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Host Preference of *Aulacaspis tubercularis* Newstead (Homoptera: Diaspididae) to Different Mango Cultivars in East Wollega and East Shewa Zones, Ethiopia

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Abstract: Scale insects are serious pests of mango (*Mangifera indica*) in many mango-producing countries of the world, including Ethiopia. Among the many scale insects, the white mango scale, *Aulacaspis tubercularis* Newstead (Homoptera: Diaspididae), is a key insect pest of mango causing devastating losses. The current experiment was conducted to study the host preference of *A. tubercularis* to different mango cultivars grown at Raj Agro Industry Loko Mango Commercial Farm (RAILMCF) in the East Wollega and Melkasa Agricultural Research Center (MARC) mango orchards in the East Shewa zones. Nine mango cultivars were included in the study, *viz*. Kent, Tommy Atkins, Apple, Kiett, Dodo, Alphonso, Van Dyke, Sabre, and Local cultivars. Among the mango cultivars included in this study, Dodo and Alphonso were grown only at RAILMCF, whereas Van Dyke and Sabre cultivars were grown at MARC. The host preference of *A. tubercularis* was determined by counting *A. tubercularis* clusters (ATCs) formed on infested mango leaves over twelve consecutive months from January to December 2018. Four mango trees from each cultivar were randomly selected, and 12 mango leaves were collected at four cardinals from the upper, middle, and lower parts of the tree at monthly bases. The results of the study revealed that the peak maximum mean ATCs were recorded during the month of June on local cultivars at RAILMCF and MARC, with values of 50.97±4.62 and 49.22±5.13, respectively. The minimum mean average clusters of *A. tubercularis* aggregation were recorded on the Dodo cultivar (0.47±0.56) at RAILMCF and on the Apple cultivar (0.33±0.48) at MARC during the month of November. At both study sites, the mean annual minimum ATCs formation was recorded on Sabre (2.14±0.41) and Vandyke (2.29±0.33), followed by Dodo (4.26±0.63) and Apple (5.20±1.02), respectively. The variation in cluster formation of *A. tubercularis* on different mango cultivars and the sampling protocol presented here could be used as initial preliminary information for future research on developing resistant cultivars for integrated pest management methods of *A. tubercularis*.

Keywords: *Aulacaspis tubercularis*, Cultivars, Clusters, Host Preference *Mangifera indica*, Infestation

1. Introduction

Mango (*Mangifera indica* L.) has become a major fruit crop of the tropics and subtropics, particularly in Asia, where mango has always been the most important fruit crop and where it has been considered the 'king of fruits' [1, 2]. It is commercially grown in over 100 countries in the world, of which more than 65 countries each produce more than 1,000 tons a year [3]. The total world production was estimated at over 55 million tons from a production area of 5.75 million hectares with a mean yield of 9.63 t ha^{-1} [4]. Annual mango production in Ethiopia is 151,331.24 tons, with land coverage of 20,782.10 ha and an average yield of 6.86 t ha^{-1} [5]. Pertinent to its global demand, mango could play a significant role in foreign currency generation, and accordingly, its production has been on a rise from time to time [6].

Among fruit crops grown in Ethiopia, mango ranked 2nd and 3rd in total production and area coverage, respectively [7-9]. Improved mango varieties grown in Ethiopia include Kent, Keitt, Tommy Atkins, Dodo, and Apple Mango [10]. A new mango cultivar called Alphonso was introduced to Ethiopia, East Wollega zone from India, by 'Green Focus Ethiopia LTD' through its investment project in 2001 and 2002 [11], now owned by Raj Agro Industry Loko Mango Commercial Farm. Sabre and Van Dyke cultivars are also newly introduced mango cultivars at MARC for adaptation trials, and the trees are few in number (personal observation).

Mango plants are attacked by a number of insect pests, among which white mango scale, *Aulacuspis tubercularis* Newstead (Homoptera: Diaspididae), is the most devastating pest. *A. tubercularis* was recorded for the first time in 2010 on the Alphonso mango cultivar in East Wollega zones, Ethiopia [11]. Damage to mango plants is due to the sucking of 'cell sap' from tender leaves, stems, inflorescences and even from growing mango fruits, which makes it unfit for human consumption [12, 13]. Currently, *A. tubercularis* has become a devastating pest of mango in western Ethiopia. Due to this alien pest infestation, mango production and productivity as well as fruit storability and quality on the market are greatly reduced [11].

Alternative pest management methods are available in mango-growing countries, but they remain ineffective for the management of *A. tubercularis.* There are limited published researches results concerning the host preference of *A. tuberculars* for different mango cultivars, there are no detailed reports exploring the resistance/susceptibility of mango cultivars to *A. tubercularis.* Therefore, the present study aimed to determine and rank the host preference (susceptibility/resistance) different mango cultivars of commercial value for *A. tubercularis* in Ethiopia. Overall, the results of this study intended to support decision making among researchers and growers for integrated pest management of this pest.

2. Materials and Methods

2.1. Description of the Study Area

The present study was carried out in two mango orchards of the East Wollega and East Shewa zones at the RAILMCF and MARC mango orchards, respectively. RAILMCF is located in Guto Gida district of East Wollega Administrative Zone (09°18'.908"N 36°31'.437"E) at a distance of 373 km from Addis Ababa and 45 km from Nekemte, the zone town, in the northwest direction. MARC (06°24'.410"N 39°17'.410"E) is located in the Adama district of the East Shewa zone at approximately 107 km from Addis Ababa, the capital city of Ethiopia.

The rainfall pattern of the East Wollega zone is unimodal, with little or no rainfall in January and February, gradually increasing to a peak between May and August and moderate rainfall from September to October, then decreasing from November to December. The rainfall pattern of the East Shewa zone is bimodal; the small rainy season (*Belg*) occurs from March to May, and the main rainy season (*Kiremt*) lasts from June to September [14]. The selected districts (Guto Gida and Adama) represent mango-producing agro-ecological zones. The altitude, rainfall, average annual mean, maximum and minimum temperatures of the study area (RAILMCF and MARC) is shown in Table 1. The mean average of the two years (2019 and 2020) relative (RH) humidity at RAILMCF was 68.5% and for Melkasa was 61.82%.

