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Farmers' knowledge, perceptions and management of spider mites (Acari: Tetranychidae) associated with tomato in Botswana

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Abstract
This paper reports on farmers' knowledge, perceptions and management practices for spider mites (Tetranychus spp.) affecting tomatoes in Botswana. A survey of 120 tomato farmers was conducted using questionnaires during the period of March to June 2019. The study findings revealed that farmers producing tomatoes are considered the most important pest of tomatoes followed by tomato leaf miner (*T. absoluta*). The red form of the spider mite is more prevalent than the green form in tomato fields across Botswana. The farmers reported that spider mites affect the quality and quantity of tomatoes and increased the cost of production. Farmers typically apply synthetic pesticides to control invertebrate pests on their crops and their action is mainly premised on the presence of the pest or symptoms of damage on the crop. Unlike most pests, spider mites quickly develop resistance to formulations employed for their control. Farmers report reduced effectiveness of the current management tactics against spider mite infestations on their tomato crop and presume it could be due to resistance development. The current management practices can be improved by sensitizing and training farmers on the use of appropriate pesticides and spray regimes for spider mites. Tomato farmers need to know the importance of integrated pest management to control spider mites and other pests on vegetables whilst delaying resistance development and avoiding harmful effects of pesticides on the environment humans and non-target organisms.

Keywords: spider mites, knowledge, perceptions, *Tetranychus* spp., pesticides, tomato

Introduction

Tomato (*Solanum lycopersicum var. lycopersicum*) is one of the most widely grown vegetable crops in Botswana and the world (Madisa *et al*. 2010; Baliyan and Rao 2013) [14]. It is a nutritionally well-balanced food that contains a substantial amounts of vitamins A and C, thus it plays an important role towards ensuring food security and nutrition (Brasesco *et al*. 2019) [5]. Globally, tomato ranks third among horticultural produce, for volumes of production, after potato and sweet potato, and first in terms of processing volumes (Brasesco *et al*. 2019) [5]. Tomato is a valuable product for both smallholder producers and large scale commercial farmers, serving mainly as a commercial crop and grown in shade nets and open field plots in most parts of Botswana. Tomato production and productivity in Botswana is low (60-100 tonnes per hectare) when compared to major tomato producers in Africa (Badimo 2020) [2]. The leading producers of tomato in Africa are Egypt (7, 297 108 tons), Nigeria (4, 100 000 tons), Morocco (1, 293 761 tons), Tunisia (1, 298 000 tons), Cameroon (1,279 853 tons), Algeria (1,286 286 tons) and South Africa (608 306 tons) (Dube *et al*. 2020). Major constraints to tomato production in Botswana include water shortage, soil fertility, weeds, pests and marketing infrastructure (Madisa *et al*. 2010) [14]. Tomato production in Botswana is repressed by a number of invertebrate pests which include the cutworm (Agrotis spp.), whitefly (*Bemisia tabaci*), African bollworm (*Helicoverpa armigera*), tomato semi-looper (*Chrysodeixis acuta*), tomato leafminer (*Tuta absoluta*), and spider mites (Tetranychus spp.) (Baliyan 2012; Leungo *et al*. 2012; Madisa *et al*. 2010; Munthali 2009) [3, 13, 14, 15].

Spider mites are reported to be one of the most important pests of tomato in Botswana (Obopile *et al*. 2018; Bok *et al*. 2006) [17, 4]. Spider mites belong to the class Arachnida and the order Acari, which contains more than 40, 000 described species. Spider mites have specialized feeding habits including parasitic, predatory and phytophagous (Grbic *et al*. 2011) [11]. The genus *Tetranychus* contains three popular species; carmine spider mite, *T. cinnabarinus* (Boisduval), Two-spotted spider mite, *T. urticae* (Koch) and the tobacco spider mite, *T. evansi* (Baker & Prichard) (Hoy 2011; Visser, 2005) [10, 21]. The carmine spider mite, (CSM) (Boisduval 1867) and the two spotted spider mite (TSSM), are reported to infest tomatoes in almost all production systems in Botswana (Munthali *et al*. 2004) [16]. Adult and immature spider mites feed mostly on the underside of the leaves by introducing their stylets into the leaves and sucking cell contents causing damage to the protective leaf surface, chloroplasts and palisade layers. Symptoms of spider mite feeding include flecking, yellowing and curling of leaves (Kaimal & Ramani 2011) [12]. In addition, the heavy webs they spin on leaves disrupt photosynthetic efficiency and transpiration of the plant. Eventually, the leaves die and fall off. Severe infestation by spider mites affects overall plant growth, flowering and fruit formation (Kaimal & Ramani 2011) [12]. Spider mites are often referred to as the "resistance champion" of arthropods, as they have an exceptional record of resistance development to every pesticide used against them (Grbic 2011; Van Leeuwen *et al*. 2010, Dermauw *et al*. 2013) [11, 20]. Unreasonable and intensive use of acaricides has accelerated the development of resistance by spider mites in many parts of the world (Bu *et al*. 2015) [6]. Although pesticides have been considered an invaluable tool for producing food for an increasing world populace, their undiscerning use has adverse environmental and human health costs (Pimentel 2009). Spider mites cause significant crop damage and affect production levels, markets, income levels and livelihoods.

