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Seasonal Population Dynamics of White Mango Scale, *Aulacaspis tubercularis* at Different Agro-ecologies and Its Cardinal Direction Preferences in Western Oromia, Ethiopia

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Abstract: Mango production is constrained by the infestation of arthropod pests, among which white mango scale, *Aulacaspis tubercularis*, is the most economically important insect pest causing devastating damage in Ethiopia. This study investigated the status of *A. tubercularis* in western Oromia, Ethiopia. A total of three districts (Guto Gida, Bako Tibe and Elu Gelan) and Nekemte city, among each, two orchards and five mango trees were selected purposively. Twelve leaves were collected monthly from each tree: from upper, middle and lower canopies and the *A. tubercularis* cluster (ATC) were recorded. RCBD was employed to determine the level ATC density. The results of the study revealed that *A. tubercularis* present in all study areas throughout the year with a fluctuating ATC *density in which* the highest ATC was concentrated on the upper side of the leaves. The abundance population density of the ATC population showed significant differences among the study months and cardinal directions, where the *A. tubrcularis* prefers the southern cardinal direction. The abundance of ATC population was significantly higher at Bako (p<0.05), where the ATC was abundant on the upper surface of the leaf in all study areas. There was a marked increase in ATC population density from March to mid-June with an increased precipitation and a swift decrease to nonexistent from mid-June to September followed by prolonged heavy precipitation. Furthermore, the study investigated the effect of basic climatic factors and cardinal direction differences on the population density of ATC, where the other contributing factors need to be investigated further.

Keywords: Abundance, *Aulacaspis tubercularis*, Cardinal Direction, Clusters, Climatic Factors, Leaf Surface Preference, Population Density

1. Introduction

Mango (*Mangifera indica* L.) ranks as the fifth most consumed fruit in the world, after citrus, banana, grapes, and apple, with an estimated total world production of 5.75 million hectares and a global harvested production of 55 million metric tons [1, 2]. Mango played an integral part in the lives of many, not only by being rich in nutrients but also used as a source of livelihood for millions of people, particularly in the tropics. Mango is grown under very diverse climatic conditions in tropical and subtropical regions [3]. Asia is the dominant mango-producing region, with a production of over 74.4 %, followed by the Americas and the Caribbean, Africa, and Oceania, producing 13, 12.4, and 0.1 %, respectively [1, 2].

Likewise, mango is the most widely grown fruit crop in Ethiopia, preceded only by bananas, in terms of economic importance. Most of the productions come mainly from the Rift valley, western and southwestern Ethiopia [4]. The cultivated area has been rapidly increasing from year to year, especially in the green legacy program of the country. The annual mango production in Ethiopia is 151,331.24 tons, with land coverage of 20,782.10 ha, and its production is 6.86 tons ha^{-1}.

There are different species of insect pests and diseases that contribute to the low yield of mango trees throughout their stages of development. Among these, fruit flies, red-banded thrips, mango tip borer, scale insects, seed weevils, mealybugs, anthracnose, bacterial black spot, and powdery mildew are some of the biotic constraints for mango production [6-9]. Among the most dominant armored scale insects, the white mango scale, *Aulacaspis tubercularis* Newstead (Homoptera: Diaspididae), is one of the most damaging scale insects in mango orchards [1, 10-14]. *Aulacaspis tubercularis* is a species native to the Asian continent, with a wide distribution in tropical and subtropical areas of America, Africa, Asia, Australia, and the Pacific [15] southern Europe, such as Spain [1].

Climatic changes have become one of the major challenges for mankind and the natural environment [16]. Climate change directly affects the reproduction, development, survival, and dispersal of pests and indirectly impacts the interactions between and within insect species, including predators, competitors, and mutualists, and interactions with their environment [17]. In addition, indirect effects can occur through the influence of climate on the insect's host plants, natural enemies and interspecific interactions with other insects [18-21].

The effect of climatic and weather factors (daily mean maximum air temperature, daily mean minimum air temperature and mean relative humidity) has a significantly high effect on the total live population of *Milviscutulus mangiferae* during the two consecutive years, and these factors vary from year to year [22]. Climate can limit distributions directly by influencing survival and fecundity, or indirectly through its effects on interacting species, including food sources, natural enemies and competitors. Phytophagous insects and their host plants are useful model systems for testing the effects of climate and biotic interactions on species distributions [23]. Temperature has a direct influence on insect activity and rate of development. The rate of development is based on the accumulation of heat measured in physiological rather than chronological time [24]. The seasonal phenology of insect numbers, the number of generations, and the level of insect abundance at any location are influenced by the environmental factors at that location [25].

A. tubercularis prefers the upper surface of mango leaves over the lower surface [26-29]. *A. tubercularis* preferred the upper surface of leaves during the cold months of winter season and preferred the lower surface of the host leaves during the hot months of the summer season [10].

There is currently limited information with published scientific studies in Ethiopia on *A. tubercularis* concerning its ecology and population density and population dynamics. The present report is an update of the currently available information on ecology and population density and population dynamics aimed to help in the development of integrated management strategies for this pest in the main mango-growing areas of Ethiopia. The present work aimed to investigate *A. tubercularis* ecological aspects, population density, population dynamics, infestation level and the effect of weather conditions, *i.e.*, temperature, relative humidity, and rainfall, on the pest population density and population dynamics in the western Oromia Regional State.

2. Materials and Methods

2.1. Description of the Study Areas

The study was conducted in western parts of Oromia, Ethiopia. Accordingly, the administrative zones covered were the East Wollega and West Shewa administrative zones of the Oromia Regional State. East Wollega zone is located in western part of Ethiopia (Figure 1) with an altitude ranging from 900 to 3,276 m above mean sea level. It lies between latitudes 8°30'0"to 10°20'0"N and 36°05'0" to 37°10'0"E at western Oromia. The zone is characterized by three major agroecologies include highland (13%), midland (57%), and lowland (30%) with hilly, undulating, and rolling topographical features. Its altitude ranges between 1000 and 2798 meters above sea level with the mean annual rainfall ranging between 1400 mm and 2200 mm. The main rainy season runs from the months of May to September. The soil types are clay and red sandy clay. *Tef*, barley, wheat, faba bean, sesame, groundnut, field pea, maize, sorghum, finger millet, potato, tomato, hot-pepper, and *nug* are some major crops grown in the zone [30]. Mango is among the fruit crops grown in lowland areas of the zone, and banana and other fruit crops are rarely grown in mid-altitude areas of the zone.

