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Perceptions of Climate Change and Drivers of Insect Pest Outbreaks in Vegetable Crops in Limpopo Province of South Africa

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Abstract: Vegetable production is a source of income for smallholder farmers in Limpopo Province, South Africa. Vegetable production is constrained by the negative impacts of climate change and pests. This study assessed farmers' awareness of climate change, farmers' knowledge of insect pests and factors that influence insect pests' prevalence. The data were collected using quantitative and qualitative methods. The data were subjected to descriptive and bivariate analysis. About 84.5% of smallholder farmers were aware of climate change. Late rainfall (24.4%), long dry spells (15%) and increased drought frequency (19.4%) were highlighted as dominant indicators of climate change by farmers. Aphids (22.2%), *Bagrada hilaris* (12.5%) and *Spodoptera frugiperda* (10.2%) were the most prevalent insect pests within the Vhembe District. Warmer winters, dry spells and high temperatures were perceived by farmers to influence insect pests' prevalence within the district. It can be concluded that farmers are aware of climate change and climatic factors influencing pest prevalence within the district. Pest risk maps are needed to improve the preparedness of the government and farmers in controlling insect pests under changing climates.

Keywords: increased temperatures; pest incidence; problematic insect pests; warmer winters

1. Introduction

The consumption of vegetables is important to overcome human malnutrition, especially to people who are more vulnerable to the lack of nutrients [1]. Smallholder farmers in the Vhembe District grow vegetables such as *Brassica oleracea* (cabbage), *Solanum lycopersicum* (tomato), *Solanum nigrum* (black nightshade) and *Vigna unguiculata* (cowpea). These vegetables contain nutrients such as vitamin A, vitamin E, protein, iron, zinc and calcium, which are essential for human diet [2]. The demand for vegetables is increasing, especially in developing countries [3]. Vegetables are mostly constrained by weeds, insect pests and diseases [4]. Weeds account for 34% of crop losses while insect pests account for 16% loss of food crops [4]. Crop losses from insect pests are severe in subtropical and tropical areas due to high temperatures. The presence of pests has caused high pesticide use by farmers due to increased pest outbreaks [4].

Climatic changes such as increased temperatures, extreme weather events, and elevated carbon dioxide are expected to increase insect pests' pressure through an increase in the population geographical range of insect pests [5,6]. The global temperature is expected to rise by 3.4 °C by the end of the 21st century [7]. South Africa experiences high temperatures especially in provinces such as Limpopo, North West and KwaZulu-Natal [8]. These provinces are vulnerable to climatic changes and are expected to have a high prevalence of insect pests as a result of increased temperatures [9]. Most insect pests are tolerant to high temperatures [5]. This may result in difficulties in managing insect pest infestations, especially under smallholder farming conditions.

Temperatures may influence the number of generations of an insect pest. High temperatures may shorten the insect's life cycle, therefore, resulting in increased pest populations [10]. It is reported that aphids increase their developmental rate when temperatures are high. This could mean that with high temperatures, aphids will develop faster with increased numbers of generations and thus leading to increased aphid populations [11]. Increased temperatures during a winter season can also influence an increase in insect pest populations and migration rate. *Herlicoverpa amigera* (African bollworm) is a problematic insect pest that has been recorded to depend on increased temperatures and it can overwinter during the warm winter season [5].

Many insects usually move from unsuitable climatic conditions to conducive environments, which enhance their development [12,13]. It has been predicted that insects will shift by 6.1 km to the north per decade due to increased temperatures [14]. The migration rate of insects such as the lepidopteran moths and butterflies has been increasing and this is linked to increased temperatures [15]. However, insect pests respond differently to increased temperatures. Most insect pests are susceptible to temperatures of below 32 °C. Temperatures above 32 °C may have a negative impact on the development of insect pests, leading to increased mortality rates [16]. Heat stress may also affect the reproduction of insect pests negatively, especially during the summer season [16,17].

In Africa, smallholder farmers are most likely to be vulnerable to climate change because high temperatures are predicted to be experienced in African regions [18]. Very little is known on how smallholder farmers perceive climate change and how it influences the emergence and spreading of insect pests in South Africa, particularly Limpopo Province. This study aimed at assessing farmers' awareness of climate change and its indicators, and climatic factors that influence insect pests' prevalence. There are few studies that have documented farmers' knowledge on climate change and outbreaks of pests. Hence, the following question was asked: Is there a link between farmers' indicators of climate change and increased pest outbreaks in vegetable production in Limpopo Province? The study aimed to evaluate farmers' awareness of climatic change and climatic factors influencing insect prevalence in Limpopo Province.

