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Original Research

White Mango Scale, *Aulacaspis tubercularis* Newstead (Hemiptera: Sternorrhyncha: Diaspididae) in Ethiopian *Mangifera indica* Orchards: Incidence, Infestation, Severity, Distribution, and Growers' Knowledge

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Abstract

White mango scale, Aulacuspis tubercularis is the devastating pest of mango in the world. A. tubercularis was introduced into Ethiopia a decade ago, however, except a few areas its distribution, incidence, infestation level, severity status and farmers' knowledge on this pest is not well studied. Thus, the survey was carried out in five regional states and one city admiration namely: Oromia, South-western Nations, and Nationalities People, Benishangul-gumuz, Amhara and Harari Regional states, and Dire-Dawa City Administration. Multistage sampling procedure was used for data sampling. A total of 1230 mango trees were selected purposively, and 12 leaves were randomly plucked from each tree at 4 cardinal directions. The presence or absence of A. tubercularis cluster was tested and rated in percentage. The result of the study confirmed that A. tubercularis was distributed in all study areas up to air distances of 239, 277, 380, and 436 km to the direction of the western, southwestern, eastern, and northern directions, respectively. The incidence of A. tubercularis cluster was significantly (P<0.05) higher in Assosa zone and the minimum was recorded in north Shewa zone. Among the respondents 63% of them attempted to manage the pest using different cultural practices like, under-tree smoking and pruning heavily infested branches. From this study, it was concluded that the distribution of the A. tubercularis was at an alarming rate and its infestation and severity status is at an increasing rate, which indicates the need for urgent action in implementing control measures and awareness creation of mango growers.

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Introduction

Mango (*Mangifera indica* L.) is one of the most popular and earliest cultivated fruits of tropical and subtropical regions and is grown in more than 100 countries (Masroor *et al*., 2016). It is one of the most important tropical fruits in the world and is known as the "king of tropical fruits" (Ebrahimi and Rastegar, 2020). It is ranked the second most cultivated tropical fruit and sixth major fruit crop worldwide (UNCTAD, 2016), and the fruit has a high cropping potential under climate change scenarios (Munir *et al*., 2015; Kumar *et al*., 2021). Mango plants not only produce fruit for consumption and add value to local agro-ecosystems, but also lend livelihood support in terms of household income, employment opportunities, timber production, livestock fodder, medicinal products, and environmental services (Kruijssen and Mysore, 2010; Anshuman *et al*., 2015).

Mango farmers in Ethiopia exercise some indigenous knowledge acquired from their ancestors of family members and neighbors in production systems and pest management (Tewodros *et al*., 2019). However, mango production in Ethiopia is constrained by several factors among which insect pests and diseases are the most important ones. Among the insect pests, the white mango scale, *Aulacuspis tubercularis* Newstead (Hemiptera: Sternorrhyncha: Diaspididae), is the recently emerging mango pest in Ethiopia causing a devastating loss in mango production

(Mohammed *et al*., 2012; Temesgen, 2014; Ofgaa and Emana, 2015; Ofgaa *et al.,* 2019).

In Ethiopia, the occurrence of white mango scale as a new mango insect pest was reported for the first time in 2010 (Mohammed *et al*., 2012; Temesgen, 2014). The study by Temesge (2014) on the initial spread of *A. tubercularis* revealed that the white mango scale covered a maximum air distance of 67 km westward (Gimbi district, Jogir kebele) and 58 km eastward (Gobu Sayo district, Sombo kejo kebele the route from Nekemete to Finfine) from its first recorded location in Loko (now known as Raj Agro Industry, formerly Green Focus Ethiopia LTD). Another study by Ofgaa *et al*. (2019) reported that the widespread presence of *A. tubercularis* from its initial location in Loco, reaching air distances of 97, 98, 92, and 43 km in the east, south, west, and north directions, respectively. The severity of infestation was notably high across most surveyed localities. Despite previous studies, there lacked a comprehensive report encompassing all cardinal directions, presenting a holistic view of *A. tubercularis* distribution, severity, and farmers' knowledge in mango-producing regions. Therefore, this study aims to comprehensively assess *A. tubercularis* distribution, incidence, severity, and the knowledge of mango growers in the designated areas.