There has not been any comprehensive study in Botswana to determine the knowledge, perceptions and practices of farmers regarding spider mite management. Farmer-level information is the foundation for introducing new interventions since farmers' experiences, perceptions and current knowledge form part of the framework on which new decisions are made (Abdollahzadeh *et al*. 2015; Fan *et al*. 2015) [1]. Agricultural development needs to build on farmers' knowledge systems to enable the tailoring of innovative solutions to local situations.

The objectives of the present study were to (1) assess farmers' knowledge and perceptions of the constraints to tomato production; (2) identify invertebrate pests that farmers perceive as important to tomato production; (3) evaluate farmers' knowledge of management of spider mites on tomato.

Materials and Methods

A total of 120 farmers from six districts were randomly selected for the study. The number of respondents interviewed varied depending on the number of active tomato farms in a particular region with the highest number of farmers interviewed being from greater Gaborone (n = 46) followed by Southern (n = 25), Central (n = 24), Francistown (n = 16), Maun (n = 5) and Gantsi (n = 4). Farms growing tomatoes at the time of the study were randomly selected to avoid bias. The farmers were visited for face-to-face interviews. In the absence of the farm owner, the interview was carried out with the farm managers or farm workers provided they had long experience and extensive knowledge of on-farm management practices. The interviews were conducted in English and Setswana. The information collected included: farmers' demographic profiles, farm characteristics, knowledge, and perceptions of spider mites, and management practices. Farmers were asked to list the management tactics they used to control spider mites. When respondents cited the use of synthetic pesticides they were asked to list the pesticides and furnish the container labels for verification. Farmers were also asked to state what prompts their decision to apply pesticides; how frequently they sprayed their crop and whether their tactics were effective. For each question, the proportion of farmers who gave similar responses was calculated and percentages were computed based on the total number of farmers who responded to each question. Farmers who did not respond to certain questions were excluded from the analysis. Where a farmer selected more than one option, percentages were calculated for each group of similar responses. Data from the questionnaires were coded and checked then analysed using IBM SPSS Statistics predictive analytics software (Version 28) to test the hypotheses. Some of the farmers gave multiple responses to the same questions, so percentages may not add up to 100. Comparative statistical tools including Chi-square and one-way analysis of variance (ANOVA) were conducted to assess differences regarding socio-demographic and farm characteristics, knowledge and perceptions of spider mites and their management practices. All hypotheses were converted to the null and tested at an alpha level of 0.05. The study sought to find out whether the demographic background (age, gender, experience, educational background) was associated with their knowledge of pests, spider mites and their management actions. The association between their demographic profile with the production system and the field plot area under tomato production was also investigated.

Results

1. Farmers' demographic background and farm characteristics

The demographic characteristics recorded in this study include gender, age, education level and marital status of the respondents as indicated in table 1. The findings indicate that tomato production in Botswana is male dominated with 73.3 % of the farmers being males and 26.7% being females. The respondents' age ranged from 20 as a minimum to above 60 years. Most farmers (32.5%) were aged 41-50 years and 50.0% were married. All of the farmers had formal education. 48.3% of the respondents had completed their secondary education and 45.9% had attended tertiary school. Most (74.2%) farmers were Batswana while 25.8% were expatriates. 65.5% of the farms interviewed were owner managed and 14.2% employed a farm manager. Most (79.2%) of the respondents were in charge of the farm (owner/manager) while 9.2% and 10.8% were farm hands and gardeners respectively. Most (68.3%) of the interviewees had more than 10 years of experience growing vegetables while 64.2% had the same level of experience growing tomatoes. Most farmers (87.5%) grew tomatoes for retail sale followed by 10.0% who produced for street vending and 2.5% for home consumption. Most farmers (80.8%) produced their tomatoes in open fields, while fewer grew them in greenhouses (13.3%), tunnels (5.0%) and hydroponics (0.8%). There was a significant relationship (at a 5% significance level) between the age of the farmer and the type of production system used (χ^2= 26.81, *df*= 12, *P*=0.008). The farmers who used greenhouses were in the age bracket 41 -50 years (10) while those who used tunnels were in the bracket 51- 60 years (4), hydroponics in the bracket 20-30 years (1) and open fields 41-60 years (54). Most (92.5%) farmers produced tomatoes over an area less than 5 ha, followed by 6-10 ha (7.5%). However, there was an insignificant relationship (χ^2= 4.112, *df*= 4, *P*=0.391) between age of farmer and size of field plot. The gender of the farmer did not influence size of field plot (χ^2= 1.204, *df*= 1, *P*=0.273). Similarly, there was no significant relationship (χ^2= 12.23, *df* = 5, *P* = 0.032) between educational background and area planted. Educational background also did not have a significant relationship (χ^2= 20.49, *df* = 15, *P* = 0.154) with the production system used.