2. Materials and Methods

2.1. Description of Study Site

The study was conducted in South Africa, Limpopo Province in the Vhembe District (22.7696° S, 29.9741° E; Figure 1). Vhembe District comprises of four municipalities, which are Mutale (22.5108° S, 30.8039° E), Thulamela (22.8922° S, 30.6200° E), Makhado (23.0462° S, 29.9047° E) and Musina (22.3953° S, 29.6963° E). Limpopo Province experiences high temperatures and it has been characterized by gradual increase in temperatures for the past decades (Figure 2). Vhembe District is characterized by semi-arid climates and dry spells with high temperatures throughout the year [19]. Dry spells and increased temperatures were hypothesized to influence increased pest populations within the district. In the Musina municipality, rainfall is around 372 mm in summer seasons [19] whereas rainfall is about 420 mm in the Mutale municipality [20]. Smallholder farmers in this district grow vegetable crops under dryland and irrigation systems. The dryland and irrigation system farmers have different farm practices. The dryland farmers usually grow crops such as maize, sweet potatoes and sorghum. Their choice of crops to grow is highly influenced by lack of water in the district. The irrigation system farmers grow crops such as tomato, cabbage, baby marrow, black nightshade and pumpkin. The dryland system smallholder farmers highly depend on rainfall, and the irrigation system smallholder farmers have access to water from boreholes, dams and rivers for irrigation purposes. The most common methods used for irrigation are drip irrigation and furrow irrigation for those who have access to water. Vegetables such as tomato, cabbage, black nightshade and mustard spinach were the common vegetables grown in this district during winter and summer seasons. These vegetables are mostly grown in areas ranging from 1 hectare and above. Maize and sweet potato are the main standard field crops grown in the Vhembe District. In most of these municipalities, vegetables are rotated with field crops occasionally.

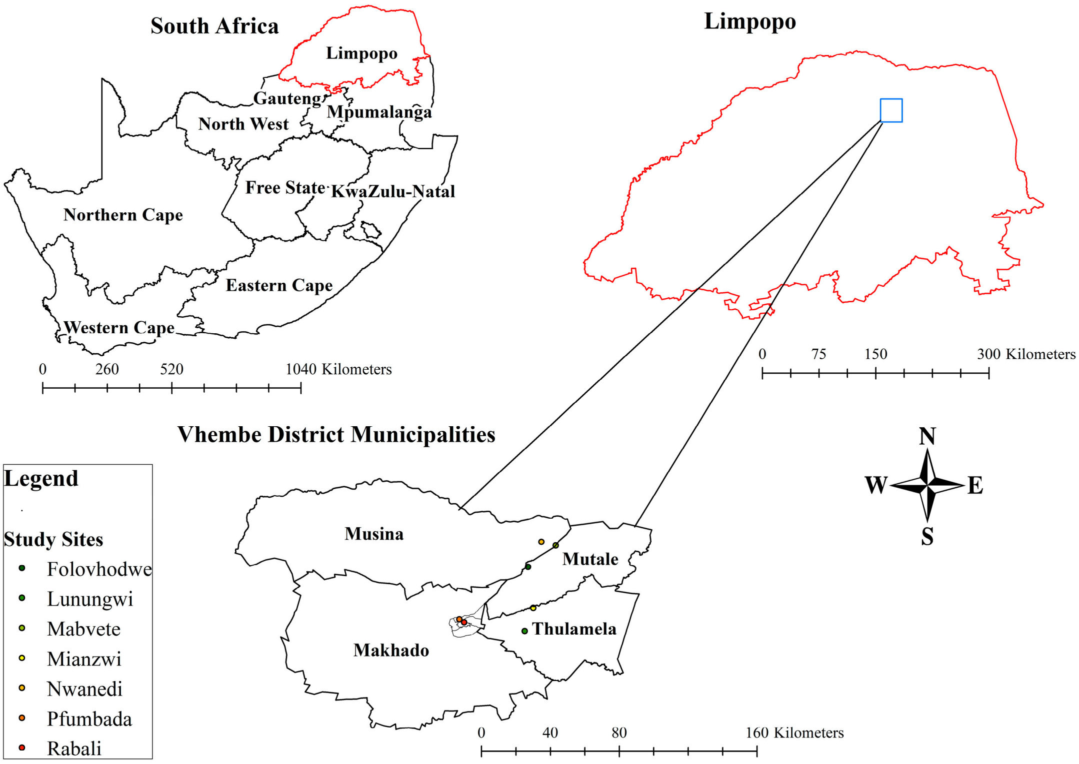

Figure 1. Map showing the study sites.