Materials and Methods

Description of the study areas

The survey was conducted during from December 2017 to November 2018 in the western, southwestern, northwestern, northeastern, central rift valley (CRV), and eastern parts of Ethiopia. It was started from Loco kebele administration, East Wollega administrative zone (09°19. 226' N and 036° 31.619' E), the place where the white mango scale was recorded for the first time and extended in nearly the four cardinal directions (Figure 4). Accordingly, the survey covered four regional states and one city admiration namely: Oromia, South-western Region (SWR), Amhara and Harari National Regional states, and Dire Dawa City Administration. In this study the administrative zones covered were East and West Wollega, Jima, Buno Bedele, Ilu-Ababora, West and East Shewa, and West and East Hararge administrative zones of Oromia Regional State, Dawro, Kefa, and Bench-Sheko zones from SWR were included in this study. From Benishangul Gumuze National Regional State Assosa zone and from Amhara National Regional State west Gojam zone, Bahir Dar special zone, and Oromo special zone were included. From the eastern part of the country, Harari Regional State and Dire Dawa City Administration were included in the study. In general, the detailed description and information of the study areas are shown in Table 1 and Figure 1 below, respectively.

Table 1. Climatological and geographical description of the study areas and their distance from the capital city of the country (Addis Ababa)

Region	Study zone/site	Town/ City	Distance (km)	Altitude m.a.s.l	Relative Humidity	Rainfall (mm)		Temperature mean (°C)		Coordinates	
						Min.	Max.	Min.	Max.	Longitude	Latitude
Oromia NRS	East Wollega	Nekemte	328	2088	72.9	1474	2411	7.7	34.8	9°50′ N	36°33 E
	West Wollega	Ghimbi	441	1844	73.8	1130	2435	7.3	35.2	9°10′ N	35°80′ E
	Buno Bedelle	Bedelle	480	1878	75.2	1387	2699	11.1	31.2	8°18′ N	35°35 E
	Ilu Abababora	Mettu	600	1632	74.8	1547	2577	12.1	33.4	8°15′ N	36°00 E
	Jimma	Jimma	335	1718	76.3	1273	2467	11.1	31.3	7°40′ N	36°50′ E
	West Shewa	Ambo	114	2101	67.7	787	1834	8.2	29.7	8°59′ N	37°51′ E
	East Shewa	Adama	99	1712	57.2	439.2	1065	12.8	33.6	8°54′ N	39.27° E
	West Hararge	Chiro	326	1826	58.1	541.3	1242	13.6	34.6	9°05′ N	40°52′ E
	East Hararge	Harar	523	1885	56.6	454.3	1164	12.9	30.3	9°19′ N	42°70′E
BGNRS	Assosa	Assosa	661	1570	61.4	621.2	2213	17.4	34.0	10°04′N	34°31′ E
SNNPRS	Dawuro	Tercha	474	1531	74.4	1318	2311	8.9	34.2	7°14′ N	37°17′ E
	Kafa	Bonga	460	1714	81.5	1536	2916	7.4	28.8	7°16′ N	36°14′ E
	Bench Sheko	Mizan Teferi	561	1451	80.1	1162	2393	9.7	31.1	6°15′ N	35°10′ E
Amhara NRS	West Gojam	Bahir Dar	565	1786	63.2	1050	2072	7.3	32.5	11°36′N	37°23′ E
	North Shewa	Shewa Robit	210	1281	59	666.4	1210	14.6	34.7	9°59′ N	39°54′ E
	Oromo zone	Kemise	325	1447	57.7	485.1	1542	8.6	33.4	10°72′N	39°86′ E
Harari Region	Harari	Yerer Weldia	535	1454	63	780	1450	7.6	34.3	9°21′ N	42°12′ E
		Sofi	529	1677	67	795	1485	7.9	34.2	9°16′ N	42°10′ E
DireDawa City	Dire Dawa	Dire Dawa	515	1276	56.6	454.3	1164	8.3	38.5	9°36′ N	41°52′ E