Table 1: Farmers' demographic characteristics and farm characteristics

Demographic characteristics	Frequency	Percent (%)	Cum. %
1. Gender			
Male	88	73.3	73.3
Female	32	26.7	100.0
2. Age of respondent (years)			
20-30	9	7.5	7.5

31-40	20	16.7	24.2
41-50	39	32.5	56.7
51-60	32	26.7	83.4
Above 60 years	20	16.7	100.0
3. Marital status			
Single	52	43.3	43.3
Married	60	50	93.3
Divorced	4	3.3	96.6
Widowed	4	3.3	100.0
4. Educational level			
Primary education	7	5.8	5.8
Secondary education	58	48.3	54.1
Diploma	31	25.8	79.9
Bachelor's degree	20	16.7	96.6
Master's degree	2	1.7	98.3
Doctorate	2	1.7	100.0
5. Nationality			
Motswana	89	74.2	74.2
Expatriate	31	25.8	100.0
6. Management of the farm			
Farm Manager	17	14.2	14.2
Owner managed	75	62.5	76.7
Employee	28	23.3	100.0
7. Responsibilities			
Farm hand	11	9.2	9.2
Gardener	13	10.8	20.0
Manager	95	79.2	99.2
Labourer	1	0.8	100.0
8. Experience growing vegetables			
Less than 10 years	38	31.7	31.7
10-20years	73	60.8	92.5
21-30 years	9	7.5	100.0
9. Experience growing tomatoes			
Less than 10 years	43	35.8	35.8
10-20years	74	61.7	97.5
21-30 years	3	2.5	100.0
10. Purpose for growing tomatoes			
Home consumption	3	2.5	2.5
Retail sale	105	87.5	90.0
Street vending	12	10	100.0
11. Production system for tomatoes			
Greenhouse	16	13.3	13.3
Open field	97	80.8	94.1
Tunnels	6	5	99.1
Hydropnics	1	0.8	100.0
13. Area planted with tomatoes			
1-5ha	111	92.5	92.5
6-10 ha	9	7.5	100.0

2. Farmers' knowledge and perceptions of constraints to tomato production

The farmers ranked the constraints basing on the impact of that constraint on their production (Table 2). Most farmers (90.0%) mentioned invertebrate pests as the most important constraint to tomato production followed by diseases (47.5%), infertile soils (18.3%), unavailability of water (12.5%), unavailability of market (12.5%), lack of irrigation facilities (5%) and poor managerial skills (1.7%). The farmers named tomato pests as shown in Figure 1. Most farmers (75.7%) identified spider mites as a major pest (75.7%) hindering economic production of tomato in Botswana followed by tomato leaf miner (56.5%), aphids (38.3%) and white fly (30.4%). Other pests reported as less damaging to tomato production were African bollworm (21.7%), semi-looper (8.7%) and variegated grasshopper (8.7%).

Table 2: Constraints to tomato production

Constraint	Frequency	% responses
Invertebrate pests	108	90.0
Diseases	57	47.5
Water unavailability	15	12.5
Lack of capital	4	3.3
Unavailability of market	15	12.5
Transport	3	2.5
Infertile soils	22	18.3
Poor management skills	2	1.7
Irrigation facilities	6	5.0