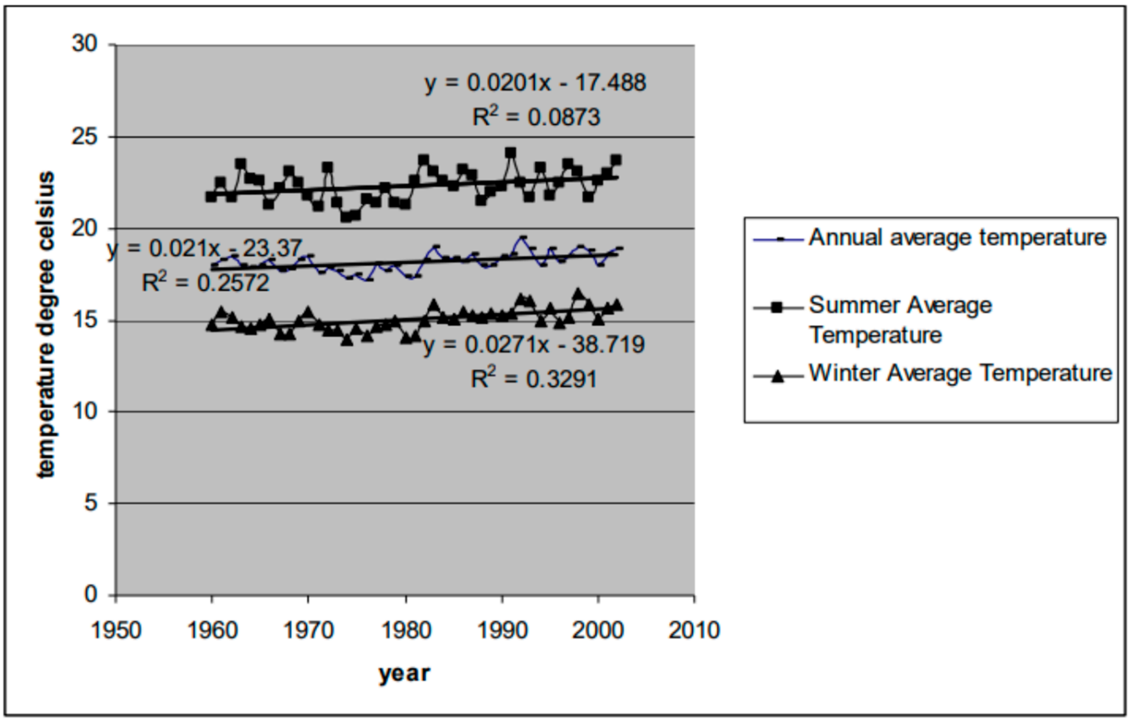

Figure 2. Trend of temperature data in Limpopo Province from 1960 to 2003 [21].

2.2. Sampling Approach

A multistage cluster sampling technique was employed to select respondents for the study. The first stage was the selection of one province in South Africa. Limpopo province was purposively selected because it is mostly affected by drought, unpredictable rainfall and high temperatures. Hence, farmers in the province are more vulnerable to climate change compared to farmers from other provinces in the country [8]. Simple random sampling technique was then used to select four municipalities within Vhembe District and two communities (dryland and irrigation systems) from each municipality were sampled. In the last stage, simple random sampling was used to select households from each community.