N.B: NRS National Regional State; BGNRS = Benishangul-Gumuze National Regional State; SNNPRS = Southern Nations and Nationalities Regional State; Min = Minimum; Ma = Maximum

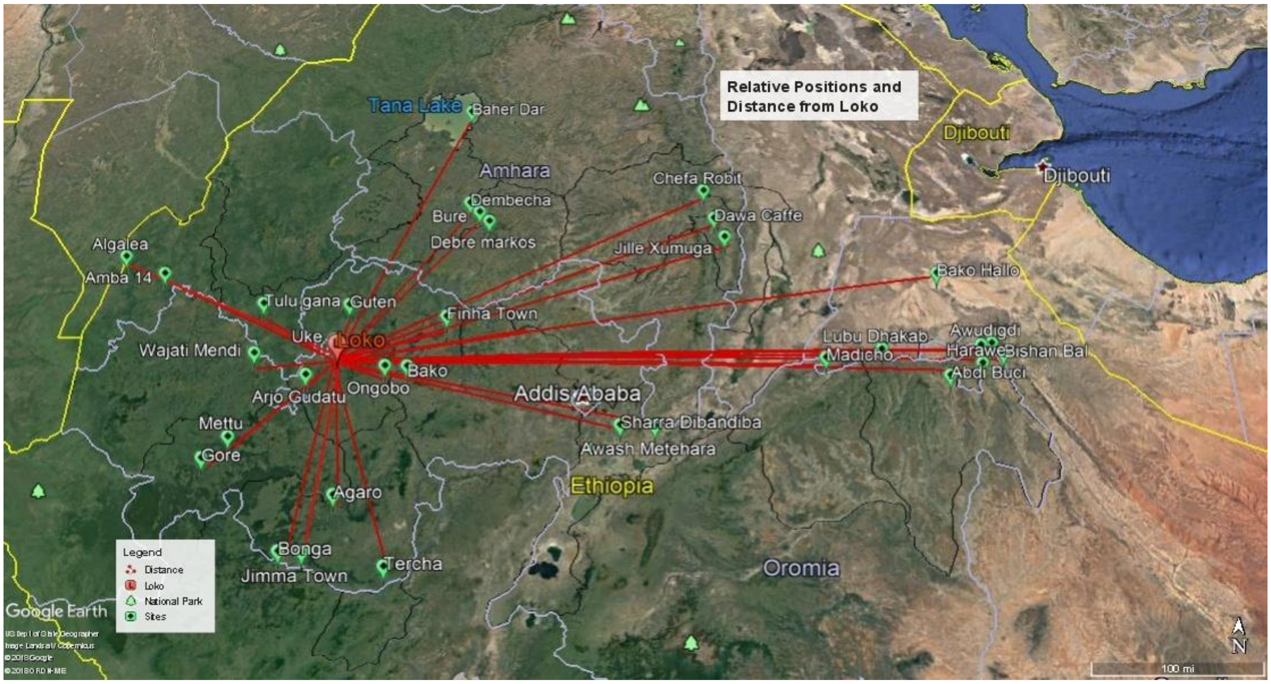

Figure 1. Geospatial map of the study areas: western, southwestern, northwestern, northeastern, central rift valley, and eastern Ethiopia**;** Red line, radiating from initial *A. tubercularis* occurrence area RAILMCF (Loko) to areas covered during the survey**.**

Research Design and Sampling procedures

The survey, conducted from December 2017 to November 2018, focused on examining the distribution, incidence, severity status, and the knowledge of mango growers regarding *Aulacaspis tubercularis* in five regional states and one city administration. The research followed a meticulous approach to ensure comprehensive coverage and reliability.