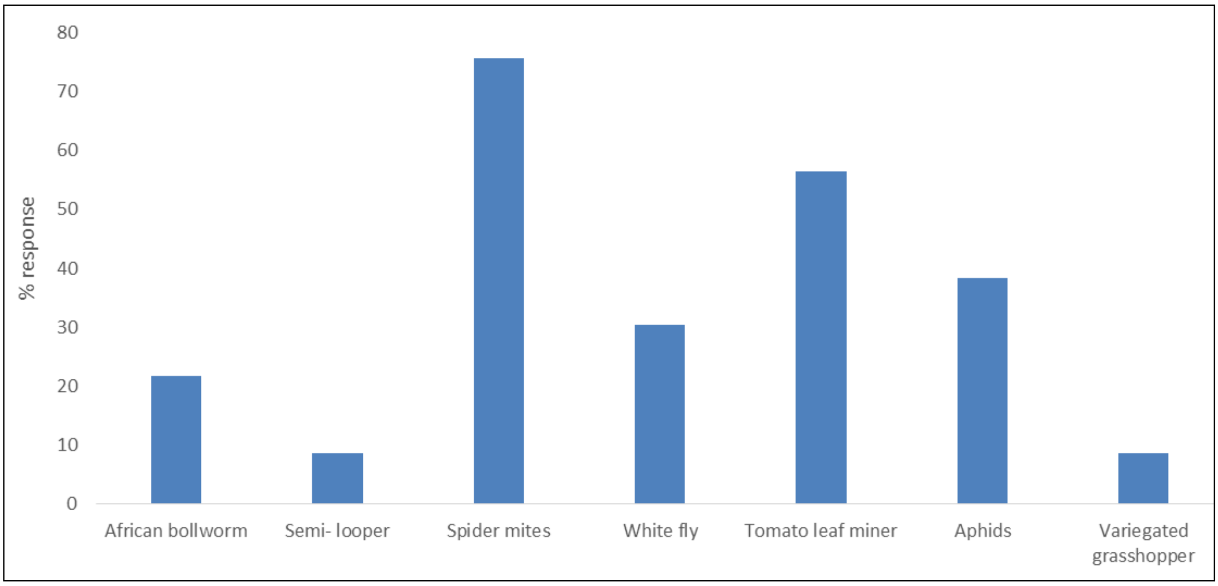

Fig 1: Invertebrate pests of tomato

3. Farmers' knowledge and perceptions of spider mites

All (100%) of the farmers interviewed reported having prior knowledge of tomato spider mites (Table 3). 48.30% reported having personal experience with spider mites in their farms while others mentioned agro-traders (23.3%) and fellow farmers (20%) as the most important sources of vegetable pest information. Other less important sources of information mentioned were agricultural extension officers (4.2%) and radio/television (3.3%). Educational background did not have a significant (χ^2= 20.07, *df* = 25, *P* = 0.743) effect on the farmers' source of vegetable pest information.

Spider mites were reported as a very serious (35.8%) constraint in most of the farms, serious (50%), moderate (8.3%) and not serious (5%) in other farms. Demographic characteristics (area planted and production system) did not have a significant effect on the seriousness of spider mite problem. However, the seriousness of the spider mite problem differed significantly (P<0.001) across districts. Most farmers in Gaborone (n = 46) reported that spider mites were very serious followed by Southern district (n = 25), Central (n = 24), Francistown (n = 16), Maun (n = 5) and lastly Gantsi (n = 4). The primary features farmers used to identify spider mites were colour (87.5%), followed by shape (6.7%) and size (5.8%). The red form of the spider mite was reported as the most prevalent (76.7%) followed by the green form (23.3%) by respondents. The farmers referred to the spider mite most prevalent in their localities as red spider mite (68.3%), carmine spider mite (8.3%) and two spotted spider mite (23.3%). Respondents attributed the seriousness of the spider mite problem to pesticide resistance development (55.0%), fast reproduction (19.2%), high population densities (13.3%) and climatic conditions (12.5%). Most farmers associated spider mites with sucking (80%) and yellowing (20%) damage to tomato plants.

Table 3: Farmers' knowledge and perceptions of spider mites

	Frequency	Percent (%)	Cum. %
3. Ever heard of spider mites before?			
Yes	120	100.0	100.0
No	0	0	100.0
4. Source of information			
Own experiences	58	48.3	48.3
Fellow farmers	24	20.0	68.3
Agro-traders	28	23.3	91.6
Agricultural extension officers	5	4.2	95.8
Researchers	1	0.8	96.6
Radio/television	4	3.3	100.0
5. Seriousness of the spider mites problem in your area			
Very serious	43	35.8	35.8
Serious	61	50.8	86.6
Moderate	10	8.3	94.9
Not serious	6	5.0	100.0
6. What do you call the spider mite prevalent in your area?			
Red spider mite	82	68.3	68.3
Carmine spider mite	10	8.3	76.6
Two-spotted spider mite	28	23.3	100.0
7. What feature do you identify spider mites with?			
Size	7	5.8	5.8
Shape	8	6.7	12.7
Colour	105	87.5	100.0