West Shewa zone has four major physiographic divisions: Plane, Mountain, Valley, and Hill based on topography; and highland (27%), midland (40%) and low land (33%) based on agro ecology. The soil type is characterized by black, reddish, and reddish brown in color; clay and heavy clay soil in texture. Categorically: Vertisols, Leptosoils and Cambisols soil types are prevailed predominantly. Vertisols is developed on the flat highland of the study area and suitable for cultivation of cereals and pulses and is a heavily textured soil dominating the study area. It is known for its mixed crop-livestock farming systems. Geographically it is located at 8°16- 9°56´N latitude and 37°05´-38°46´E longitude. *teff*, wheat, barley, faba bean, field pea, Chickpea, maize, sorghum, potato, tomato, hot-pepper, and *nug* are some major crops grown in the zone [31]. Among the fruit crops, mango is cultivated in lowlands and *enset* is the fiber crops mostly cultivated in mid and highland areas of the zone.

In the aforementioned two zones, based on the availability of mango planation, three districts and one urban town were purposively selected *vis*., Guto Gida district and Nekemte city from East Wollega zone, and Bako Tibe and Ilu Gelan districts from West Shewa zones were selected for this study. The Guto Gida district study site distance from Nekemte ranges of 35 to 45 km from the town zone, and Nekemte is found at a distance of 328 km from Addis Ababa. The Bako Tibe and Elu Gelan districts are found at distances of 239 and 209 km, respectively. Bako Tibe and Elu Gelan districts study sites are located at 5km and 30km, respectively from the meteorological station of Bako Agricultural Research Center, where as Guto Gida district and Nekemte city study sites are located at a distance of 35 km and 2 km from the meteorological station located in Nekemte City. The rain was unimodal and was received from April to September, but the heavy rain was received from June to August. In general, the latitude and longitude of the study sites (Lat./Long.), average minimum and maximum temperature, annual rainfall, and geographical information of the study area presented in Table 1.

Table 1. *Agro-ecological and coordinates of the study area in East Wollega and West Shewa zones.*

Districts	**Site/Orchard**	**Geographical Coordinates**		**Altitude**	**Mean temperature (°C)**			**RH**	**Annual Rainfall**
		Latitude	**Longitude**	**m. a. s. l**	**Min.**	**Max.**	**Aver.**	**%**	**mm**
Guto Gida	Uke	9°37.601″	36°52.701″	1391	14.41	37.12	27.20	69.00	1725.98
	Loko/RAILMCF	9°18.688″	36°32.373″	1409	11.71	34.79	27.03	69.50	1728.98
Nekemte City	Cheleleki 03	9°05.271″	36°33.130″	2082	12.0	33.45	25.60	74.47	2237.92
	Bekenisa Kasie 04	9°05.260″	36°32.530″	2118	12.0	33.45	25.60	74.47	2237.92
Bako Tibe	Bako H. S	9°07.095"	37°03.630"	1674	11.56	34.31	27.35	71.88	2194.09
	Gibe River Bank	9°09.061	37°11.054	1763	10.93	34.76	28.42	72.01	2167.15
Elu Gelan	Ejaji H. S.	9°18.48″	37°19.49"	1744	10.31	32.52	26.69	69.84	2072.41
	Ejaji P. S	9°18.43″	37°19.45"	1742	10.31	32.52	26.69	69.84	2072.41

NB: High School; P. S= Primary School; Min. =Minimum; Max. =Maximum; Aver. = Average; m. a. s. l. = meter above sea level; mm= millimeter; RH=Relative Humidity, EWFWLDE= East Wollega Forest & Wild Life Development Enterprise

2.2. Study Design, Sampling Procedure, and Data Collection

The study was carried out from May 2019 to April 2020. Existing mango orchards, which are known to be infested by *A. tubercularis,* were purposively selected in the aforementioned three districts, including one urban city. From each selected district and city/town, two administrative kebeles and from every kebele, three sites (mango orchards) were purposively selected for data collection. Accordingly, from Guto Gida district, Raj Agro-Industry Mango Commercial Farm (RAILMCF), and Uke Kersa Administrative kebele's, from Nekemte City private mango groves of Cheleleki 03 and Bkekenisa Kesse 04 kebele's mango groves were purposively selected from east Wollega zone. Likewise, from the west Shewa zone, the Bako Tibe and Elu Gelan districts were purposively selected. Hence, from Bako Tibe district, Bako high school and mango orchard found on Gibe riverbank and from Elu Gelan district, Ejaji high school & primary school mango orchards were selected.

In each orchard, three blocks, and from each block, five mango trees were specified and marked, one at each of the four corners and the center. Hence, a randomized complete block design was used. Then, twelve leaves were plucked from the upper, middle, and lower canopies of a mango tree. The sampling started from the marked mango trees at each corner of the blocks, continued on the way to the center, and continued in the four cardinal directions on consecutive mango trees, once within a month for twelve successive months, *i e*., twelve collection dates were made consecutively during the study year. All mango orchards selected for the study were not treated with any pesticides before and during the period of investigation but received the same cultural management practices.

The study on cardinal direction preference of *A. tubercularis* was carried out separately during the peak period of infestation from May to June 2020. Following the procedure mentioned above, twelve mango leaves were randomly plucked from each sampled mango tree once monthly through three successive months from four cardinal directions (north, south, east, and west) at the lower, middle and upper canopy of the mango tree. The sampled leaves from each mango tree were carefully placed in separate paper bags, labeled, kept in plastic bags, and transported to Wollega University, Veterinary School Vector and Parasitology Laboratory for further investigation. *A. tubercularis* cluster (ATC) population density on the collected mango leaves were counted visually, and in some cases, a stereomicroscope was used for the identification of different stages of the insect and for searching for associated natural enemies. Accordingly, the male and female sheaths/scales were broken and opened using a dissecting needle to expose the male and the female with their underlying eggs and early hatched crawlers.

The monthly meteorological parameters, such as maximum temperature (Temax), minimum temperature (Temin), mean temperature (Tem), rainfall (Rf), and relative humidity (RH), were obtained from the Ethiopian National Meteorology Agency. The altitude and coordinates of each site were recorded using GPS.

2.3. Data Analysis

The collected data were organized by the use of Microsoft Excel Office Windows 2010. Simple descriptive statistics (count, percentage, tables, and figures) were used to assess different variables. Data were subjected to Statistical Analysis System (SAS) computer software version 9.0 [32] for data analysis. The ecological aspects of *A. tubercularis* and its cluster population density on the upper and underside of the sampled mango leaves, its abundance, cardinal direction preference and variation in mean cluster population between administrative zones, districts, villages and study sites/orchards were analyzed by using Proc ANOVA (analysis of variance) at $P\leq 0.05$ significance. Significant means of ANOVA were separated using Tukey's test (HSD). To normalize the data obtained from ATC count, square root transformation was used where applicable. The correlation coefficients between ATC and basic climatic factors were analyzed using IBM SPSS Statistics version 20 [33] predictive analysis software.