Data collection involved a combination of quantitative and qualitative research methods. The approach used was centered on understanding farmers' awareness of climate change and climatic factors influencing the prevalence of insect pests on vegetables. Farm household was the unit of analysis, and 161 households from the four municipalities were randomly selected based on the household lists provided by the agricultural extension officers (an agricultural extension officer is an advisor who operates between agricultural research institutions and farmers). The data collection tools used included semi-structured questionnaires, focus group discussion and key informant interviews. A semi-structured questionnaire was pretested on 10 respondents, modified and used for data collection. A structured checklist was used to collect qualitative data in Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) on community awareness of climate change to triangulate the household data. The checklist was used to collect data on the most prevalent pests in the municipalities and the main factors influencing pest prevalence in the municipalities. Three FGDs were conducted in each municipality. A separate group of seven female farmers, a separate group of seven male farmers and a combined group of seven female and seven male farmers participated in the FGDs. Farmers who participated in the FGDs did not participate in the quantitative surveys. The key informants used were extension officers and older farmers in the municipality. Qualitative data from KIIs and FGDs transcriptions were analyzed thematically. The results were then presented in the form of textual expressions and direct quotations.

Climate change awareness and emerging pests were coded as binary variables in SPSS. The data were descriptively analyzed to give frequencies and proportions. Since descriptive statistics were not enough to determine significant relationships between dependent and independent variables, chi-square tests were used to determine the association between variables. The dependent variable in this study was the pests and the independent variable was the climate. The associations tested were climatic changes and increased pests outbreaks, increased pest incidence and seasons. Cross tabulation was used to determine the significance between the variables of interest to see if there was a relationship between the independent and dependent variables. Chi-square was used to assess the degree of associations between the dependent variables and independent variables. The associations were tested to determine whether climatic changes influence the prevalence of insect pests in the district. The p-value was used to indicate the significance of the chi-square score.

3. Results

3.1. Farmers' Awareness of Climate Change in Vhembe District

The awareness of climate change was analyzed to compare the farmers' perception among the different municipalities, which are within the Vhembe District. The p-value (0.090) showed that there was no significant difference amongst the different municipalities with respect to farmers' awareness of climate change in Vhembe District (Table 1). About 84.4% of farmers were aware of climate change within the Vhembe District (Table 1). Within the irrigation system municipalities, the Thulamela and Makhado municipalities had the highest percentage of farmers who were aware of climate change. Within the dryland system municipalities, the Makhado municipality had the highest percentage of farmers who were aware of climate change within the district.

Table 1. Farmers' awareness of climate change across municipalities in Vhembe District.

Land Use	Municipality	Farmers' Response (%)	Total Number of Respondents	*p*-Value	Chi-Square
Dryland system	Mutale	11.3	23	**0.090**	**10.934**
	Thulamela	11.9	22		
	Makhado	12.5	24		
Irrigation system	Mutale	8.1	20		
	Thulamela	13.8	22		
	Makhado	13.8	25		
	Musina	13.1	24		

3.2. Indicators of Climate Change Mentioned by Smallholder Farmers

According to the chi-square test results, there were no significant differences regarding climate indicators within the municipalities and their land uses. The chi-square value reported was 28.788 (irrigation system) and 13.880 (dryland system). The *p*-value also showed that there was no significant difference between the municipalities from the two land uses with respect to perceptions of climate indicators by the farmers. Within the dryland system municipalities, increased drought frequency and late rainfall were mentioned as main indicators of climate change by farmers (Table 2). Within the irrigation system municipalities, late rainfall and increased drought frequency were also mentioned as the major indicators of climate change. Farmers who mentioned none, are those who were not aware of climate change in the district. There has been an increase in temperature by 1 °C for the past 43 years in Limpopo Province. The summer average temperature, annual temperature and winter average temperature have shown to be increasing over time, thus indicating climatic changes in Limpopo Province.

Table 2. Climate indicators perceived by farmers within municipalities in Vhembe District.

		Climate Indicators (%)									
Land Use	**Municipality**	**Late Rainfall**	**Long Dry Spells**	**Erratic Rainfall**	**Short Rainy Season**	**Increased Drought Frequency**	**High Temperatures**	**Warmer Winter**	**None**	**Chi-Square**	***p*-Value**
Dryland system	Mutale	7.2	2.9	2.9	1.4	8.7	4.3	0	5.8	**13.880**	**0.459**
	Thulamela	7.2	4.3	2.9	0	8.7	4.3	2.9	1.4		
	Makhado	7.2	8.7	4.3	0	5.8	0	5.8	2.9		
Irrigation system	Mutale	3.3	1.1	3.3	0	3.3	3.3	1.1	6.6	**28.788**	**0.119**
	Thulamela	7.7	5.5	1.1	2.2	4.4	0	3.3	0		
	Makhado	9.9	1.1	2.2	1.1	5.5	0	3.3	4.4		
	Musina	5.5	6.6	1.1	3.3	3.3	2.2	1.1	3.3		

3.3. New and Emerging Pests in Vhembe District

Regarding the insect pests' prevalence in the district, aphids were reported to be the most prevalent pests, followed by the *Bagrada* bug, whitefly and fall armyworm. *Tuta absoluta* and African bollworm were the least problematic insect pests in the district (Table 3).