The survey covered 9 Administrative zones within 18 districts in 36 administrative villages (kebeles') distributed in 108 sample sites from Oromia Regional State; one administrative zone within 2 districts in 4 villages distributed in 12 sample sites from Benishangul-Gumuz Regional State and 3 Administrative zones within 6 districts in 12 Administrative kebeles' distributed in 36 sample sites from Southwestern National and Nationalities People (SWNNP) Regional State were purposively selected. Similarly, the survey comprised of 2 zones and 1 special zone (City) within 4 districts in 8 Administrative kebeles' distributed in 24 sample sites from Amhara Regional State; 2 districts distributed in 4 Administrative kebeles' within 12 sample sites from Harari Regional States, and 2 Administrative kebeles' distributed in 6 sample sites from Dire Dawa City Administration were purposively selected. Hence, the survey areas covered 5 Regional States having 16 Administrative zones, 1 special zone and 1 City Administration in 40 districts within 82 villages distributed in 246 sample sites.

In the selected districts mango growers' field were randomly sampled at a distance of 15 to 20 km intervals in the administrative villages following on the main and accessible rural roads. Multistage sampling procedure was used for sampling data.

Survey Area Selection**:** Purposively selected regions included Oromia, Benishangul-Gumuz, SWNNP, Amhara, Harari, and Dire Dawa City Administration, covering 13 administrative zones, 1 special zone, and 1 City Administration. The survey encompassed 40 districts within 82 villages, amounting to 246 sample sites.

Multi-Stage Sampling**:** A multi-stage sampling procedure was employed to systematically gather data. From each administrative kebele, 12 mango producers were purposively selected, totaling 840 mango producers across all regions. These producers were chosen based on the number of mango trees in their possession and their experience in mango cultivation.

Farmer Interviews and Sample Collection: Structured questionnaires were administered to collect socio-economic and biodata from all respondents. From the selected mango growers, three were further chosen for the sampling of infested mango trees and leaves. A total of 1230 mango trees, representing diverse sizes and ages, were purposively selected for sample collection. Twelve leaves, distributed among the upper, center, and lower canopies from the four cardinal directions, were plucked from each tree, resulting in the collection of 14,740 mango leaves.

***Data Collection*:** The collected data encompassed mango growing systems, the number of mango trees owned, source of mango seedlings, mango cultivars, management practices, and the knowledge of mango growers regarding *A. tubercularis*. Specifics such as the presence of *A. tubercularis* clusters, their prevalence, severity status, and associated factors were meticulously recorded during the data collection process.

Data Validation and Cross-Verification: The research prioritized data validation and cross-verification to ensure accuracy and reliability. Direct observations and inspections were conducted by researcher, validating the information obtained from farmers and enhancing the overall robustness of the study.

Environmental and Climate Data: Coordinates, altitude, and climatic parameters were recorded using GPS (Wright, 1996; RISC, 2008). Meteorological data were obtained from the National Meteorology Agency of Ethiopia and NASA's POWER global meteorology (https://power.larc.nasa.gov/data-access-viewer/). The relative frequency and severity of *A. tubercularis* occurrence were calculated by the use of the equation adopted from Kataria and Kumar (2012) to provide a comprehensive understanding of the pest's impact across different localities. *A. tubercularis* incidents were rated as a percentage of ATC formed on mango leaves within the quadrant. The *A. tubercularis* clusters severity was scored on a rating scale of 0–4, where;

0 =No visible symptoms of ATC seen on mango leaves;

1 =Scattered appearance of ATCs seen on few mango leaves with < 25 % coverage;

2 =Severe incidence of ATCs on one branch with 25–50% coverage per leaf;

3 = Severe incidence of ATCs on two & more than two branches with 50–75 % coverage per leaf and

4 =Severe incidence of ATCs on the whole mango branches and leaves with75–100 % coverage per leaf.

The severity of the scales was converted to the percent severity index (PSI) (Osunga *et al*., 2017). *A. tubercularis* prevalence was determined as the ratio of the number of fields where ATCs were present to the total number of fields assessed. This was used to interpret the severity index of the pest from which severity status at each study site was determined (Table 2).