3. Results and Discussion

3.1. Ecological Aspects of Aulacaspis tubercularis

During the study period, monthly 2,160 leaf samples (totally N = 25,920) were collected monthly from 180 mango trees over twelve months. The results of this study revealed that *A. tubercularis* was present and evenly distributed in all selected agro-ecologic study zones, *viz*., lowland, mid-land, and transitional-highland areas, which range at altitudes of 1280 to 1500, 1501 to 1800, and 1801 to 2123 m above sea level, respectively. During the peak period, un matured males were grouped into clusters/colonies of individuals who contained more than 150 male individuals, which eventually allowed them to occupy the entire mango leaf independent of the season. Mean *A. tubercularis* cluster formation on infested mango trees per mango leaf in two zones, four districts and twelve Kebeles are presented in Table 2.

3.2. Population Density of A. tubercularis

The results revealed that there were population fluctuations of sessile *A. tubercularis* (nymphs, male colonies, and females) clusters formed on infested mango leaves at all study sites, which followed more or less similar patterns of distribution across the months of the study period. In all study sites of Uke, RAILMCF, Bako, Ejaji, and Nekemte City mango orchards, the *A. tubercularis* clusters and the sessile were persisted throughout the sampled months of the year with fluctuating population densities (Figures 1 to 4). There was a marked increase in ATC population density with a general trend of increased precipitation (from slight to medium), and there was a decreased cluster population density with a trend of decreased precipitation. Population peaks were recorded from April to May at Bako and RAILMCF and from May to June at Nekemte and Ejaji, respectively. At Bako and RAILMCF, the maximum numbers of ATC populations recorded per leaf were 63 and 59, respectively, which was in May, but only 2 and 3 clusters were recorded from October to November. At Nekemte city and Ejaji mango orchards, the maximum number of ATC populations recorded per leaf was 51 and 56, respectively, which was in May, whereas the minimum was one to two clusters per leaf from September to November.

Figure 1. *Aulacaspis tubercularis cluster formation on mango leaves at Ejaji, male colonies are conspicuous here not others such as females or crawlers: (A) in January 2019; (B) in mid-June 2019.*

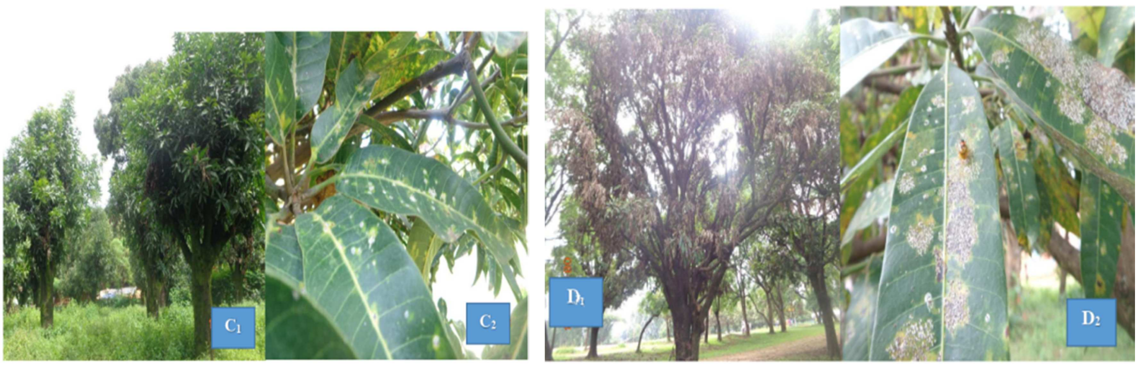


Figure 2. *Aulacaspis tubercularis cluster formation on mango leaves and twigs at Bako high school mango grooves: (C_1) Less infestation on stand tree; (C_2) Less infestation on leaves; (D) Heavily infested mango tree twigs and leaves partly dried; (D_2) Infested leaves from the part of the tree (D_1) [Photo: From field study by Temesgen Fita, mid-June 2019].*

Figure 3. *Aulacaspis tubercularis cluster formation on mango leaves and fruits at RAILMCF: (E) in mid-January; (F) in mid-June, [Photo: From field study by Temesgen Fita].*

Figure 4. *Aulacaspis tubercularis sever infestation on mango leaves and twigs and cluster formation at Nekemte Temporary mini insectary (NTMI) mango grooves: (G) in the month of January; (H) in the month of mid-June; (I and J) mango tree branches, twigs, shoots, stems and leaves exhibiting necrosis due to heavily infestation and cluster formation at NTMI mango grooves: in the month of mid-June [Photo: From field study by Temesgen Fita].*

3.3. Leaf Surface Preference of White Mango Scale, A. tubercularis

The highest peak *A. tubercularis* cluster formation was observed on the upper side of the leaf surface in the month of mid-June, followed by the month of May, but the underside of the leaf surface recorded the lowest fluctuating mean cluster population throughout the study periods. The monthly mean cluster population of *A. tubercularis* on mango leaves on the upper and underside surfaces is presented in Table 6. The underside surface of the mango leaf records a smaller number of clusters during all months of the study. The ATCs population per leaf was significantly higher ($P<0.05$) on the upper side of the leaf surface than on the underside at Bako Tibe, with a mean (±SD) value of 51.42±8.00, followed by Guto Gida district, with a value of 48.74±6.01. During the same study, the 2[nd] highest mean cluster count was observed on the upper side of the leaf surface in the month of May, which recorded mean (±SD) numbers of 40.05±0.42, 38.47±5.59 and 38.26±6.73, and 36.71± 6.96 in Bako Tibe, Elu Gelan and Guto Gida districts, and Nekemte city, respectively. Likewise, the mean population density of *A. tubercularis* clusters was observed at the underside surface of the leaf surface (0<0.05), with mean (±SD) numbers of 11.83±1.76, 10.33±2.61 and 9.74±2.28 and 10.01±2.22 in Bako Tibe, Elu Gelan and Guto Gida districts, and Nekemte city, respectively.