Table 1. *Geographical coordination and climate conditions at RAILMCF and MARC.*

Study site	Geographical coordination		Altitude	Annual mean temperature (°C)			Annual average
	Latitude (N)	Longitude (E)	(m.a.s.l.)	Max	Min	Average	Rainfall (mm)
RAILMCF	9°18.908	36°31.473	1403	34.5	8.3	27.2	1728
MARC	8°24.744	39°17.410	1550	34.3	9.1	25.2	968.8

Source: Ethiopian National Meteorology Agency and 'NASA' 'POWER' global meteorology, surface solar energy and climatology data https://power.larc.nasa.gov/data-access-viewer/

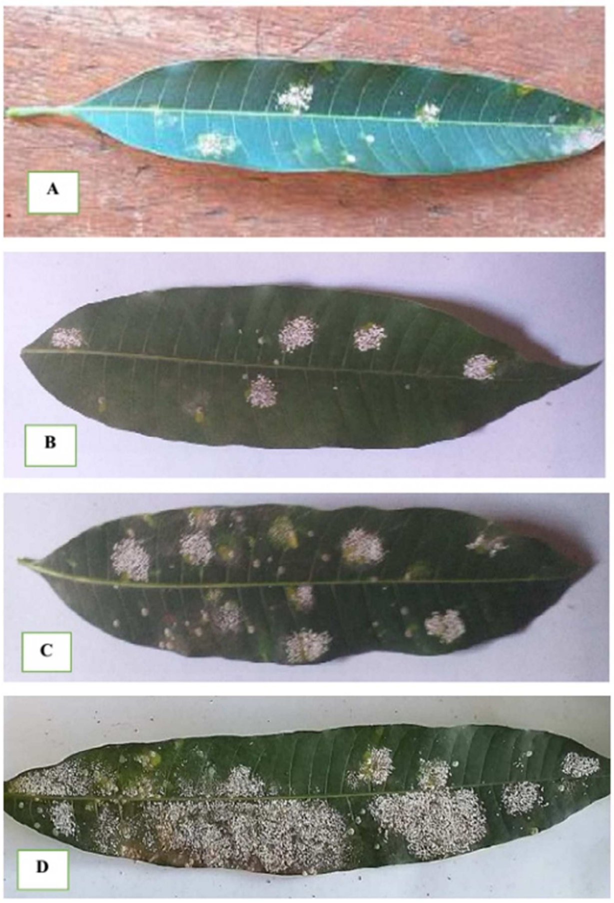
2.2. Experimental Materials and Sampling Procedures

The study was conducted from January to December 2018 to examine the host preference (resistance/susceptibility) of *A. tubercularis* on existing mango cultivars in the study areas. There are seven mango cultivars grown at the RAILMCF orchard, namely, Kent, Apple Tommy Atkins Keitt, Dodo, Alphonso and Local mango. Likewise, there are seven mango cultivars grown at the MARC mango orchard *viz*. Kent, Keitt, Tommy Atkins, Apple, Van Dyke Sabre and local cultivars. Four mango trees from each cultivar, almost equal in height, vegetative growth and age, were selected, and marked for data recording on *A. tubercularis* cluster (ATC) formation. Selected trees were labeled with 'quartz paint'. All the experimental trees were kept free from insecticidal spray during the course of investigation. The total numbers of ATCs formed on the upper and lower surfaces of the mango leaves were counted and recorded in the field during the sample collection date, and presented as the mean number of ATCs formed per leaf to express its aggregation size.

2.3. Data Collection on A. tubercularis Cluster Formation and Mango Leaf Infestation Rating

From the selected mango trees, samples of 12 leaves were randomly picked monthly from the terminal shoots of each tree at four cardinals from the upper, middle and lower parts of the tree. A total of 4,032 mango leaf samples were collected at each study site over 12 months. The mango leaf infestation rating was conducted by visual counting of ATCs formed on leaves following the techniques [15] scoring scale methods, with some modifications. This scoring method is divided into four grades, *i.e.*, 0−3, based on the number of clusters: 0 = complete absence of ATCs; 1 = 1−3 ATCs per leaf; 2 = 4−6 ATCs per leaf, and 3 = greater than 6 ATCs per leaf. Inspection and data collection were carried out during the last weeks of the months on days 26−27 and 29−30 at MARC and RAILMCF, respectively. The mean cluster population grade for each cultivar was calculated and rounded to the nearest value. These grades were used for grouping the cultivars into four categories *viz*. leaves having zero grade of ATC population were grouped as less preferred/resistant (Category I). Leaves having a grade 1 ATC population were grouped as moderately preferred/ resistant (Category II), leaves with a grade 2 ATC population were grouped as the preferred/susceptible cultivars (Category III), and leaves with a grade 3 ATC population were grouped as highly preferred/susceptible cultivars (Category IV).

Following [16] with some modifications, the leaf injury level (Figure 1) was estimated as the percent infested leaf injury index. This injury level is rated as 0 to ≤ 5% = ± 50 sessile scale insects per leaf; 6 to 15% = ±125 sessile scale insects per leaf; 16 to 30% = ±250 sessile scale insects per leaf; 31 to 50% = ± 500 sessile scale insects per leaf; 56 to 75% = ± 750 sessile scales and 76 to 100% = ±1000 sessile scale insects per leaf.



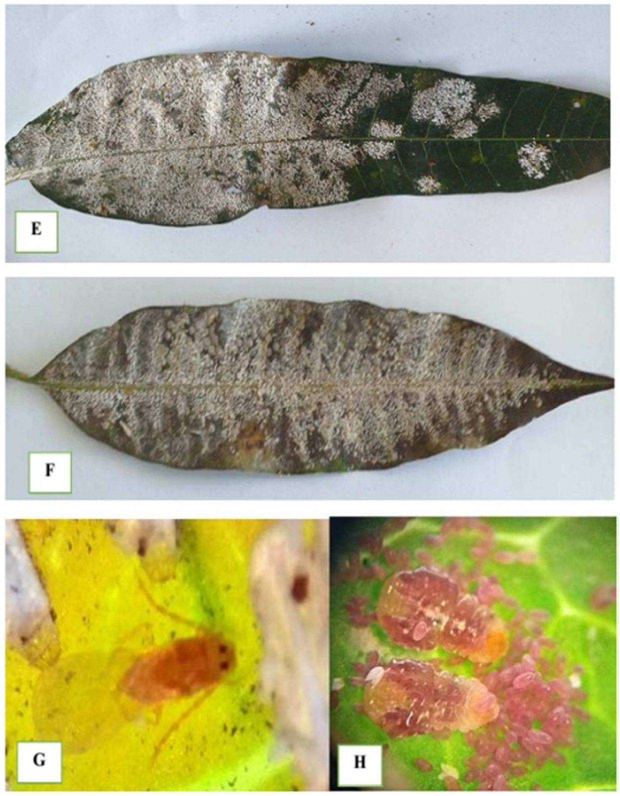


Figure 1. *Mango leaf infested by A. tubercularis and damaged leaf area intervals used to measure plant physiological parameters; where, 0 to ≤ 5% = ± 50 scales (A); 6 to 15% = ±125 scales (B); 16 to 30% = ±250 scales (C); 31 to 50% = ± 500 scales (D); 56 to 75% = ± 750 scales (E); 76 to 100% = ±1000 scales (F); adult male (G) and adult female with eggs (H). Adopted from [16].*

The meteorological data of the study area, such as temperature (minimum and maximum), relative humidity and rainfall, were collected from the National Meteorology Agency of the country and from Google ′NASA′ ′POWER′ global meteorology, surface solar energy and climatology data https://power.larc.nasa.gov/data-access-viewer/.