Table 2. Techniques of data summary used for determination of *A. tubercularis* severity status, severity index, *A. tubercularis* clusters (ATCs) formation on mango leaves

Relative frequency of ATCs occurrence per mango leaf (leaf area coverage in percent)	Severity Index (SI)	Levels of A. tubercularis (ATCs) infestation	Rate of severity Status
0	0	No infestation	No infestation
1-15	1	Scattered appearance of few clusters of A. tubercularison few mango leaves on one branch	Mild infestation
16-30	2	Severe incidence of ATCs on one to two branches only	Medium infestation
31-50	3	High severe incidence of ATCs on three to five branches	High infestation
≥51	4	Very high severe incidence of ATCs on the whole branches of mango tree	Very high infestation

The percentage of incidence was calculated by the use of the equation suitable formula adopted from Kataria and Kumar (2012). *Aulacaspis tubercularis* incidence percentage was recorded by counting plants showing visible symptoms of ATCs in the central rows and the data were expressed as a percentage of the total assessed plants using the following formula:

$$\text{Percentage incidence (PI)} = \frac{\text{No. of infested mango plants}}{\text{Total mango plants observed}} \text{X } 100$$

The severity index (SI) was calculated by the use of the equation adopted by Kataria and Kumar (2012) mentioned as follows: Severity index (SI) = Sum of the total grade points (1-4) infestation grade G_1 to G_4, respectively) of the infested plant/Total number of infested plants observed.

$$\text{SI} = \frac{\text{Sum of the total grade points of infestation (grade 0 to 4) of the infested plant}}{\text{Total No. of infested plant from the survey site}}$$

Data Analysis

The survey data underwent a rigorous analysis utilizing the Statistical Package for Social Sciences (SPSS), version 20.0. The objective was to derive meaningful insights from the collected information, employing various statistical methods.

Descriptive statistics: Descriptive statistics, including means, standard deviations, and minimum and maximum values, were employed to summarize and interpret the quantitative data. The frequencies and percentages of *A. tubercularis* clusters across different locations and the sampled mango tree leaves were subjected to ANOVA, with Tukey's studentized range test applied for post hoc analysis at a significance level of P<0.05.

Quantitative data analysis: Calculation of percentages and frequency counts was a pivotal part of the analysis, providing a clear overview and serving as a foundational tool for interpreting quantitative data. For close-ended questions, tables presenting frequency and percentages were utilized for result comparison.

Qualitative data analysis: Open-ended questions from interviews and observations were analyzed using descriptive methods, ensuring a comprehensive exploration of the qualitative aspects of the collected data. This approach allowed for nuanced insights to enrich the overall analysis.

Comparative statistical analysis: Chi-square (χ2) emerged as a crucial comparative statistical method. It was employed to identify variations in socio-demographic characteristics, farm attributes, and the information and knowledge related to *A. tubercularis*, along with its management practices. This comparative analysis contributed to a deeper understanding of the diverse factors influencing the research outcomes.

This meticulous research design and sampling procedure aimed to ensure a comprehensive understanding of *A. tubercularis* infestations in mango orchards, incorporating both quantitative and qualitative data to support robust analysis and meaningful conclusions.

Results

Demographic Characteristics of Respondents

Age characteristics and family size

The demographic characteristics of respondents in terms of age and family size is presented in Table 3. Of the total 840 interviewees, all actively participated in the study, providing a comprehensive view of the mango-growing community. The majority, constituting 90.02%, were males, while the remaining 9.98% were females. Notably, respondents within the age range of 46–55 (28.87%) formed the largest group, followed by those aged 56–65 (20.82%). This indicates a prevalent trend of mango growers falling within the adult age bracket of 46–65, possibly due to the perennial nature of mango cultivation and the preference of older farmers for less labor-intensive activities. This could be because mango is a perennial crop and the youth groups lack farmland and adequate capital to grow mango. It could also be due to the reason that the youth groups are educated and they preferred to be engaged in off-farm activities in urban areas. Family sizes varied, with 2–3 member households comprising 11.40%, 4–5 member households at 38.94%, and 6–7 member households constituting 32.84%.