8. What is the colour of the spider mite prevalent in your area?			
Yellow	0	0	0
Green	28	23.3	23.3
White	0	0	23.3
Red	92	76.7	100.0
Blue	0	0	100.0
9. Cause of seriousness of spider mite problem.			
Climate	15	12.5	12.5
Fast reproduction	23	19.2	31.7
Pesticide resistance	66	55.0	86.7
High population	16	13.3	100.0
10. What type of damage do you associate with spider mite			
Sucking	38	31.7	31.7
Yellowing	73	60.8	92.5
Leaf cutting	0	0.0	0.0
Stem boring	0	0.0	0.0
Leaf mining	9	7.5	100.0

4. Farmers' knowledge and perceptions of spider mite damage and economic impact

Results in Table 4 show that most farmers (47.5%) strongly agree that spider mite infestations are characterised by the yellowing of plant leaves followed by those that agree (38.3%), slightly agree (10%), slightly disagree (1.7%), disagree (1.7%) and strongly disagree (0.8%). Most (42.5%) of the respondents strongly agree with the statement that spider mites suck sap from plant leaves while 40.8 % agree followed by slightly agree (7.5%), slightly disagree (4.2%) and disagree (5%). The majority of farmers (44.2%) strongly agree that spider mites multiply quickly followed by those who agree (40.8%), slightly agree (11.7%), slightly disagree (0.8%) and disagree (2.5%). Most (43.3%) of farmers strongly agree that spider mite outbreaks are common during summer months followed by those who agree (40.8%), slightly agree (14.2%) and disagree (1.7%). 45.8% strongly agree that spider mite infestations negatively affect farmers' income followed by agree (45%), slightly agree (8.3%) and slightly disagree (0.8%). Majority (50%) of the farmers strongly agree that spider mites are a threat to the horticulture industry while others agree (40.8%), slightly agree (6.7%) and disagree (2.5%). Majority (49.2%) strongly agree that spider mites reduce fruit quality followed by those who agree (44.2%), slightly agree (5.8%) and slightly disagree (0.8%). Half (50.0%) of the respondents strongly agree that spider mite infested tomatoes attract poor market followed by those who agree (45.8%) and slightly agree (4.2%). More than half (53.3%) of interviewees strongly agree that spider mite infested tomato plants usually bear less fruit followed by those who agree (41.7%), slightly agree (2.5%) and slightly disagree (2.5%). Majority (46.7%) of farmers agree that spider mites can transmit plant diseases followed by those who agree (45.0%), slightly agree (5.8%), slightly disagree (1.7%) and disagree (0.8%). More than half (55.0%) of the farmers strongly agree that spider mites are difficult to control followed by those who agree (42.5%) and slightly agree (2.5%). The majority (51.7%) of the farmers strongly believe that spider mite infestations increase the cost of production followed by those who agree (37.5%), slightly agree (10.0%) and disagree (0.8%).

Table 4: Farmers' knowledge and perceptions towards spider mite damage and economic impact

Statements	Rating scale					
	SD	D	SLD	SLA	A	SA
1. Spider mite causes yellowing of plant leaves.	1 (0.8%)	2 (1.7%)	2 (1.7%)	12 (10.0%)	46 (38.3%)	57 (47.5%)
2. Spider mite damage plants by sucking sap.	0 (0%)	6 (5.0%)	5 (4.2%)	9 (7.5%)	49 (40.8%)	51 (42.5%)
3. Spider mites reproduce and multiply quickly.	0 (0%)	3 (2.5%)	1 (0.8%)	14 (11.7%)	49 (40.8%)	53 (44.2%)
4. Spider mite outbreaks occur during summer months.	0 (0%)	2 (1.7%)	0 (0%)	17 (14.2%)	49 (40.8%)	52 (43.3%)
5. Spider mites reduce farmers' income.	0 (0%)	0 (0%)	1 (0.8%)	10 (8.3%)	54 (45.0%)	55 (45.8%)
6. Spider mites are a threat to the horticulture industry.	0 (0%)	3 (2.5%)	0 (0%)	8 (6.7%)	49 (40.8%)	60 (50.0%)
7. Spider mites reduces fruit quality.	0 (0%)	0 (0%)	1 (0.8%)	7 (5.8%)	53 (44.2%)	59 (49.2%)
8. Spider mite infested tomatoes attract poor market.	0 (0%)	0 (0%)	0 (0%)	5 (4.2%)	55 (45.8%)	60 (50.0%)
9. Infested plants usually bear less fruit.	0 (0%)	0 (0%)	3 (2.5%)	3 (2.5%)	50 (41.7%)	64 (53.3%)
10. Spider mite can transmit plant diseases.	0 (0%)	1 (0.8%)	2 (1.7%)	7 (5.8%)	54 (45.0%)	56 (46.7%)
11. Spider mites are difficult to control.	0 (0%)	0 (0%)	0 (0%)	3 (2.5%)	51 (42.5%)	66 (55.0%)
12. Spider mite increases the cost of production.	0 (0%)	1 (0.8%)	0 (0%)	12 (10.0%)	45 (37.5%)	62 (51.7%)