2.4. Data Analysis

Data were analyzed using SPSS Statistics software package for Windows Version 20.0 [17]. Data are expressed as the means and standard deviation (±SD). The standard deviation was computed for numerical variables, and correlation analyses were carried out between *A. tubercularis* mean cluster populations with weather parameters *viz*. minimum temperature (Tmin) and maximum temperature (Tmax), rainfall (Rf) and relative humidity (RH) separately, and the significance was tested at $p < 0.05$ [18].

3. Results

3.1. Aulacaspis tubercularis Cluster (ATC) Formation and Mango Leaf Infestation Rating

Aulacaspis tubercularis cluster (ATC) formation and mango leaf infestation rating on existing different mango cultivars at two study sites were presented in Table 2. At

RAILMCF orchard, seven mango cultivars were evaluated against *A. tubercularis* infestation under natural infestation conditions. There were highly significant differences (P<0.05) among the cultivars in *A. tubercularis* cluster formation. The results showed that the maximum mean annual ATC formation was observed on local (21.44±2.08) and alphonso (20.62±2.09) mango cultivars (Category IV), followed by Tommy Atkins (18.48±1.81) (Category III), while the remaining cultivars, Kent (12.42±1.23) and Kiett (11.42±0.77b), were considered moderately preferred (Category II). The lowest mean values of clusters were recorded from the Dodo (4.26±0.63), followed by the Apple (6.11±0.49) (Category I) cultivar. The position of host preference/susceptibility of the tested mango cultivars to *A. tubercularis* in ascending order was Dodo > Apple > Kiett >Tommy Atkins >Kent > Alphonso >Local mango cultivars.

Similarly, at MARC mango orchard, wide ranges of variation were observed among the studied mango cultivars. The results showed that the maximum mean (±SD) annual ATC formation was observed on local mango (20.07±1.19) (Category IV), followed by Tommy Atkins (16.38±1.19), which could be considered a preferred (susceptible) cultivar (Category III). The lowest mean (±SD) annual ATC formation was recorded on Sabre (2.14±0.41) and Van Dyke (2.29±0.33), followed by the Apple (4.28±0.42) cultivar (Category I), which were also considered less preferred or resistant cultivars. The remaining cultivars, Kiett (9.20±0.71) and Kent (13.18±1.33), were considered moderately preferred (Category II). The position of host preference/susceptibility of the tested mango cultivars to *A. tubercularis* in ascending order was rated as Sabre >Van Dyke > Apple > Kiett > Kent >Tommy Atkins >Local mango cultivars.

In general, the results obtained in the current study revealed that ATCs were recorded in all investigated mango varieties throughout the year with fluctuating densities. This pest has three different categories of seasonal fluctuations, with less cluster formation in the months of October to January; moderate cluster formation in the months of February, March, April, August and September; and high cluster formation in the months of May to July throughout the year. In general, the infestation of *A. tubercularis* on the tested mango cultivars was higher at RAILMCF than at MARC in all months except November and December.

Table 2. *Mean ATCs population density per mango leaf in RAILMCF and MARC mango orchards indicating host preference of A. tubercularis on different mango cultivars.*

Mango Cultivars	**Mean ± SD *Aulacaspis tubercularis* cluster formation per mango leaf**			**Resistance category**
	RAILMCF	**MARC**	**Mean**	
Tommy Atkins	18.48±1.81d	16.38±1.19cd	17.43±1.86cd	Category III
Kent	12.42±1.23c	13.16±1.29c	12.79±1.31c	Category II
Kiett	11.42±0.77bc	9.20±0.71b	10.31±1.34b	Category II
Apple	6.11±0.49ab	4.29±0.42a	5.20±1.02ab	Category I
Dodo	4.26±0.63a	-	4.26±0.63a	Category I
Alphonso	20.62±2.09d	-	20.62±2.09d	Category IV
Van Dyke	-	2.29±0.33a	2.29±0.33a	Category I
Sabre	-	2.14±0.41a	2.14±0.41a	Category I
Local mango	21.44±2.08d	20.07±1.19d	20.75±1.82d	Category IV

Means with different letters within the column are significantly different at P<0.05

The average mean maximum ATCs formation was recorded at RAILMCF in June (31.73±16.19), followed by May (28.49±13.10). Similarly, at the MARC, the average mean maximum cluster formation was recorded in the month of June (24.21±17.23), followed by the month of May (21.00±14.92). On the other hand, the average mean minimum ATCs were recorded in November at RAILMCF (1.25±1.24), followed by MARC (1.60±1.85). The mean average ATCs population density on different mango cultivars at both study sites is presented in Tables 3 to 6. The trend in the increase in cluster formation from January to June with an increase in precipitation and relative humidity showed that these six consecutive months are favorable seasons for the development and buildup of *A. tubercularis* populations.

Table 3. *Mean (±SD) monthly ATCs population density on different mango cultivars during 2019 cropping season at RAILMCF and MARC.*

Months	**Annual mean (Mean ± SD) *Aulacaspis tubercularis* clusters (ATCs) formation for the two sites**		
	RAILMCF	**MARC**	**Mean**
January	4.37±2.54a	3.46±2.50a	3.91±2.56a
February	9.69±5.63b	6.34±4.48ab	8.02±5.35b
March	16.02±9.46c	9.83±6.69b	12.92±8.75bc
April	22.61±12.44d	15.95±11.96c	20.06±13.03d
May	28.49±13.10e	21.00±14.92d	24.75±14.52d
June	31.73±16.19e	24.21±17.23d	27.97±17.12e
July	22.20±11.71d	15.18±12.36c	17.91±12.03c
August	13.13±6.28bc	8.66±6.36b	10.90±6.70b
September	7.55±3.86ab	4.71±3.67a	6.13±4.02ab
October	3.69±2.22a	2.81±2.34a	3.25±2.32a

Months	Annual mean (Mean ± SD) *Aulacaspis tubercularis* clusters (ATCs) formation for the two sites		
	RAILMCF	**MARC**	**Mean**
November	1.25±1.24a	1.60±1.85a	1.43±1.59a
December	1.71±1.30a	2.01±1.62a	1.86±1.49a
Mean	13.54±8.20bc	9.65 ±6.68b	11.59±6.88bc

Means with different letters within the column are significantly different at P<0.05

Table 4. *Mean (±SD) monthly ATC formation/population density per mango leaf at RAILMCF indicating host preferences on different mango cultivars in the 2019 cropping season.*