Table 3. Respondents' demographic characteristics (gender, age and family size) in the study area (N=840)

	% Response in different regions						Mean		
Characteristics	Orom N=511	Amha N=133	BGum N=72	SWR N=48	HarRS N=48	DDA N=28	%	χ^2	P-value
Gender								24.0	0.242
Male	90.8	93.23	90.28	87.5	85.42	92.86	90.02		
Female	9.19	6.76	9.72	12.5	14.58	7.14	9.98		
Age of respondent (years)								30.0	0.242**
Below 25	1.76	3.76	4.16	1.04	6.25	7.14	4.02		
26 – 35	8.61	10.53	7.2	14.58	8.33	10.71	9.99		
36 – 45	16.63	30.83	25.0	18.75	4.16	3.57	16.49		
46 – 55	35.42	23.31	16.66	31.25	34.42	32.14	28.87		
56 – 65	23.47	12.78	33.33	14.58	22.92	17.86	20.82		
Above 66	13.11	18.79	6.94	14.42	22.92	28.57	17.46		
Family size								20.0	0.220**
2 to 3	20.44	16.69	12.85	8.87	5.21	4.35	11.40		
4 to 5	52.94	57.67	58.81	24.59	21.16	18.48	38.94		
6 to 7	20.01	19.55	20.47	45.16	47.85	44.02	32.84		
8 to 9	5.95	4.77	6.43	16.93	19.33	25.54	13.16		
> 9	0.65	1.34	1.43	4.43	6.44	7.61	3.65		

Note: **Statistically significant at P < 0.01

N.B. Orom=Oromia; Amha= Amhara;BGum=Benishangul-Gumuz; SWR=Sowthwesten Region; HarRS=Harari Regional State; Dire Dawa City Administration.

The family size of the households was greatly varied, *i.e*., those having family members of 2–3 were 3.2 % (27), those having 4–5 family members were 46.3 % (389), and those having 5.3– 6.3 family members were 50.5 % (424). Individual households have minimum and maximum family members of 1 and 9, respectively.

Education status

The educational status of mango growers in the study area is outlined in Table 4. A nuanced distribution revealed that 18.36% were illiterate, 24.2% attended adult education, and varying percentages attended different grade levels. Illiteracy was more prominent in the eastern parts of Ethiopia, reflecting potential gaps in accessing technological advancements in mango production and pest management.

Table 4. Respondents Education Levels in the Study Area (N= 840

Characteristics	Percent (%) Response in different Regions						Mean %	χ^2	P-value
	Orom N=511	Amha N=133	BGum N=72	SWR N=48	HarRS N=48	DDA N=28			
Educational level								42.0	0.227**
Never attend school	8.63	13.53	26.38	16.66	27.08	17.86	18.36		
Adult education	19.17	27.82	16.66	14.58	31.25	35.71	24.20		
Attend grade 1–6	50.68	38.34	43.05	52.08	39.58	39.28	43.84		
Attend grade 7–8	12.52	15.03	9.72	12.5	2.08	7.14	9.31		
Attend grade 9–12	6.06	3.01	1.39	4.16	0	0	2.44		
Diploma	1.76	1.5	2.77	0	0	0	1.01		
First Degree	1.17	0.75	0	0	0	0	0.32		

Note: **Statistically significant at P < 0.01

Farmers' Experience and Mango Cultivars Grown in the Study Areas

The mango production experience of the respondents and different mango cultivars grown in the study area is shown in Table 5. Data obtained from the respondents indicated that mango production was a common farming practice in western, southwestern, central rift valley, eastern, northwestern and northeastern Oromia, Benishangul-Gumuz (BGum), Amhara, South-western Region (SWR),Harari Regional State (HarRS) and Dire Dawa Administration (DDA) parts of the country, where it is steadily expanding in all cardinals of the country. Among 840 respondents, 3.02 % of them replied that they started mango production before 50 years while 8.75 %, 16.08 %, 22.72 %, 31.65 % and 17.7 % of them indicated that they have experience of mango production. from 40-50 years, 30−40 years, 20−30 years and < 15 years back, respectively.