Table 3. Perceptions of respondents regarding the prevalence of insect pests in Vhembe District.

Insect Pest	Farmers' Responses (%)
African bollworm	4.8
Aphids	22.2
Cutworms	9.9
Fall armyworm	10.2
Red spider mite	8.6
Beetle	6.3
Whitefly	11.4
Diamondback moth	5.5
Bagrada bug	12.5
Armored bush cricket	5.5
South American tomato leaf miner	3.1

Key informants were also interviewed on the most prevalent insect pests damaging vegetables and field crops. Armored bush cricket was reported to be a problematic insect pest of tomato and maize crops (Table 4). Aphids were problematic on green beans, black nightshade, mustard spinach and red pepper (Table 4). Results from focus group discussions showed that aphids were problematic in all municipalities except the Musina municipality (Table 5).

Table 4. Perception of the problematic insect pests across municipalities mentioned by key informants.

Municipality	Insect pest	Crop
Thulamela	Aphid	Cabbage, tomato, mustard spinach
	Diamondback moth	Cabbage
	Red spider mite	Tomato
	American bollworm	Tomato
	Whitefly	Tomato
	Bagrada bug	Mustard spinach
	Fall armyworm	Maize
	Stalk borer	Maize
	Armored bush cricket	Maize
Makhado	Aphid	Cabbage, black nightshade
	Diamondback moth	Cabbage
	Bagrada bug	Mustard spinach
	Stalk borer	Maize
	Fall armyworm	Maize
Mutale	Aphid	Cabbage
	Whitefly	Cabbage
	Snail	Cabbage
	Bagrada bug	Mustard spinach
	Red spider mite	Pumpkin
	Armored bush cricket	Maize
	Stalk borer	Maize
	Fall armyworm	Maize
Musina	Armored bush cricket	Tomato
	Red spider mite	Tomato
	Aphid	Tomato, baby marrow
	American bollworm	Tomato
	Thrips	Tomato
	Tomato leaf miner	Tomato, pumpkin
	Whitefly	Tomato, pumpkin
	Fruit fly	Baby marrow
	Stalk borer	Maize

Table 5. Perception of the problematic insect pests across municipalities mentioned in a Focus Group Discussions.

Land Use	Municipality	Pest
Dryland system	Thulamela	Fall armyworm, red spider mite, stalk borer, *Bagrada* bug, aphids, diamondback moth, whitefly
	Makhado	Red spider mite, cutworm, *Bagrada* bug, aphids, locust, armored bush cricket, blister beetle, ants
	Mutale	Fall armyworm, stalk borer, *Bagrada* bug, locust, aphids, blister beetle, cutworm, red spider mite, whitefly
Irrigation system	Thulamela	Fall armyworm, stalk borer, cutworm, aphids, beetle, *Bagrada* bug, whitefly
	Makhado	Fall armyworm, red spider mite, *Bagrada* bug, cutworm, blister beetle, aphids, armored bush cricket
	Mutale	Stalk borer, fall armyworm, *Bagrada* bug, diamondback moth, aphids, weevils, red spider mite
	Musina	Whitefly, south American tomato leaf miner, diamondback moth, red spider mite, local leaf miner, thrips

3.4. Factors Influencing Insect Pest Incidence across Municipalities

Responses were significantly different regarding factors influencing pest incidence between the dryland and irrigation municipalities in the district (Table 6). The majority of farmers in the dryland system municipalities mentioned high temperature as a factor influencing increased pest incidence. The highest percentage of respondents was from the Mutale municipality (17.4%) and the lowest was found in the Makhado municipality (2.9%; Table 6). With respect to warmer winter influencing increased pest incidence, Thulamela municipality had the highest respondents amongst the dryland system municipalities (Table 6). In the irrigation system municipalities, 38.5% of farmers mentioned that dry spells were influencing increased pest incidence. Majority of farmers also mentioned that warmer winters influenced increased pest incidence within the irrigation system municipalities (Table 6). Farmers who participated in the focus group discussions mentioned that warmer winters and increased temperatures were influencing insect pest prevalence in the Vhembe District (Table 7). Poor phytosanitary measures at country borders were mentioned to be influencing insect pest incidence by farmers from the Thulamela and Musina municipalities (Table 7).