Months	Mean ±SD *Aulacaspis tubercularis* clusters (ATCs) formation on different mango cultivars								
	Tommy Atkins	**Kent**	**Kiett**	**Apple**	**Dodo**	**Sabre**	**Van Dyke**	**Alphonso**	**Local mango**
January	6.31±1.74a	3.08±0.97a	2.81±1.56a	2.42±0.73a	1.83±0.81a	NP	NP	7.28±1.56b	6.86±1.57b
February	13.19±3.74b	6.83±1.25b	8.19±1.95b	4.39±0.87b	3.17±1.00b	NP	NP	15.03±3.16c	17.06±3.93c
March	23.81±4.89c	11.83±2.38c	12.33±2.20c	6.25±1.11b	4.58±1.20c	NP	NP	27.36±4.65d	25.94±4.68d
April	32.67±4.23d	17.83±3.03c	17.94±2.64c	9.75±1.57c	6.25±1.08d	NP	NP	38.31±5.81e	35.53±4.33f
May	37.28±4.29d	24.89±3.45d	26.86±3.97d	14.11±2.56d	8.22±1.22e	NP	NP	40.89±4.64e	43.44±5.32 g
June	43.48±4.44e	29.72±4.55d	30.61±4.73d	11.92±1.93d	9.78±1.40e	NP	NP	49.56±4.92f	50.97±4.62 g
July	27.00±5.25c	24.47±5.04d	16.67±3.08c	9.11±1.51c	7.36±1.10d	NP	NP	32.06±5.69d	38.72±6.35f
August	18.06±4.39b	13.69±3.02c	9.72±1.49b	7.92±1.44c	5.00±0.93c	NP	NP	18.11±5.15c	19.44±4.78c
September	10.64±3.29b	7.86±2.44b	7.00±1.01b	3.89±0.79b	2.33±0.76b	NP	NP	10.64±3.48c	10.50±2.47b
October	5.61±1.96a	4.39±1.34a	2.97±1.03a	1.64±0.87	1.19±0.75a	NP	NP	4.42±2.06b	5.64±1.78b
November	1.92±1.57a	2.22±1.48a	0.86±0.76a	0.81±0.71a	0.47±0.56a	NP	NP	1.14±1.05a	1.33±1.24a
December	2.11±1.39a	2.14±1.61a	1.06±0.75a	1.19±0.79a	0.92±0.84a	NP	NP	2.72±1.21a	1.86±1.22a
Mean	18.48±1.81	12.42±1.23	11.42±0.77	6.11±0.49	4.26±0.63	NP	NP	20.62±2.09	21.44±2.08

Means with different letters within the column are significantly different at P<0.05
N. B.: The cultivars indicated by 'NP' designated that the cultivars were not present (NP) in the indicated orchard.

Table 5. *Mean (±SD) monthly ATC population density per mango leaf at MARC indicating host preferences of A. tubercularis on different mango cultivars in January 2018 to December 2019 cropping seasons.*

Months	Mean ±SD *Aulacaspis tubercularis* clusters (ATCs) formation on different mango cultivars								
	Tommy Atkins	**Kent**	**Kiett**	**Apple**	**Dodo**	**Alphonso**	**Van Dyke**	**Sabre**	**Local mango**
January	4.92±1.57a	3.64±1.27a	3.42±1.08a	1.75±0.65a	NP	NP	1.31±0.92a	1.36±1.02a	7.81±1.85a
February	10.44±3.38b	8.53±2.17b	6.03±1.28b	2.97±0.77b	NP	NP	1.78±1.07b	1.97±1.00b	12.64±2.70b
March	16.94±4.19b	15.33±3.23c	9.03±2.12b	4.42±0.94c	NP	NP	2.75±0.69b	2.69±0.82b	17.61±2.48b
April	28.69±5.18c	24.86±4.48d	14.11±2.79c	6.36±0.93d	NP	NP	3.03±1.00d	3.61±2.25c	31.47±5.55c
May	35.36±2.77d	32.61±5.47d	22.25±3.36d	8.31±1.09e	NP	NP	4.25±1.11d	3.94±1.90c	40.64±4.96d
June	41.42±3.47d	33.39±4.62d	26.44±3.93d	10.03±1.52e	NP	NP	5.06±1.24c	3.11±1.47c	49.22±5.13d
July	29.11±4.86c	19.17±4.68c	12.56±2.61c	6.94±0.89d	NP	NP	2.72±0.88b	1.56±1.05a	34.19±5.03c
August	14.61±2.96b	10.06±1.85b	7.69±1.72b	4.97±0.70c	NP	NP	1.94±0.98b	2.08±1.54b	19.25±3.44b
September	6.75±1.87a	4.69±1.09a	4.25±1.03a	3.00±0.79b	NP	NP	1.42±1.03a	1.28±0.97a	11.61±2.88b
October	3.75±1.13a	2.14±0.83a	1.83±0.97a	1.39±0.73a	NP	NP	1.44±0.77a	1.58±1.20a	7.56±1.63a
November	1.61±1.02a	0.83±0.74a	0.81±0.71a	0.33±0.48a	NP	NP	0.75±0.65a	1.72±1.30a	5.17±1.86a
December	2.97±1.67a	2.53±1.13a	1.92±0.91a	1.00±0.79a	NP	NP	1.11±0.82a	0.81±0.86a	3.72±2.09a
Mean	16.38±1.19	13.16±1.29	9.20±0.71	4.29±0.42	NP	NP	2.29±0.33	2.14±0.41	20.07±1.19

Means with different letters within the column are significantly different at P<0.05
N. B.: The cultivars indicated by *'NP' indicates that the cultivars were not present (NP) in the indicated orchard

Table 6. *Mean (±SD) ATC population density per mango leaf at both study sites (RAILMCF and MARC) indicating the host preferences of different mango cultivars in the January 2018 to December 2019 cropping seasons.*

Months	Mean ±SD *Aulacaspis tubercularis* cluster (ATCs) formation on different mango cultivars								
	Tommy Atkins	**Kent**	**Kiett**	**Apple**	**Dodo**	**Van Dyke**	**Sabre**	**Alphonso**	**Local mango**
January	5.61±1.79a	3.36±1.15a	3.11±1.37a	2.08±0.77a	1.83±0.81a	1.31±0.92a	1.36±1.02a	7.28±1.56b	7.33±1.77a
February	11.82±4.80b	7.68±1.96a	7.11±1.97a	3.68±1.09a	3.17±1.00a	1.78±1.07b	1.97±1.00b	15.03±3.16c	14.85±4.02b
March	20.38±5.69c	13.58±3.32b	10.68±2.72b	5.33±1.37a	4.58±1.20a	2.75±0.69b	2.69±0.82b	27.36±4.65d	21.78±5.61b
April	30.68±5.10c	24.67±4.74c	16.03±3.31b	8.06±2.14b	7.36±1.10b	3.03±1.00d	3.61±2.25c	38.31±5.81d	35.10±6.96c
May	36.32±3.71d	28.75±5.98c	26.43±5.86c	11.21±3.52c	8.22±1.22b	4.25±1.11d	3.94±1.90c	40.89±4.64e	42.04±5.30d
June	42.35±4.06d	31.56±4.91c	26.65±3.93c	10.97±1.97c	9.78±1.40b	5.06±1.24c	3.11±1.47c	49.56±4.92e	50.10±4.93d
July	28.06±5.13c	18.50±3.97b	14.61±3.51b	8.03±1.64b	6.25±1.08b	2.72±0.88b	1.56±1.05a	32.06±5.69d	34.86±4.70c