3.4. Monthly Variation in A. tubercularis Clusters (ATCs) Population Density & Population Dynamics on Mango Leafs

The monthly counts of the total cluster population of *A. tubercularis* throughout the study period (twelve successive months) are tabulated in Table 2. The data tabulated on the monthly variation in ATCs population density clearly show that the favorable periods for its development and increased population density slightly started from the month of March following the onset of rainfall and steadily increased from May to mid-June. The population density of ATCs through the month showed a significant difference ($P<0.05$) among the months and the study sites. The monthly mean values of *A. tubercularis*c cluster population density recorded per leaf in March were (±SD) 23.47±6.00, 30.89±9.21, 22.49±5.34, and 24.12±5.73 in Guto Gida, Bako Tibe, Elu Gelan districts, and Nekemte city, respectively. Likewise, the highest mean values of *A. tubercularis* cluster population density per leaf were recorded in mid-June, with values of (±SD) 51.42±8.00, 48.74±6.01, 47.19±9.59, and 47.39±5.85 in the Bako Tibe, Guto Gida and Elu Gelan districts, and Nekemte city, respectively. Likewise, the highest mean values of *A. tubercularis* cluster population density per leaf were recorded in mid-June, with values of (±SD) 51.42±8.00, 48.74±6.01, 47.19±9.59, and 47.39±5.85 in the Bako Tibe, Guto Gida and Elu Gelan districts, and Nekemte city, respectively. On the other hand, the average mean values of *A. tubercularis* cluster population density over the 12 months per leaf recorded values of (±SD) 15.47±1.32, 15.01±1.45, 20.04±3.06, and 16.47±2.26 in the Guto Gida, Bako Tibe and Elu Gelan districts and Nekemte city, respectively. The three districts (Bako Tibe, Guto Gida and Elu Gelan) and Nekemte city showed significant differences ($P < 0.05$) in the abundance of ATC population density on the upper side of mango leaves. Regarding this, the Bako Tibe and Guto Gida districts registered the highest ATCs, with values of (±SD) 51.42±8.00 and 48.74±6.013, respectively, followed by Nekemte city and Elu Gelan district, with values of (±SD) 47.39±5.85 and 47.19±9.59, respectively.

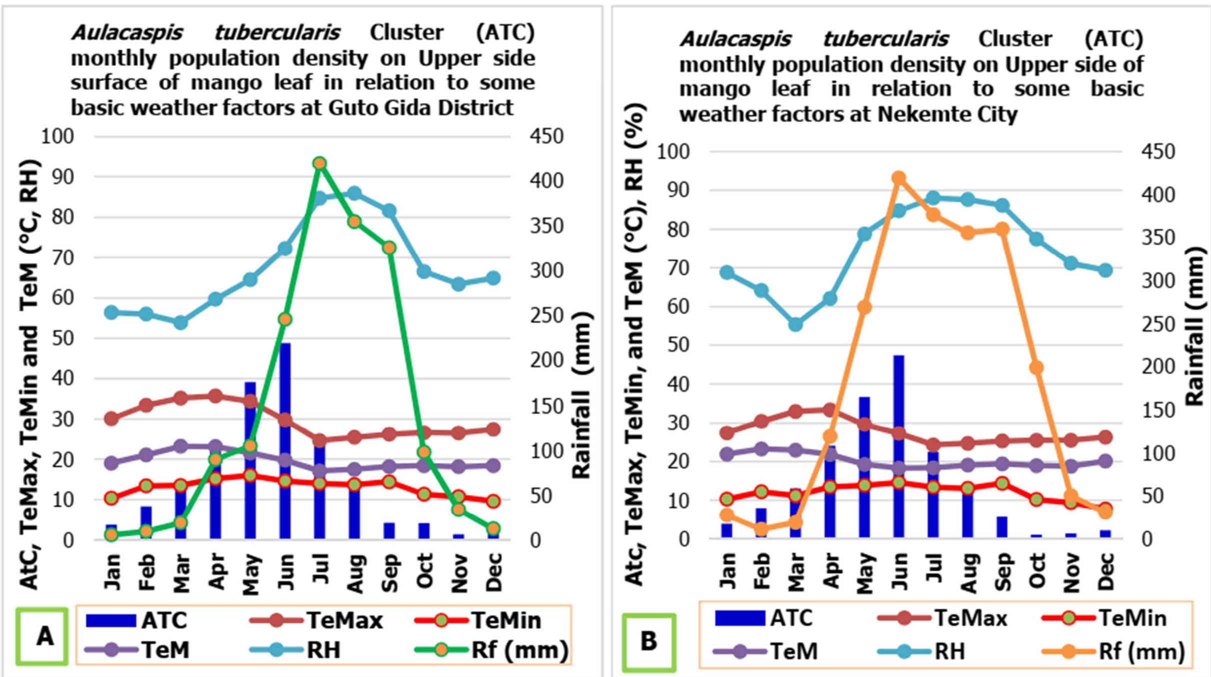
***Table 2.** Mean (±SD) A. tubercularis cluster (ATC) population density per mango leaf on the upper and lower sides of the leaf surface in the study area.*

Months	East Wollega				West Shewa			
	Guto Gida District		Nekemte City		Bako Tibe District		Elu Gelan District	
	Upper side	Under side	Upper side	Under side	Upper side	Under side	Upper side	Under side
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
January	3.54±1.80e	0.68±0.75f	3.91±1.79f	0.64±0.72 g	5.28±2.25 g	3.65±1.15fe	3.43±1.74 h	0.78±0.73 h
February	8.17±1.67de	2.34±1.09de	8.04±1.90e	2.19±1.08e	11.98±4.67f	4.47±0.83f	8.18±1.92 g	2.43±1.28f
March	13.21±2.22d	3.61±0.95d	13.09±3.73d	3.59±0.97d	20.46±7.49d	5.48±0.99d	13.63±3.28f	3.83±1.04e
April	23.47±6.00c	5.20±1.35c	24.12±5.73c	5.39±1.33c	30.89±9.21c	7.16±0.97c	22.49±5.34d	5.76±1.34d
May	38.26±6.73b	7.41±1.58b	36.71±6.96b	7.37±1.48b	40.05±6.42b	8.72±1.13b	38.47±5.59b	7.73±1.62b
June	48.74±6.013a	9.74±2.28a	47.39±5.85a	10.01±2.22a	51.42±8.00a	11.83±1.76a	47.19±9.59a	10.33±2.61a
July	24.43±5.21c	5.93±1.45c	22.46±5.15c	5.81±1.39c	37.13±6.99bc	8.66±1.06b	33.12±7.96c	6.53±2.34c
August	13.98±2.95d	3.67±1.02d	13.92±3.83d	3.63±1.03d	24.17±6.38d	6.96±1.11c	20.81±6.26d	5.60±1.57d
September	4.22±0.81e	1.89±0.83e	5.69±1.78ef	1.86±0.83ef	8.19±3.76 fg	4.20±0.79f	4.46±0.69 h	2.65±0.86f
October	3.82±1.66e	1.79±1.01e	1.11±1.09 g	1.79±0.82ef	3.62±2.53 g	3.38±0.58fe	1.33±0.74i	2.46±0.64f
November	1.36±1.35e	1.70±0.80e	1.38±0.93 g	1.73±0.82ef	3.36±0.71 g	2.97±0.79e	2.25±1.48hi	1.93±0.65 g
December	2.30±1.76e	1.84±0.78e	2.21±1.33f	1.88±0.78ef	4.36±0.94 g	3.36±0.83fe	3.01±1.62 h	2.54±1.25f
Mean	15.47±1.32d	3.82±0.44d	15.01±1.45	3.83±0.44d	20.04±3.06d	5.92±0.43d	16.47±2.26df	4.39±0.52ef

* Note: Means followed by the same letter(s) in a columns are not significantly different at a P<0.05 level of significance by Tukey's Studentized Range (HSD) test.