5. Farmers' knowledge of management actions against spider mites

The use of chemical pesticides was by far the most commonly mentioned (85.8%) method of controlling spider mites followed by water sprinkling (23.3%), controlled entry (16.7%), crop rotation (15.8%) and weeding (13.3%) (Figure 2). Other management tactics mentioned but were perceived as less important were hand picking, use of bio-pesticides, intercropping, sanitation, tillage, burning crop residues.

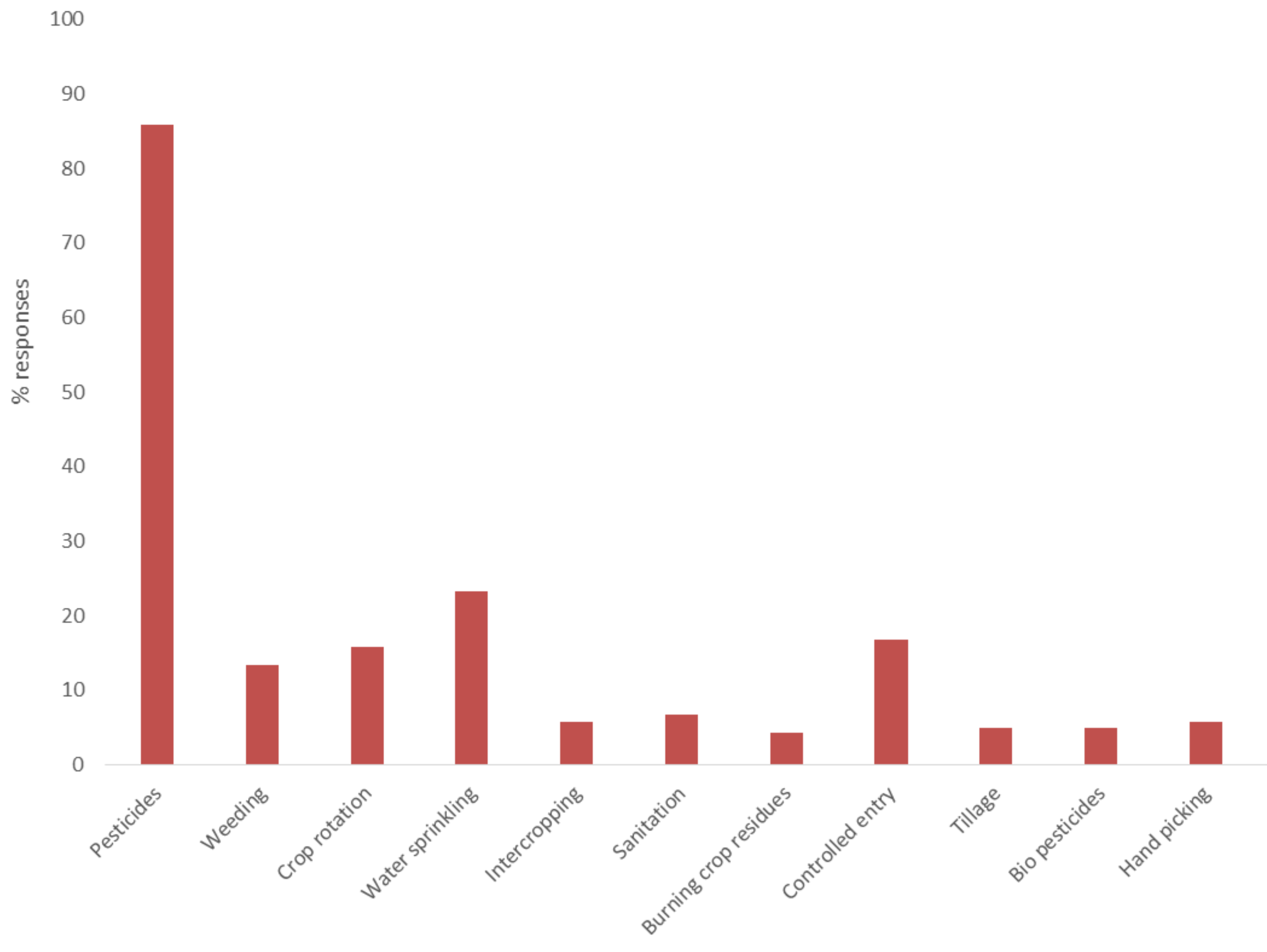

Fig 2: Farmers' management actions against spider mites

The results of the survey show that 29 pesticide active ingredients were used by the farmers to control spider mites on tomatoes in Botswana (Table 5). The chemical groups most cited were organophosphates (11), pyrethroids (5), carbamates (3), avermectins (2), organochlorines (2), pyrazole (1). The type of pesticides included 18 insecticides, 3 acaricides, 3 insecticides/ acaricides, 2 insecticide/ nematicides and 1 fungicide. The most commonly used pesticide was abamectin (79.2%) followed by methomyl (61.7%), chlorfenapyr (69.2%), emmamectin benzoate (61.7%), cypermethrin (55.8%), dicofol (52.5%), carbaryl (50.8%), beta-cyhalothrin (46.7%), lambda-cyhalothrin (41.7%), endosulfan (39.2%), chlorpyrifos (33.3%) and trichlofon (33.3%). Other pesticides which were mentioned are shown in Table 5. Among the commonly used pesticides, eight are classified as extremely (class 1a) or highly hazardous (class 1b) by the World Health Organisation (WHO 2020) [22].

Table 5: Pesticides used in Botswana to control pests of tomato

Active ingredient	Chemical type	WHO hazard class	Count	%
Cypermethrin (I)	PY	II	67	55.8%
Emmamectin–Benzoate (Avermectin)(I)		II	74	61.7%
Alpha – Cypermethrin (I)	PY	II	43	35.8%
Abamectin (Avermectin)(AC)		1B	95	79.2%
Lambda-cyhalothrin(I)	PY	II	50	41.7%
Chlorfenapyr (I/AC)	PZ	II	83	69.2%
Chlorpyrifos (I)	OP	II	40	33.3%
Malathion (I)	OP	III	13	10.8%
Dimethoate (I)	OP	II	15	12.5%
Methomyl (I)	C	1B	74	61.7%
Carbaryl (I)	C	II	61	50.8%