Table 6. Factors influencing insect pest incidence mentioned by smallholder farmers across municipalities.

		Factors Influencing Pest Incidence							
Land Use	Municipality	Warmer Winter	Dry Spells	Pesticide Resistance	Poor Pest Management	Low Rainfall	High Temperature	Chi-Square	*p*-Value
Dryland system	Mutale	4.3	4.3	0	1.4	5.8	17.4	**21.648**	**0.017**
	Thulamela	13.0	7.2	1.4	0	1.4	8.7		
	Makhado	10.1	7.2	2.9	7.2	4.3	2.9		
Irrigation system	Mutale	5.5	7.7	0	4.4	0	4.4	**35.682**	**0.002**
	Thulamela	12.1	12.1	0	0	0	0		
	Makhado	11.0	4.4	4.4	3.3	1.1	3.3		
	Musina	3.3	14.3	3.3	2.2	3.3	0		

Table 7. Factors influencing insect pest prevalence mentioned in FGDs by smallholder farmers.

Land Use	Municipality	Reasons for Pest Prevalence
Dryland system	Thulamela	Increased temperature, low rainfall, poor phytosanitary measures at country border
	Makhado	Increased temperature
	Mutale	Increased temperature, erratic rainfall, trade of agricultural seeds
Irrigation system	Thulamela	Increased temperature, warmer winter
	Makhado	Warmer winter, increased temperature, poor sanitation
	Mutale	Increased temperature, lack of chemicals
	Musina	Increased temperature, poor chemical application, trade of agricultural inputs, poor phytosanitary measures at country border

3.5. Insect Pest Prevalence across Seasons

Results revealed that there was a significant difference between perceptions regarding pest prevalence across seasons in the different municipalities reporting a *p*-value of 0.357 in the dryland system and 0.002 in the irrigation system. About 56% of farmers from the irrigation system municipalities mentioned that insect pests were more prevalent in the summer season, while 31.9% of farmers mentioned that insect pests were prevalent in the winter season (Table 8). Within the dryland system municipalities, 62.3% farmers mentioned that insects were more prevalent in the summer season and 30.4% mentioned that insect pests are more prevalent in winter season (Table 8).

Table 8. Insect pest prevalence across seasons within municipalities.

		Seasons						
Land Use	**Municipality**	**Summer**	**Autumn**	**Winter**	**Spring**	**All Year Round**	**Chi-Square**	***p*-Value**
Dryland	Mutale	23.2	0	8.7	0	1.4	**6.621**	**0.357**
	Thulamela	18.8	2.9	10.1	0	0		
	Makhado	20.3	0	11.6	0	2.9		
Irrigation	Mutale	6.6	0	13.2	0	2.2	**21.319**	**0.002**
	Thulamela	19.8	0	3.3	0	1.1		
	Makhado	14.3	0	5.5	0	1.7		
	Musina	15.4	0	9.9	0	1.1		

4. Discussion

It is evident from the results (Table 1) that smallholder farmers were aware of climate change and its indicators. Long dry spells, erratic rainfall, high temperature and warmer winters were among the dominant climate change indicators that farmers highlighted. The magnitude of community awareness of climate change mirrors its level of exposure to climate risks. The study revealed that 84.4% of the respondents were aware of climate change whereas 15.6% were not aware of climate change. The results are consistent with the findings of Mandleni and Anim [22] who reported that 85% of the farmers from South Africa were aware of climate change. The findings are also supported by the climatic data for Limpopo Province which revealed an increase in temperature and decrease in rainfall respectively, which agree well with other studies [21,23]. Winter temperatures, summer temperatures and average temperatures in Limpopo Province have increased gradually, and 81% of farmers in the Limpopo Basin have reported a decrease in rainfall, delay of the start of rainfall season and a shorter rainy season for the past thirty years [24]. Therefore, this explains why farmers in the district have highlighted warmer winters, late rainfall, increased drought frequency, long dry spells as major indicators of climate change. Farmers' awareness of climate change is a critical factor in the implementation of effective measures for climate change adaptation [25]. Smallholder farmers in this district apply adaptive strategies such as drilling boreholes for irrigation, using drought-resistant varieties and fertilizer application [19]. However, poor resource farmers in this district who highly depend on rainfall are more vulnerable to climate change impacts compared to the irrigation system farmers.