Months	Mean ±SD *Aulacaspis tubercularis* cluster (ATCs) formation on different mango cultivars								
	Tommy Atkins	Kent	Kiett	Apple	Dodo	Van Dyke	Sabre	Alphonso	Local mango
August	16.33±4.10b	11.88±3.09b	8.71±1.89a	6.44±1.86b	5.00±0.93	1.94±0.98b	2.08±1.54b	18.11±5.15c	19.35±4.14b
September	8.69±3.30b	6.28±2.37a	5.62±1.72a	3.44±0.90a	2.33±0.76a	1.42±1.03a	1.28±0.97a	10.64±3.48b	11.06±2.72b
October	4.68±1.85a	3.26±1.58a	2.40±1.15a	1.51±0.81a	1.19±0.75a	1.44±0.77a	1.58±1.20a	4.42±2.06a	6.60±1.95a
November	1.76±1.33a	1.53±1.35a	0.83±0.73a	0.57±0.65a	0.47±0.56a	0.75±0.65a	1.72±1.30a	1.14±1.05a	3.25±2.49a
December	2.54±1.58a	2.33±1.39a	1.49±0.93a	1.10±0.79a	0.92±0.84a	1.11±0.82a	0.81±0.86a	2.72±1.21a	2.79±1.94a
Mean	17.43±1.86	12.79±1.31	10.31±1.34	5.20±1.02	4.26±0.63	2.29±0.33	2.14±0.41	20.62±2.09	20.75±1.82

Means with different letters within the column are significantly different at P<0.05

3.2. Weather Conditions and Population Fluctuation of ATCs at RAILMCF and MARC

The result of the study at RAILMCF depicted that ATC formation has its peak population on the local mango cultivar followed by Alphonso through the months of March to July, with considerable differences in ATC population density in relation to some basic climatic factors among the months (Figure 2). *Aulacaspis tubercularis* cluster formation persisted throughout the year. There was marked population fluctuation of ATCs on all mango cultivars, with a declining trend of decreased precipitation and relative humidity. A high population of ATC aggregation on mango leaves was observed from April to July. The average maximum aggregate ATC recorded per local mango leaf was 51 clusters, which covered more than 75% of the leaf surface area.

Population aggregations of ATCs at RAILMCF begin to build up in February and reach its peak in June on Local and Alphonso mango cultivars. *Aulacaspis tubercularis* cluster aggregation peaks were also evident in these months. The current study identified four phases of ATC aggregation. The first phase was from January to March, when the cluster aggregation began to build up toward its initial peak. The second phase, from April to June, was characterized by a sharp buildup of cluster aggregation. The third phase, from July to September, was characterized by a sharp decline in cluster aggregation. The fourth phase was from October to December, during which the cluster population remained low and indistinct.

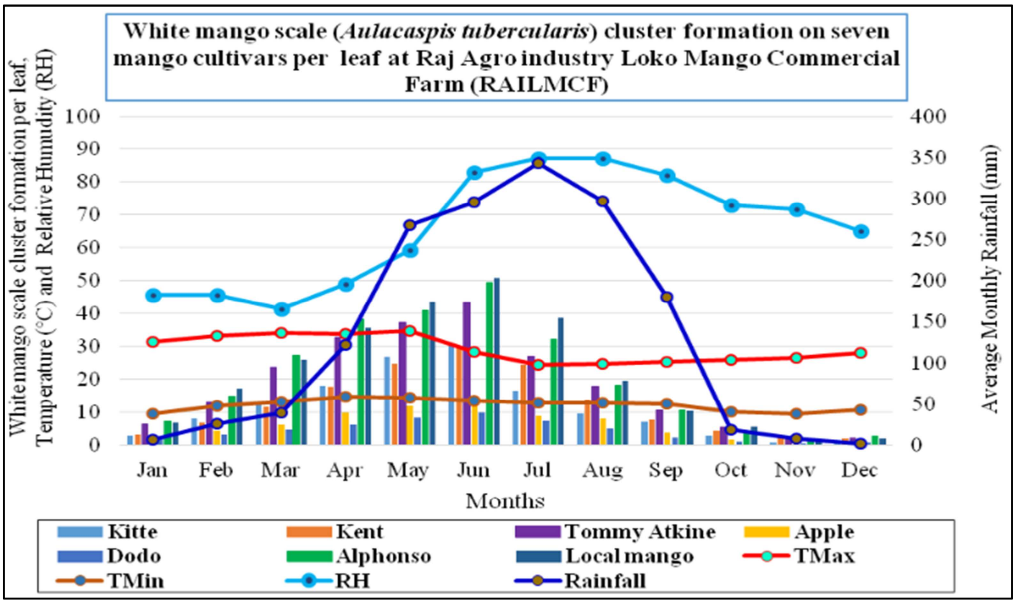


Figure 2. Graphical presentation of the mean A. tubercularis cluster population on seven mango cultivars in relation to some basic climatic factors at RAILMCF from January 2018 to December 2018.

Similarly, at the MARC, the results of the study showed that ATC aggregation peaked in the local mango cultivar followed by Tommy Atkins through the months of March to July, with considerable differences among the months (Figure 3). There was marked population fluctuation of ATCs aggregation on all mango cultivars, with a declining trend of decreased precipitation and relative humidity. *Aulacaspis tubercularis* cluster formation persisted throughout the year. High aggregation of ATCs on mango leaves was observed from April to June. The average maximum aggregate clusters of *A. tubercularis* were recorded on local mango leaves, with a value of 47 clusters, which covered approximately 75% of the leaf surface area.

At the MARC, four phases of ATC aggregation were also observed. The first phase was from January to March, and the second phase had the highest aggregation recorded from April to June. The third phase was from July to September, where the aggregation of ATCs declined precipitously, giving way to the last phase, from October to December, in which the population remained low on local and Tommy Atkins cultivars and undetectable on other mango cultivars.

