management, to apply control measures appropriately and effectively. Lower risk biological control utilising botanicals, biopesticides, pheromones, and natural enemies should be promoted and inculcated into farmers' IPM programmes.

Acknowledgements

The author would like to express gratitude towards tomato growers for allowing the interviewer entry into their farms to conduct interviews, and for volunteering their time to participate. Gratitude is extended to Ministry of Agriculture (MoA), Department of Crop Production, extension officers in various regions for assisting with farm selection and administration of the questionnaires. The Local Enterprise Authority (LEA), Glen Valley incubator and Impala Training and Research Centre for allowing the researcher to interview their trainees. Many thanks to the Department of Plant Protection, Ministry of Agriculture for providing Agrochemical data used in this study.

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