3.5. Effect of Main Weather Factors on A. tubercularis Clusters (ATCs) Population

Population fluctuation of ATCs on mango leaves followed a nearly similar pattern over the months of the year. There was noticeable ATC population fluctuation with a general trend of decline with a decreasing trend in precipitation. Perceptible ATCs persisted with a similar pattern throughout the year at Bako, Elu Gelan, RAILMCF, and Nekemte, but the population density of ATCs was almost knocked down below undetectable levels in the months of October, November, and December (Figure 5 A-D).



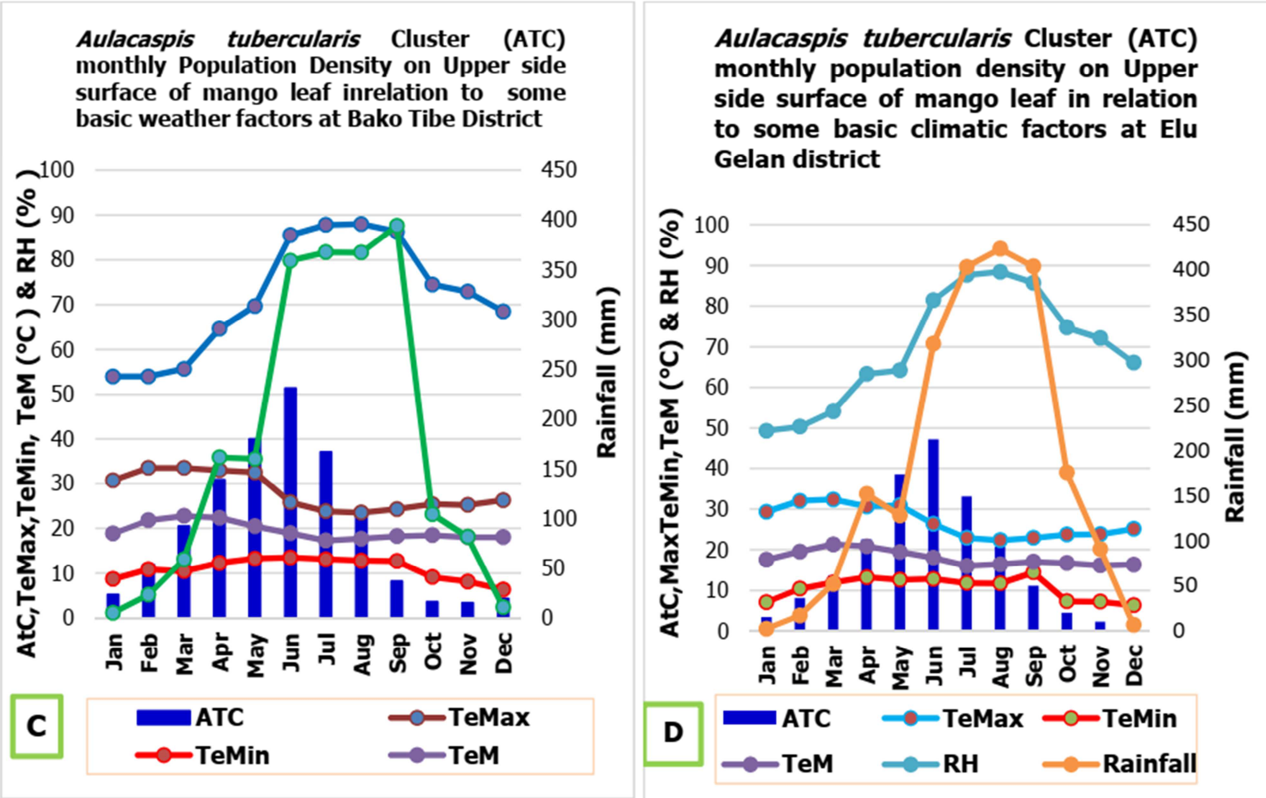


Figure 5. *Aulacaspis tubercularis cluster (ATCs) population density recorded monthly in relation to some basic weather factors in four districts in western Oromia: (A) Guto Gida district, (B) Nekemte City, (C) Bako Tibe district, (D) Elu Gelan district.*

3.6. Distribution of the A. tubercularis Clusters (ATC) in Different Cardinal Directions of the Mango Tree Canopy

The results revealed that in all sampled districts and Nekemte city study sites, the *A. tubercularis* cluster was present in all cardinal directions, where the pest preferred the south cardinal direction with high population density followed by the east, west and north cardinal directions (Table 3 and 4). There were significant differences (*P<.0001*) in ATC population density at the RAILMCF and Uke study sites among the cardinal directions. The highest mean number of ATCs recorded per leaf at RAILMCF and Uke sites was in the southern cardinal direction, with the values of (±SD) 55.04±7.45 and 53.64±7.16, respectively.

Likewise, at Bako High school and Sheboka Primary School mango orchards of Bako Tibe district, there were significant differences (*P <.0001*) in ATC population density among the study sites and the four cardinal directions. The highest mean number of ATCs recorded was in the southern cardinal direction, with values of (±SD) 56.05±7.66 and 54.49±7.99 for the Bako High school and Sheboka study sites, respectively. The lowest mean cluster population was recorded in the northern cardinal direction (28.88±5.81) at Sheboka Primary School mango groves.

With the same trend, at Ejaji high school and primary school mango orchards of Elu Gelan District, there were significant differences (*P<.0001*) among the four cardinal directions and the two study sites. The highest mean cluster population was recorded in the southern direction, with values of (±SD) 56.17±7.73 and 54.87±7.15 for Ejaji high school and Ejaji primary school mango orchards, respectively, where the lowest ATC population density was recorded in the northern direction (29.94±6.45) at Ejaji Primary school.

Among the mentioned study sites, Nekemte city and the surrounding area are not known for mango production, but the residents sparsely plant mango trees in their residential areas, where after fruit sett, maturity is delayed, even staying for a long period at the greening stage with no use. At the sampled sites, all mango trees were infested by *A. tubercularis,* and the cluster population density showed significant differences (*P <.0001*) in all cardinal directions, with values of (±SD) 50.26±6.46 and 49.82±6.57 at the Cheleleki and Bakanisa Kase sites, respectively. The lowest mean ATC population density was recorded in the northern cardinal direction at the Bakanisa Kase study site (25.97±5.62).