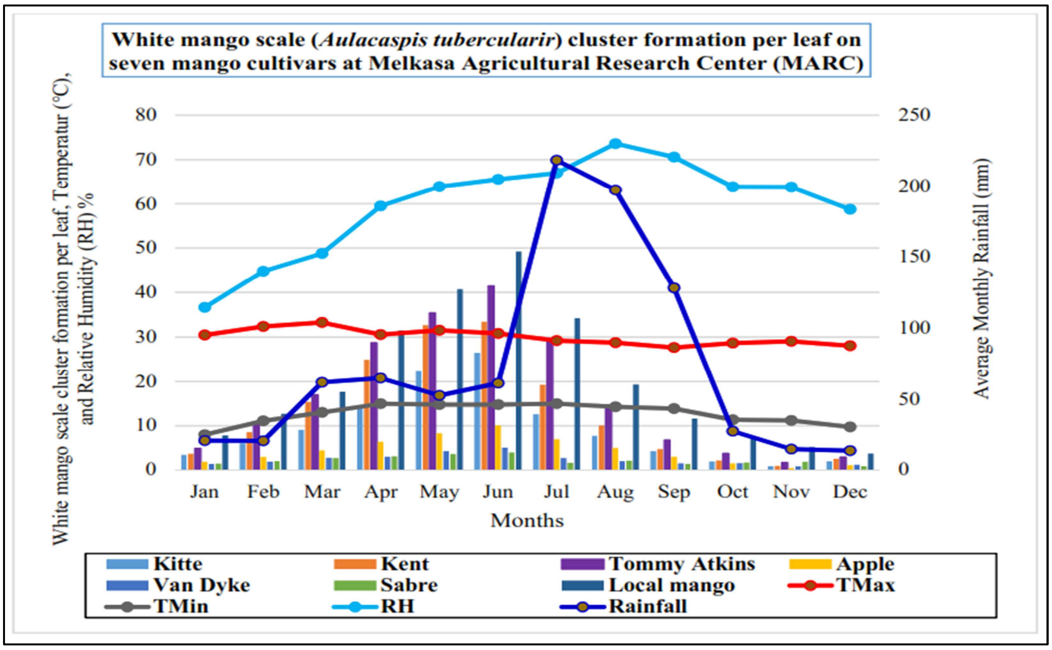


Figure 3. *Graphic presentation of the mean A. tubercularis cluster population on seven mango cultivars in MARC mango orchards in relation to some basic climatic factors from January 2018 to December 2018.*

The results of the study from the nine tested mango cultivars show that the mean ATCs aggregation at both mango orchards has its peak population on local mango cultivars, followed by Alphonso and Tommy Atkins through the months of April to June, with considerable differences in ATCs aggregation (Figure 4). There was marked population fluctuation of ATCs aggregation on all mango cultivars from January 2018 to December 2018. Aggregated ATCs formation persisted throughout the year, and cluster aggregation decreased with declining trends of precipitation and relative humidity. High aggregation of ATCs was observed from April to June and declined starting in July. The average maximum aggregate clusters of *A. tubercularis* per mango leaf recorded were on local and Alphonso mango cultivars in June, with 50.1 and 49.5 clusters per leaf respectively, which covered approximately 75% of the leaf surface area. The minimum aggregated clusters of *A. tubercularis* were recorded in November on Sabre and Van Dyke, followed by the Dodo and Apple cultivars.

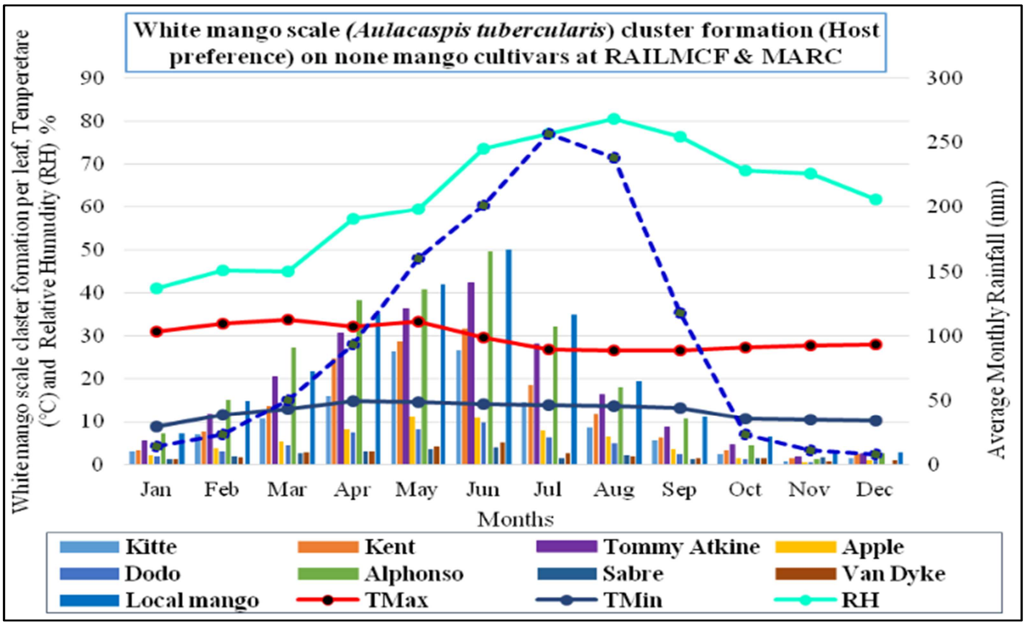


Figure 4. *Graphical presentation of A. tubercularis mean cluster population on nine mango cultivars in relation to some basic climatic factors at RAILMCF and MARC mango orchards during January 2018 to December 2018.*

At both mango orchards, the mean value of aggregated cluster formation revealed that the first phase for ATCs formation began from January to March, and the second phase continued from April to June. The third phase was from July to September, where the aggregation of ATCs declined abruptly, giving way to the last phase in which the population remained low on local mango, Alphonso and Tommy Atkins cultivars, and from October to December, it was undetectable on other mango cultivars.

3.3. Correlation Coefficient Study on ATCs Population Aggregations with Climatic Factors

Correlation coefficient '*r*' of ATC aggregation populations studied with the climatic factors *viz*. maximum temperature (Tmax), minimum temperature (Tmin), rainfall (Rf) and relative humidity (RH), which indicates the level of significance at RAILMCF and MARC, are presented in Tables 7 to 9. Overall, both study sites the correlation coefficient studies revealed that the scale numbers (ATCs populations) were significantly positively correlated with rainfall and minimum temperature but weakly with RH and Tmax. Scale numbers were significantly positively correlated with rainfall and Tmin but weakly with RH and Tmax.

Table 7. *Correlation matrix showing a correlation coefficient of ATCs population density per mango leaf at RAILMCF in relation to some basic climatic factors indicating the level of significance.*

	Tmax	Tmin	Rf	RH	Kitte	Kent	ToAt	Apple	Dodo	Alph.	LoMg
Tmax	1										
Tmin	0.406	1									
Rf	-0.281	0.678*	1								
RH	-0.890**	-0.015	0.633*	1							
Kitte	0.290	0.874**	0.740**	0.127	1						
Kent	0.114	0.859**	0.852**	0.278	0.970**	1					
ToAt	0.338	0.919**	0.714**	0.053	0.981**	0.962**	1				
Apple	0.215	0.912**	0.813**	0.196	0.976**	0.979**	0.981**	1			
Dodo	0.238	0.873**	0.788**	0.142	0.970**	0.980**	0.975**	0.980**	1		
Alph	0.348	0.913**	0.698*	0.032	0.978**	0.960**	0.997**	0.973**	0.977**	1	
LoMng	0.280	0.888**	0.747**	0.094	0.977**	0.980**	0.988**	0.972**	0.984**	0.991**	1

N. B. Tmax =Maximum temperature; Tmin = Minimum temperature; Rf = Rainfall; RH = Relative humidity ToAt = Tommy Atkins; Alph. = Alphonso; LoMg = Local Mango

**. Correlation is significant at the 0.01 level.

*. Correlation is significant at the 0.05 level.