Problematic pests were perceived to be more prevalent in the summer and winter season by approximately 58.8% and 31.3% of farmers respectively. For the past 43 years, temperatures in this province have increased gradually by 1 °C [8]. Average winter temperatures are about 20 °C and summer temperatures are higher than 25 °C [26]. These temperatures are optimal for insect pest survival and fitness. Farmers mentioned that the increase in insect pests was resulting from dry spells, high temperatures, warmer winters and poor pest management. Increased temperatures resulting in the warmer winter season can result in mortality reductions of insect pests, and therefore influencing high population rates, which may lead to increased crop damage [27]. A lack of chemicals and poor insect pest management are the main critical factors that result in increased pest resistance to pesticides.

Farmers mentioned aphid, *Bagrada* bug, whitefly and fall armyworm as the most problematic insect pests within the district. These insect pests require high temperatures, which are below their optimal level for survival [28]. Increased temperatures below insect optimal level influence an increase of pest generations and increased pest distribution, [6] and this means that the more the pest population, the higher the crop damage, thus leading to increased vulnerability of smallholder farmers to pest outbreaks. An increase in aphids and whiteflies could result to an increase in virus transmission to crops and thus, affecting crop yield [9]. *Tuta absoluta* was the least prevalent insect pest within the district. *Tuta absoluta* is a tomato pest and it was more problematic in Musina municipality. This insect pest was found in abundance in Musina municipality because tomato crops were widely grown in this area. Limpopo Province produces 66% of all tomatoes produced in South Africa [29] and the major producers in this province are the Letaba and Musina areas, which grow the crop on 3259 ha and 859 ha respectively [30]. Farmers mentioned that the pest was first detected in Limpopo Province in 2016. This is consistent with the study conducted by Visser et al. [31] who reported the first detection of *Tuta absoluta* in South Africa during August and October 2016. The fall armyworm was mentioned to be feeding on maize crops within the district. This pest was first detected in the early months of 2017 in Limpopo Province and was causing severe damage to maize crops [32]. The dry spells and warmer conditions may influence the spread of these pests since they require warmer environments to enhance their survival and increase their reproduction rate [33]. Farmers who are growing these crops in other provinces with similar climatic conditions as Limpopo Province are expected to be vulnerable to pest damage influenced by climate change.

5. Conclusions

The study assessed farmers' perceptions on climate change indicators and their influence on insect pest prevalence. Most farmers were aware of climate change as evidenced by their ability to articulate the key indicators of climate change such as long dry spells, late rainfall, high temperatures and warmer winter seasons. The most problematic insect pests mentioned were the *Bagrada* bug (*Bagrada hilaris*), aphids, whiteflies and fall armyworm (*Spodoptera frugiperda*). Very little is known on the factors influencing insect pests' prevalence in Limpopo Province. However, in this study, farmers perceived that the prevalence of these insect pests was influenced by warmer winter, dry spells and increased temperatures. Farmers mentioned that poor pest management also influenced the prevalence of insect pests within the district. Insect pests were more prevalent during the summer and winter seasons.

We hypothesized that increased temperature experienced might lead to increased populations of problematic insect pests. Limpopo Province is characterized by dry spells and increased temperatures. Therefore, this explains the increased pest prevalence as mentioned by farmers. However, increased temperatures beyond optima may affect the survival of insect pests negatively. Smallholder farmers in other provinces with similar climate conditions as Limpopo Province will be vulnerable to increased insect pests. The farmers' awareness of climate change can be strengthened through thorough training of farmers on climate change and variability and adoption of enhanced technologies such as planting improved crop varieties, access to climate information and improved pest management strategies. There is a need for early warning systems and risk maps of new and emerging pests for farmers to be aware of and to prepare management measures of these pests under changing climates. More research is needed on the study of the biology and behavior of these insect pests under different temperature conditions.

Author Contributions: M.M.P. Conceptualization: obtained the data, created figures and tables. M.M.P. and S.L. ran the statistical analysis. M.M.P. Writing: prepared the original manuscript, P.M. reviewed the methodology, statistical analysis and did the supervision. All authors contributed in the discussion of the results and reviewed the manuscript. All authors reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

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