Overall, the results of our study revealed that there were significant differences in the abundance of ATC population density among the different sampling sites and dates of sampling months, where the highest peaks were recorded in mid-June, followed by May and July of the sampling period. Among the study sites, the highest mean ATC population was recorded at Ejaji High School mango orchard (56.17±7.73), followed by the Bako High School (56.05±7.66) mango orchard. However, the populations of ATCs were distributed in all cardinal directions of the trees, where the *A. tubercularis* scale preferred the southern followed by the eastern cardinal directions. The four districts (eight sampling locations) also showed differences in the abundance of ATC colonies at the scale.

Table 3. *Mean (±SD) ATC population density distributed at different cardinal directions of the mango tree canopy in the study sites (N = 180x8 = 1440).*

Study/zone/district/kebele/site			Samples	Population density of ATC in different cardinal directions of the mango tree				
				South	East	West	North	Mean
Zone	District	Kebele/Site	N	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
East Wollega	Guto Gida	RAILMCF	180	55.04±7.45ba	43.93±5.10ba	31.80±6.01c	29.80±5.78cb	40.17±4.13c
		Uke	180	53.64±7.16b	42.42±5.63c	30.13±5.93d	29.63±5.94cb	38.98±4.45d
	Nekemte City	Cheleleki (03)	180	50.26±6.46c	39.01±5.27d	29.34±6.34cd	26.88±4.85d	36.40±3.58e
		Ba. Kase (04)	180	49.82±6.57c	37.74±5.73e	29.98±6.39d	25.97±5.62d	35.91±3.78e
West Shewa	Bako Tibe	Bako H. S.	180	56.05±7.66a	43.64±5.64b	35.06±6.81b	31.23±6.09a	41.52±4.84b
		Sheboka P. S.	180	54.49±7.99b	44.26±4.84ba	36.67±6.16a	28.88±5.81c	41.09±4.06b
	Elu Gelan	Ejaji H. S.	180	56.17±7.73a	43.91±5.99ba	37.79±5.91a	32.11±5.83a	42.52±4.52a
		Ejaji P. S.	180	54.87±7.15ba	44.74±6.28a	33.96±7.08b	29.94±6.45b	40.91±4.38b
Mean				53.79	42.46	33.09	29.31	39.69
SE				6.82	4.91	5.67	4.88	3.54
CV				12.67	11.56	17.15	16.64	8.93
F value				3.04	4.67	14.28	10.45	7.94
Pr > f				0.0166	0.0010	<.0001	<.0001	<.0001
R^2				0.267	0.403	0.399	0.415	0.498

*Note: Means followed by the same letter(s) in a column are not significantly different at a P<0.05 level of significance by Tukey's Studentized Range (HSD) test.
N. B: RAILMCF= Raj Agro Industry Loco Mango Commercial Farm; Ba. = Bakanisa; H. S. = High School; P. S. = Primary School

Table 4. *Distribution of ATCs population density at different cardinal directions of mango tree canopy in the sampled districts of East Wollega and West Shewa zones during 01 May to 30 June 2020 growing seasons.*

Zone	District	Samples	Population density of ATC among the study areas in different cardinal directions of the mango tree				
			South	East	West	North	Mean
		N	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
East Wollega	Guto Gida	360	54.34±7.33bc	43.18±5.42b	30.97±6.02b	29.72±5.85b	39.58±4.33b
	Nekemte	360	50.04±6.51a	38.37±5.53a	29.66±6.36a	26.43±5.26a	36.15±3.98a
West Shewa	Bako Tibe	360	55.27±7.85c	43.95±5.27b	35.86±6.54c	30.06±6.06c	41.31±4.47c
	Elu Gelan	360	55.52±7.47c	44.32±6.15c	35.88±6.79c	31.03±6.25d	41.71±4.52c
Mean			53.79	42.46	33.09	29.31	39.69
SE			6.82	4.91	5.67	4.88	3.54
CV			12.67	11.56	17.15	16.64	8.93
F value			35.94	86.75	4.78	44.46	85.14
Pr > f			<.0001	<.0001	0.0085	<.0001	<.0001
R^2			0.267	0.403	0.399	0.415	0.496

*Note: Means followed by the same letter(s) in a column are not significantly different at a P<0.05 level of significance by Tukey's Studentized Range (HSD) test.
N. B: RAILMCF= Raj Agro Industry Loco Mango Commercial Farm; H. S. = High School; P. S. = Primary School

3.7. Correlation Between Weather Factors and A. tubercularis Cluster (ATC) Population Density

The correlation between the ATC population and some weather factors (maximum temperature (TeMax), minimum temperature (TeMin), mean temperature (TeM, rainfall (Rf), and relative humidity (RH) in four study areas, *i e*., the districts of Guto Gida, Bako Tibe, Elu Gelan, and Nekemte City, is presented in Table 5. The result revealed that there were a significant and moderate positive relationship between maximum temperature (TeMax) and the monthly counts of the ATC population, with values of r = 0.51, P<0.05; r = 0.40, P<0.05; r = 0.57, P<0.05 and r = 0.56, P<0.05 for Guto Gida, Nekemte City, Bako Tibe, Elu Gelan districts. This implies that the presence of mean maximum temperature in the environment tends to cause a positive effect on the pest population, but an increase in maximum temperature tends to cause a negative effect on the pest population growth.

Likewise, there were significantly high and moderate positive correlations between minimum temperature (TeMin) and ATC population density, with values of r = 0.81, P<0.05; r = 0.66, P<0.05; r = 0.74, P<0.05 and r = 0.61, P <0.05, for Guto Gida, Nekemte City, Bako Tibe, and Elu Gelan districts, respectively. This implies that a steady decrease in mean minimum temperature tends to cause a negative effect on the ATC population density. Moreover, there were a moderate positive relationship between the average mean temperature (TeM) and the ATC population density in the Guto Gida, Bako Tibe, and Elu Gelan districts, with values of r = 0.49, P<0.05; r = 0.63, P<0.05 and 0.67, P<0.05, respectively, but a weak negative correlation in Nekemte city, with values of -0.15, P<0.05. This implies that a moderately constant temperate tends to have a positive effect (an increase) on the ATC population density in low land areas but a slight decrease at mid-altitudes or transitional-highland.

There was a weak positive relationship between RH and ATC population density, with values of r = 0.07, P<0.05; r = 0.14, P<0.05; r = 0.33, P<0.05 and r = 0.19, P<0.05, which implies that a moderate RH in the environment tends to have positive effect in the ATC population density. Likewise, there was no significant correlation between relative humidity (RH) and the ATC population density, $r = 0.32$, $P<0.05$.