Fenthion (I)	OP	II	9	7.5%
Diazinon (I)	OP	II	6	5.0%
Demeton-s-methyl (I)	OP	1B	10	8.3%
Trichlorfon (I)	OP	II	40	33.3%
Endosulfan (I)	OC	II	47	39.2%
Deltamethrin (I)	PY	II	11	9.2%
Parathion (I)	OP	1A	6	5.0%

Dichlovos (I)	OP	1B	3	2.5%
Methamidophos (I)	OP	1B	37	30.8%
Dicofol (AC)	OC	II	63	52.5%
Fenamiphos (I/N)	OP	1B	7	5.8%
Carbofuran (I/N)	C	1B	1	0.8%
Mancozeb (Dithio)(F)		U	1	0.8%
Bifenazate (Bifenazate)(AC)		U	29	24.2%
Etoxazole (Pyrroles)(I/AC)		III	30	25.0%
Clofentezine (chlorobenzene) (I/AC)		III	23	19.2%
Beta-cyhalothrin	PY	II	56	46.7%

OP = organophosphate; PY = pyrethroid; OC = organochlorine; Carb = carbamates; Dithio = dithiocarbamate; PZ = Pyrazole; AC = acaricide; F = fungicide; H = herbicide, I = insecticide; N = nematicide; 1A = extremely hazardous; 1B = highly hazardous; II = moderately hazardous; III = slightly hazardous; U = unlikely to present acute hazard in normal use (WHO, 2020).

Most (54.2%) of the respondents mentioned that they apply management measures when they discover the pest on their plants while 15.8% based their decision on an existing spray program, 22.5% on noticing damage symptoms and 7.5% on economic decision levels (Table 6). There was no significant relationship between age and the decision to spray. Regarding their spray frequencies, 38.3% mentioned that they spray on weekly basis, 29.2% spray once a month, 23.3% spray every two weeks and 9.2% spray twice a week. The frequency of spraying was significantly (P = 0.001) associated with the age of the farmer. When asked about the effectiveness of their management actions, 59% of the farmers indicated that they were moderate, slightly effective (28%), not effective (20%) and only 13% indicated that they were effective. Most farmers (49%) mentioned that in order to avoid resistance development they alternate several different pesticides, 20% use integrated pest management, 10% reduce spray frequency, 9.2% increase pesticide dosage, 8.3% increase spray frequency and only 3.3% observe economic thresholds.