Table 8. *Correlation matrix showing a correlation coefficient of ATC population density per mango leaf at MARC with some basic climatic factors indicating the level of significance.*

	Tmax	Tmin	Rf	RH	Kitte	Kent	ToAt	Apple	Sabre	VaDy	Lomg
Tmax	1										
Tmin	0.212	1									
Rf	-0.274	0.616*	1								
RH	-0.495	0.657*	0.583*	1							
Kiett	0.494	0.662*	0.170	0.132	1						
Kent	0.548	0.770**	0.208	0.211	0.904**	1					
ToAt	0.492	0.804**	0.327	0.259	0.935**	0.983**	1				
Apple	0.434	0.807**	0.432	0.290	0.911**	0.946**	0.977**	1			
Sabre	0.629*	0.730**	0.197	0.156	0.947**	0.959**	0.966**	0.940**	1		
VaDy	0.707*	0.650*	-0.035	0.161	0.791**	0.878**	0.840**	0.764**	0.905**	1	
LoMg	0.447	0.805**	0.342	0.302	0.930**	0.971**	0.994**	0.983**	0.956**	0.828**	1

N. B. Tmax =Maximum temperature; Tmin = Minimum temperature; Rf = Rainfall; RH = Relative humidity; ToAt = Tommy Atkins; VaDy = Van Dyke; LoMg = Local Mango

**. Correlation is significant at the 0.01 level.

*. Correlation is significant at the 0.05 level.

Table 9. *Correlation matrix showing a correlation coefficient of mean ATC population density at RAILMCF & MARC with some basic climatic factors indicating the level of significance.*

	Tmax	Tmin	Rf	RH	Kitte	Kent	ToAt	Apple	Dodo	Alph	Sabre	VaDy	LoMg
Tmax	1												
Tmin	0.158	1											
Rf	-0.277	0.759**	1										
RH	-0.823**	0.390	0.658*	1									
Kiett	0.379	0.813**	0.670*	0.147	1								
Kent	0.380	0.847**	0.663*	0.148	0.984**	1							

	Tmax	Tmin	Rf	RH	Kitte	Kent	ToAt	Apple	Dodo	Alph	Sabre	VaDy	LoMg
ToAt	0.367	0.841**	0.690*	0.146	0.983**	0.995**	1						
Apple	0.325	0.858**	0.752**	0.203	0.983**	0.983**	0.985**	1					
Dodo	0.370	0.826**	0.711**	0.132	0.968**	0.980**	0.987**	0.978**	1				
VaDy	0.433	0.764**	0.611*	0.073	0.967**	0.964**	0.971**	0.948**	0.966**	1			
Sabre	0.519	0.687*	0.395	0.003	0.873**	0.877**	0.854**	0.840**	0.832**	0.973**	1		
Alph	0.412	0.842**	0.660*	0.097	0.973**	0.989**	0.996**	0.972**	0.987**	0.851**	0.905**	1	
Lomg	0.331	0.837**	0.713**	0.179	0.982**	0.990**	0.998**	0.987**	0.982**	0.991**	0.844**	0.968**	1

N. B. Tmax =Maximum temperature; Tmin = Minimum temperature; Rf = Rainfall; RH = Relative humidity; ToAt = Tommy Atkins; Alph. = Alphonso; VaDy = Van Dyke; LoMg = Local Mango

**. Correlation is significant at the 0.01 level.

*. Correlation is significant at the 0.05 level.

4. Discussion

In Ethiopia prior to this study, no research was carried out that attempted to study the host preference of *A. tubercularis* to existing mango cultivars. In view of this, cultivars of mango, *viz*., Tommy Atkins, Kent, Kiett, Apple, Dodo, Van Dyke, Sabre, Alphonso and local mango cultivars, were included to study the host preference of *A. tubercularis* or the resistance or susceptibility of these cultivars against *A. tubercularis* infestation. The results of the present study showed that there was a significant difference in the host preference of *A. tubercularis* (susceptibility/ resistance) among the tested mango cultivars.

The infestation of *A. tubercularis* on the tested mango cultivars slightly increased from January to March and steadily increased from April to June. On the other hand, the infestation of *A. tubercularis* slightly decreased from July to August and steadily decreased from September to November. The increase or decrease in population size of ATCs may be related to the frequency and intensity of precipitation. The decrease in the ATC population could be due to washing away the insects by heavy precipitation. The population dynamics of the herbivore (insect pest) also related to the annual growth cycle. Mango trees grow through a series of growth events: shoot flush, root flush, shoot dormancy, flowering, fruit set, fruit development, root flush and harvest (https://www.horticulture.com.au/globalassets/hort-innovation/resource-assets/mg15006-understanding-crop-nutrition-mango.pdf). The cultivar/variety, the environment, and the management aspects influence these events.

In mango growing areas of the country, Ethiopia, the season from July to September is known as the total dormancy period of the mango tree, and from October to December is the period of shoot dormancy, shoot flush, and flowering stage, where the availability of carbohydrates starts to rebuild and accumulate. In this study, it was observed that the population of ATC starts to decrease from July to November when mango tree is at dormant stage and showed a slight increase from December to March, when the tree is at flowering and fruit setting stage, and then the population of ATC abruptly increased from April to June. In addition to climatic factors for the population dynamics of *A. tubercularis*, the availability and concentration of carbohydrate and other nutrients may need further study.

Carbohydrate availability of the host plant, the mango tree, is high during the period of flowering, fruit setting, fruit development and maturity [19], which is from January to June. A review paper by Luis A et al. [20] mentioned that the mango variety and ripening stage play an important role in the amount of carbohydrates present in the fruit. A related study by Cavalcante I. H. L. et al. [21] also mentioned that lower carbohydrate concentrations were recorded in both leaves and shoots from the middle to the end of the shoot maturation phase, showing that plants at flowering induction (end of shoot maturation) presented higher soluble carbohydrate concentrations.

The population of the herbivore is high when carbohydrate availability of the host plant is high, in which the readily available soluble food is present in the host leaf, succulent stems, twigs and fruits that helps the sucking pests obtain readily available solute/liquid food. Carbohydrates and other nutrients decrease during total dormancy of the tree and during the period of flush (shoot) growth, which could have a negative impact on the population growth of the herbivore [21]. The study [22] on the 'Lifetime consequences of food protein-carbohydrate content for an insect herbivore', mentioned that the population size of the herbivore (insect pest) was largest on diets with a balanced protein/ carbohydrate (p/c) ratio and declined steadily and strongly as the p/c ratio became increasingly more imbalanced.

In general, during the twelve months, the highest sum mean number of aggregated clusters per mango leaf was observed on local mango, with a mean value of 20.75±1.82, followed by the Alphonso cultivar, with a mean value of 20.62±2.09. Tommy Atkins was in the third place, with a mean value of 17.43±1.86. The lowest aggregated mean clusters per mango leaf were observed on Sabre with a mean of 2.14±0.41 and Van Dyke 'mean (2.29±0.33), followed by Dodo (4.26±0.63) and Apple mango cultivars with a mean value of 5.20±1.02. This shows that local and Alphonso cultivars were highly preferred cultivars, whereas Sabre and Van Dyke were less preferred cultivars, followed by Dodo and Apple mango.