In the same activity, there was a negative correlation between rainfall (*Rf*) and ATCs population density at Guto Gida, Bako Tibe, Nekemte City and Elugelan, with values of $r = -0.01$, $P < 0.05$; $r = -0.05$, $P < 0.05$; $r = -0.01$, $P < 0.05$ and $r = -0.02$, $P < 0.05$, respectively, which implies that a moderate rainfall intensity tends to have a positive impact in the ATC population density.

Table 5. *Correlation coefficient between ATC population density and some basic weather factors in four districts (Tables 5, A-E).*

A) Correlation between ATCs population density and some basic weather factors at 3 districts and 1 City.

	Correlation (*r*) between ATCs and weather factors			
Parameters	**Guto Gida**	**Nekemte**	**Bako Tibe**	**Elu Gelan**
TeMax	0.51082	0.40154	0.56844	0.56411
TeMin	0.81211	0.66200	0.73816	0.60699
TeM	0.49384	-0.14724	0.63515	0.67132
RH	0.06668	0.14037	0.32821	0.18788
Rf (mm)	-0.10090	-0.05288	-0.01504	-0.02364

B) Correlation between ATCs population density and some basic weather factors at Guto Gida district.

Parameters	**ATC**	**TeMax**	**TeMin**	**TeM**	**RH (%)**	**Rf (mm)**
ATC	1					
TeMax	0.51082	1				
TeMin	0.81211	0.40878	1			
TeM	0.49384	0.97807	0.44019	1		
RH	0.06668	-0.74365	0.27262	-0.70055	1	
Rf (mm)	-0.10090	-0.69527	0.27536	-0.62523	0.91492	1

C) Correlation between ATCs population density and some basic weather factors at Nekemte City.

Parameters	**ATC**	**TeMax**	**TeMin**	**TeM**	**RH (%)**	**Rf (mm)**
ATC	1					
TeMax	0.40154	1				
TeMin	0.66200	0.12712	1			
TeM	-0.14724	0.76532	-0.18833	1		
RH (%)	0.14037	-0.78726	0.47503	-0.85038	1	
Rf (mm)	-0.05288	-0.68598	0.46760	-0.65336	0.84019	1

D) Correlation between ATCs population density and some basic weather factors at Bako Tibe district.

Parameters	**ATC**	**TeMax**	**TeMin**	**TeM**	**RH (%)**	**Rf (mm)**
ATC	1					
TeMax	0.56844	1				
TeMin	0.73816	0.49134	1			
TeM	0.63515	0.93932	0.67116	1		
RH (%)	0.32821	-0.44898	0.48564	-0.26728	1	
Rf (mm)	-0.01504	-0.45120	0.47673	-0.23218	0.84092	1

E) Correlation between ATCs population density and some basic weather factors at Elu Gelan district.

Parameter	**ATC**	**TeMax**	**TeMin**	**TeM**	**RH (%)**	**Rf (mm)**
ATC	1					
TeMax	0.56411	1				
TeMin	0.60699	0.59160	1			
TeM	0.67132	0.81315	0.43326	1		
RH (%)	0.18788	-0.46288	0.33339	-0.34582	1	
Rf (mm)	-0.02364	-0.38417	0.43208	-0.48186	0.86519	1

N. B.: ATC= *A. tubercularis* cluster; TeMax=Maximum temperature; TeMin= Minimum temperature; TeM=Mean average temperature; RH=Relative humidity; Rf =Rainfall

4. Discussion

The results of the study confirmed that *A. tubercularis* was present in all sampled study areas throughout the study period with a fluctuating cluster population density. The results of this study revealed that the highest population density of ATCs was concentrated on the upper side rather than on the underside of the infested mango leaves. The study districts (Bako Tibe, Guto Gida and Elu Gelan) and Nekemte city showed significant differences in the ATC population density on the upper surface of mango leaves. Bako Tibe and Guto Gida districts registered the highest ATCs, followed by Nekemte City and Elu Gelan district. Nekemte city is a mid-altitude area with moderate temperatures that receives high rainfall when compared to the rest of the three districts. The population density of ATCs recorded in Nekemte city was relatively similar to the population density recorded in the rest of the study districts, which comparably ranged in hot low land with high temperatures and receiving moderate rainfall. However, regarding climate factors, the study by [34] mentioned that the highest averages of scale infestation correspond to plantations located at low altitudes, possibly due to the effect of temperature.

The current results are in agreement with the results of [26-29, 35-36], who found that *A. tubercularis* prefers the upper surface of mango leaves over the lower surface. A related study by [10] mentioned that *A. tubercularis* preferred the upper surface of leaves during the cold months and preferred the lower surface of leaves during the hot months. The study by [10] also complemented the results of this study, which found that *A. tubercularis* prefers the upper surface in the winter season, whereas in the summer, they prefer the lower surface of the host plant.

The results of this study indicate that when limited temperature prevails in mango orchards, it has a positive impact on the population density of ATCs. That is, as the temperature moderately increased, the density of the scale cluster population also increased. In this same case, there was a marked increase in ATC population density from March to mid-June, with a general trend of slight to medium increased precipitation. Conversely, there was a swiftly decreased cluster population (from scarce to nonexistent) from mid-June up to September followed by prolonged heavy precipitation, probably due to this heavy precipitation the scale clusters wash-down from mango leaves. During and after the months of heavy precipitation, most of the infested mango leaves exhibited yellow blemishes and necros (researcher, personal surveillance), indicating that the patch from which the scale clusters formed was washed down by heavy precipitation. This finding is in line with [37], who mentioned that a low-density period of the *A. tubercularis* population was from the end of the rainy season in Egypt. The results of this study coincide in part with the results of the studies by [34, 38], who mentioned that the populations of *A. tubercularis* are lower during the rainy season from July to September, with a period of population growth from December to February. The highest population densities occur during the dry and warmer season of the year, from March to the beginning of rain in June.

The highest populations were detected from April to June, and the lowest were detected during the rainy season between July and October. This means that ATC populations are guided by food rather than rain. April to June is the time when the trees produce food and the time when scales maximize their presence. After that, the rains start, the scales are washed away, and food becomes scarce. This condition continues until December or January. The study by [39] reported that the *A. tubercularis* population abundance is affected by rain. Likewise, [10] also revealed that a low population density of *A. tubercularis* was recorded during the rainy season. A related study by [40] mentioned that a low population density of *A. tubercularis* was recorded from the end of the rainy season in Egypt. The result of the study by [28] on the effect of climatic weather factors on the population abundance of *A. tubercularis* confirmed that the population abundance and percentages of infestation by *A. tubercularis* were significantly affected by the recorded weather factors, *viz*., daily mean air temperature, mean relative humidity, and mean dew point. A related study by [41] mentioned that the combined effect of climatic factors, *viz*., maximum temperature, minimum temperature, and solar radiation, was responsible for the population changes in nymphs, adult females, and the total population of this scale insect, respectively.