Table 6: Farmers' management actions on tomato

	Frequency	Percent (%)	Cum. %
3. Frequency of application of pesticides.			
Weekly	46	38.3	38.3
Twice a week	11	9.2	47.5
Every two weeks	28	23.3	70.8
Once a month	35	29.2	100.0
4. What influences your decision to spray?			
Pest presence	65	54.2	54.2
Spray programme	19	15.8	70.0
Damage symptoms	27	22.5	92.5
Economic thresholds	9	7.5	100.0
5. How effective are your current management tactics?			
Very effective	13	10.8	10.8
Slightly effective	28	23.3	34.1
Moderate	59	49.2	83.3
Not effective	20	16.7	100.0
6. Does spider mite develop resistance?			
Yes	120	100.0	100.0
No	0	0.0	100.0
7. When did you notice?			
This year	15	12.5	12.5
One year ago	77	64.2	76.7
Two or more years back	28	23.3	100.0
8. How do you avoid resistance development?			
Increase dosage	11	9.2	9.2
Alternate pesticides	59	49.2	58.4
Increase spray frequency	10	8.3	66.7
Reduce spray frequency	12	10.0	76.7
Integrated pest management	24	20.0	96.7
Observe economic thresholds	4	3.3	100.0

Discussion

The findings of this study that invertebrate pests are important constraints to profitable tomato production in Botswana are in agreement with Baliyan and Rao (2013); Obopile *et al*. (2008) [17]; Munthali *et al*. (2004) [16]. Tomato is attacked by several invertebrate pests but the most serious were spider mites followed by the tomato leaf miner. The results suggest that the spider mite problem was more pronounced in the greater Gaborone, Southern, Central and Francistown areas than Maun and Gantsi. This may be due to the fact that farmers in these areas undertake intensive production of tomato for the urban market. Spider mites are capable of inflicting serious damage to the tomato crop thereby affecting the income level of the farmer. These results are similar to Mwandila *et al*. (2013) and Bok *et al*. (2006) where heavy spider mite infestations drastically reduce yield. Apart from affecting yield levels, tomatoes with spider mite streaks on them fetch very low prices and are more likely to be discarded. Like in previous studies (Munthali 2009; Leungo 2012) [15, 13]. farmers depended immensely on pesticides to control invertebrate pests including spider mites. Most of the pesticides were mentioned in the Gaborone, Southern, Central and Francistown study areas. This is consistent with the level of production in these areas and consequently high pesticide usage. The high value put on tomatoes coupled with the ease of application and accessibility of pesticides make them the first choice for farmers to ensuring the production of good yields. However, pesticides are very expensive and increase the cost of production. Some farmers report reduced effectiveness of some formulations in controlling spider mites which forces them to seek new, more toxic and more expensive formulations. Labour that would otherwise be used for other aspects of production is diverted to spraying and management of spider mites. Not all pesticides mentioned by farmers are recommended for spider mite control. This highlights the unselective use of pesticides by some farmers. Moreover, several of the pesticides mentioned are classified under the highly hazardous and extremely hazardous (1A and 1B) categories by the World Health Organisation. This has harmful consequences on the environment and the health of farmers. More focus should be put on educating farmers on proper spray regimes to reduce the amount of active ingredients and frequency applied to crops. The development of economic decision levels can help farmers reduce the amount of pesticide applied and reduce the cost to the farmer. Farmers can be assisted to develop spray schedules for their fields to reduce the risk of resistance development. Since farmers do not seem to realise that weeds serve as alternate hosts for spider mites they should be made aware of the importance of weeding and general hygiene in controlling this pest. Integrated pest management (IPM) remains a vital tool for the management of vegetable pests therefore emphasis should be on the use, in addition to chemical control, of cultural and biological control to reduce dependence on synthetic pesticides for spider mite control. Farmers indicated that pest information was gained from personal experiences, agro-traders and fellow farmers. Our results that agricultural extension officers play a small role in information dissemination to vegetable farmers are similar to those of Madisa *et al*. (2010) [14] and TAHAAL (2000) who reported low delivery of advisory services to farmers. This has a negative impact on vegetable production since agricultural extension officers have a critical role to play in increasing farmers' awareness of pest management and pesticides usage. According to Abdollahzadeh *et al*. (2015) [1], farmers in close contact with extension officers are most likely to employ alternative methods of pest control, such as integrated pest management. Extension and education programs are critical in pest management, providing farmers with the knowledge for the selection of the appropriate pest control options (Prudent *et al*. 2007) [18]. An effective way of addressing the problems that hamper the productivity of the vegetable sub-sector is to develop and disseminate appropriate technologies and policies to farmers according to their social and economic situations (DAR 2000) [8]. Government should take into consideration farmers' sentiments and put emphasis on extension services, particularly for the vegetable sub-sector. In conclusion, innovations designed to control spider mites on tomatoes in Botswana should consider farmers' knowledge of, the pest, socio-economic circumstances and current management practices.

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