The results of this study compared favorably with the results of related studies [23] and a review paper [24], who reported that Apple and Keitt mango varieties were more tolerant to *A. tubercularis* than other varieties, such as Alphonso, Kent, Tommy Atkins and Dodo. In addition, research results [23] also mentioned that white mango scales on Tommy Atkins leaves and fruits were more profuse. The current results also revealed that among the tested cultivars, local mango, Alphonso and Tommy Atkins were grouped as highly preferred/susceptible cultivars (Category III). Among the rest of the cultivars, Dodo and Apple cultivars were grouped as Category II (less or moderately preferred cultivars). The Sabre and Van Dyke cultivars had the lowest population density of ATCs and were rated as relatively resistant to *A. tubercularis* infestation over the entire year. Contrarily to the research [23], the results of the present study identified that Dodo was a relatively tolerant cultivar that ranked third to Sabre and Van Dyke cultivars, which were grouped as Category I. This finding agreed with the results [25], who stated that some mango varieties are susceptible while others are resistant due to differences in their genetic makeup and/or the metabolites they produce [25-27].

In this study, the aggregated ATC population began to build up in February, reached its peaks in June and started to decline from July to October. The results mentioned by the author [28] revealed that the southern side of mango plants had a maximum population of mango mealybugs compared with the western and eastern sides. However, a lower abundance of mango mealybugs occurred on the leaves and inflorescence in the north than in the southern cardinal direction of the tree, which was contrary to the findings of the present research. Moreover, it was also observed that the peak period for the ATC population was observed in the 2nd week of May to the 3rd week of June following the onset of rainfall and the increase in relative humidity, which coincides with flush growth, and the population decreased thereafter with an increase in rainfall frequency and intensity.

At the RAILMCF mango orchard, the population aggregation of ATCs on the susceptible local mango and Alphonso cultivars on the 4th week of January 2018 was 6.3 and 7.3 aggregate clusters per leaf, respectively. The cluster population increased on the subsequent dates of observation and reached a mean maximum peak of 51 aggregate clusters per leaf on the 4th week of June 2018, with maximum and minimum temperatures of 29.5°C and 14.1°C, respectively, and a relative humidity of 73.5%. Likewise, at the MARC mango orchard the aggregate populations of *A. tubercularis* clusters on the susceptible local and Tommy Atkins mango cultivars were clearly observed on the 4th week of January 2018, with 8 and 5 aggregate clusters, respectively, per mango leaf. This population increased consequently and reached peaks of 49 and 41 aggregate clusters, respectively, on the 3rd week of June 2018 when the maximum and minimum temperatures were 30.8 and 14.8°C, respectively, with a relative humidity of 63.9%.

The present result was related to the findings reviewed by Skendzic et al. [29], who mentioned that temperature is the most important environmental factor that affects insect population dynamics. Global climate warming could trigger the expansion of their geographic range, increased overwintering survival, increased number of generations, increased risk of invasive insect species and insect-transmitted plant diseases, as well as changes in their interaction with host plants and natural enemies. The present study is also related to the findings [30-32], which stated that the impact of agro-ecological parameters such as temperature, rainfall, and relative humidity greatly influence the eruption of the insect population. This study identified that ATC aggregation occurred year-round from the minimum to maximum population and had four overlapping generations in both mango orchards, RAILMCF and MARC. A related study by [33] indicated that *A. tubercularis*is exists year-round with overlapping generations.

As observed in most events during the start/onset of rainfall, the ATC population gradually builds up when the summer rainfall intensity and frequency are normally distributed, and its population decreases steadily when the rainfall intensity and frequency increase at an increasing rate. A study [34] mentioned that in Egypt, weather factors affected the population density of *A. tubercularis*. A related study [35] on the effects of climate change on agricultural insect pests mentioned that small-bodied pests such as aphids, mites, jassids, whiteflies, etc., could be washed away during heavy rainfall. The present finding also agreed with the results [36, 37], who mentioned that *A. tubercularis* had four overlapping annual generations per year. Study [38] reported that this insect had 3 to 4 generations per year, while [39] reported that *A. tubercularis* had three generations annually in the top and bottom levels of mango trees. The result of the study [40] also reported that *A. tubercularis* had three peaks on mango, which occurred during March, June and November through each of the two years of study. A related study [41] also mentioned that *A. tubercularis* had four peaks of activity during April, June, September and January and had four overlapping generations in the two seasons of study.

In general, broad variability exists among the tested cultivars of *Mangifera indica* for *A. tubercularis* tolerance. There were cultivars with less than 10% (±5 clusters) infested leaves and others with almost 75 to 100% infestation (±75 clusters). This finding demonstrated that the host preference of *A. tubercularis* is compatible with fruit quality, productivity, and varietal genetic makeup.

The correlation coefficient of average data at RAILMCF and MARC best signifies the effect of climatic factors on seasonal abundance and formation of ATC populations. In consideration of climatic variables, *A. tubercularis* incidence peaked during May and June, as the climatic conditions favored crest population development. As the temperature increased, the ATC population was found to increase, but in extreme conditions of high temperature and increased precipitation, the cluster population drastically decreased. The correlation coefficients with meteorological parameters indicated that the most effective variables for the *A. tubercularis* nymph, adult male and female populations increased with Tmin and adequate precipitation. Moreover, the results demonstrated that the combined effect of rainfall, temperature (minimum and maximum) and relative humidity has a significant effect on the numbers of ATC aggregations. As most of the climatic factors are interdependent, any change in a single climatic factor may lead to multiple effects on pest structure. In Egypt, daily mean temperature and relative humidity positively influenced population density, but wind speed and dew point negatively influenced the population density of *A. tubercularis* [34].

In general, knowledge of the host preference of *A. tubercularis* (resistance/susceptibility) to the existing mango cultivars helps in managing this recently introduced pestiferous insect pest of mango. The utilization of insect-resistant mango cultivars is economically and environmentally advantageous. Application of these practices as part of integrated pest management (IPM) can protect mango yield losses by insect pests, and money is saved without or with minimum use of insecticides.

5. Conclusion

In this study, we have confirmed that mango cultivars vary in susceptibility to *A. tubercularis*. A significantly positive correlation is confirmed between scale abundance and rainfall and minimum temperature, but not with other weather variables.

Data Availability Statement

Primary raw data not presented in this study are available as supplementary material on request from the first author without undue reservation.

Authors' contributions: Temesgen F. Conceptualization of study design, accomplishes the experiments, statistical analysis, and writes down the document. Prof. Emana G., Dr. Mulatu W., and Prof. Kebede Woldetsdik advise the principal author all over the work and evaluate the document. All coauthors look through and accepted the final document for publishing.

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Conflict of Interest

The research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest so that the authors declared that there has no conflict of interest.

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