The correlation coefficient (*r*) between some basic weather factors (maximum temperature, minimum temperature, rainfall, and relative humidity) and the monthly recorded population abundance of the ATC population density showed weak to moderate positive correlations in the four study areas and a weak negative correlation with the mean average temperature (TeM) in Nekemte city. The results of this study agree with [41], who mentioned that the statistical analysis of simple correlation showed a positive insignificant correlation between the mean maximum temperature and nymphal population of *A. tubercularis*. The study by [41] also reported that the precise effect of mean minimum temperature on the nymphal population showed a highly significant positive correlation, and the simple correlation between the population density of adult *A. tubercularis* females and the mean maximum temperature showed an insignificant positive correlation. This study also revealed that there was an insignificant positive correlation detected between the mean minimum temperature and the adult female *A. tubercularis* population. The results of this study also revealed that in all the study areas, there was a significant and moderate positive correlation between relative humidity (RH) and the ATC population density. This implies that a moderately stable RH has a positive correlation with the ATC population and that a decrease in RH in the orchard environment tends to cause a population reduction in ATCs. Conversely, [35] obtained a different conclusion on mean temperature and the total population of *A. tubercularis*, which mentioned that there was a negative correlation between the fluctuations of the *A. tubercularis* population and the temperature degrees. A similar study by [10] reported that the variables of temperature and RH (percentage) had a slight effect on the *A. tubercularis* population but did not reach a significant level except for the effect of maximum RH, which was highly significant, and minimum RH, which was significant. A study by [36] stated that the combined effect of mean air temperature (°C), relative humidity (RH %), and light intensity (lux) had a combined effect on the total number of live *A. tubercularis* sessile stages, with values of 77.66 and 39.44 % during the first and second years of the study, respectively. The study by [28] also mentioned that there were positive significant correlations between the daily mean temperature and the total population of *A. tubercularis.* Furthermore, the studies by [34] showed that the incidence of *A. tubercularis* was limited by environmental conditions, with the combination of higher mean temperatures and low relative humidity being the most appropriate for its development.

The results of this study revealed that the population peaks were recorded from April to May at Bako, Uke, and RAILMCF and from May to mid-June at the Nekemte and Ejaji study sites, respectively, when the rainfall intensity was from minimal to medium precipitation. In addition, the monthly counts of the total ATC population throughout the study period (twelve successive months) of investigation showed significant differences in the abundance of ATC density at different sampling dates of the month. The highest peaks were recorded in mid-June, followed by May and July in the sampling year. Likewise, the minimum mean value of cluster density was recorded from the months of October to January. A related study by [13] mentioned that throughout the study period, seasonal fluctuation of different developmental stages of *A. tubercularis* recorded three peaks for total numbers of the live population, as well as three peaks for immature stages and two peaks for adult stages. This scale insect recorded its maximum activity starting from spring (March to May) and early June (summer). The remaining unexplained factors and the experimental error are assumed to be due to the influences of other unconsidered and undetermined factors that were not included in this study.

The results of this study revealed that ATC is distributed in all four cardinal directions with significant differences in population density, where this scale insect prefers the southern cardinal direction followed by the eastern cardinal direction and the center of the mango tree canopy. A related study by [13] mentioned that the pest *A. tubercularis* is more abundant on lower, south-facing aspects of trees, and its crawlers are probably dispersed by wind currents. The study by [42] demonstrated that the south face of the mango tree is more prone than other faces due to weather factor differences. The results of [43] are partially in agreement with the findings of our study, which mentioned that populations of *A. tubercularis* were distributed in all cardinal directions of the mango trees, where the *A. tubercularis* scale preferred the southern and northern directions. Conversely, the results of our study identified that the northern cardinal direction was the least preferred direction. The eastern cardinal direction was the second preferred direction in the current results; however, the findings by [29, 34] mentioned that *A. tubercularis* was more concentrated in the eastern direction than in the other directions. Another study by [35] mentioned that *A. tubercularis* perfected in the east and west directions during cooler and summer weather. The differences between the results of the previous study and the present study may be attributed to the variation between some weather factors and/or agro-ecosystems.

In general, the variation in the *A. tubercularis* cluster (ATC) distribution observed in the present study was probably due to cardinal direction differences and temperature differences. Other factors those were not included in this study, such as sunlight intensity, which may cause mortality during dry seasons, and wind force, which may directly affect crawler establishment and indirectly increase evapotranspiration, which reduces moisture levels, may need further investigation.

5. Conclusions

The current studies have focused on four key components of ATC formation: its abundance and cluster population density, preference for leaf surface area, cardinal directional preference, and the correlation between cluster population density and some basic climatic factors, viz., temperature, rainfall and relative humidity. The study results showed that on infested mango leaves, *A. tubercularis* was present in all sampled study areas, with a fluctuating cluster population density throughout the study period. The highest population density of ATCs was concentrated on the upper side rather than on the underside surface of the leaf. The investigation showed that there were significant differences in the abundance of ATC density in all the study areas on different sampling dates of the study months.

With a general trend of slight to moderately increased precipitation, from March to mid-June, the ATC population seemed to increase, while with prolonged precipitation, the ATCs were seen to decrease, most likely due to washing down the scale clusters by prolonged heavy precipitation. The study also confirmed that the population peaks were recorded from April to May at the Bako, Uke, and RAILMCF study sites and from May to mid-June at the Nekemte and Ejaji study sites. The last two study sites were found at mid-altitudes ranging from 1742 to 2082 m above sea level for Ejaji (Elugelan) and Nekemte city.

The results of our study also revealed that the ATC population was distributed in all four cardinal directions with significant differences in population density. This scale insect prefers the southern cardinal direction primarily and the eastern cardinal direction as the second choice of this insect pest, whereas the northern cardinal direction is the list preferred direction, although the other contributing factors need to be investigated further. Furthermore, the correlation coefficient between some basic weather factors, *viz*., temperature, rainfall, and relative humidity, and the ATC population density showed weak to moderate positive correlations in the four study areas and a weak negative correlation with mean average temperature (TeM) in Nekemte city. Moreover, strict controls on the movement of infected planting materials and fruits are needed if *A. tubercularis* is to be prevented from colonizing the rest of the un infested mango-producing areas of the country.

Author Contributions

Temesgen F. conceptualized the study design, performed the experiments and statistical analysis, and wrote 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 reviewed and accepted the final document for publication.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding/ first author on reasonable request without undue reservation.

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Conflicts 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 author declared that there is no conflict of interest.

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