In the study area, different mango cultivars have been grown; among these local and improved cultivars constituted 85.75 % and 14.25 %, respectively. Further, the highest number of mango trees owned by single farmers was 120 and the least number was 5 trees. and the average number of mango trees per farmer was 42. The approximate highest age of the mango tree was 78 years, and the least age was 5 years. The average high, medium, and low age of mango in the study area was 51.4, 30, and 10.5 years, respectively, with an average age of 30.6 years. Most of the improved mango cultivars are grown at RAILMCF, Upper UAAI and MARC. In the Loco area, a few farms like 'Sat-Catar-Hawas, Techane Debalkie, and other few farmers grow improved cultivars of mango. Among the most grown improved mango cultivars in the aforementioned study areas are Apple mango (11.6 %), Tomy Atkins (2.44 %), Kent (0.58 %), and Dodo cultivars. Dodo and Alphonso were the newly introduced mango cultivars by RAILMCF, and two new cultivars named "Van Dyke" and "Sabre" was introduced for adaptation trial by MARC.

Table 5. Respondents' mango production experience and cultivars grown in the study area (N=840)

Characteristics	Percent (%) Response in different Regions						Mean %	χ^2	P-value
	Orom N=511	Amha N=133	BGum N=72	SWR N=48	HarRS N=48	DDA N=28			
Mango Production experience (years)								30.0	0.224**
50 and above	2.15	0.0	9.72	0	6.25	0	3.02		
40 to 50	7.43	3.01	11.11	4.17	12.5	14.28	8.75		
30 to 40	19.18	6.76	16.67	22.92	16.67	14.29	16.08		
20 to 30	29.16	22.55	19.44	22.92	20.83	21.43	22.72		
15 to 20	25.63	39.09	30.55	35.42	27.08	32.14	31.65		
<15 years	16.44	28.57	12.5	14.58	16.67	17.86	17.77		
Mango cultivars used								36.0	0.287**
Local	83.95	81.95	90.28	66.67	91.67	100.0	85.75		
Apple mango	12.13	18.05	9.72	18.75	8.33	0	11.16		
Kent	1.37	0	0	2.08	0	0	0.58		
Tommy Atkins	2.15	0	0	12.5	0	0	2.44		
Kiett	0	0	0	0	0	0	0.00		
Dodo	0.2	0	0	0	0	0	0.03		
Alphonso	*	0	0	0	0	0	0.00		
Van Dyke	*	0	0	0	0	0	0.00		
Sabre	*	0	0	0	0	0	0.00		

Note: **Statistically significant at P < 0.01

Knowledge and awareness of mango growers on *A. tubercularis* occurrence

The result of the study revealed that about 55.87 % of respondents were aware of *A. tubercularis* occurrence in their fields. Among those who knew, 32.37% observed the pest in the past 2–3 years and 13.93 % in the past 4−5 years, 4.01 % in the past 6−9 years, whereas 3.23 % of them noticed *A. tubercularis* as a mango pest for the past 10 years (Table 6). Based on the extent of *A. tubercularis* problem, 29.35 % of the observed infestation was recorded as sever infestation, 22.65 and 4.99 % recorded as moderate and minor infestation, respectively and 38.75 % recorded as not observed.

Table 6. Respondents' knowledge and awareness of mango growers on *A. tubercularis* occurrence in the study area (N=840)

Characteristics	Percent (%) Response in different Regions						Mean %	χ^2	P-value
	Orom N=511	Amha N=133	BGum N=72	SWR N=48	HarRS N=48	DDA N=28			
Knowledge and awareness on *A. tubercularis*								2.0	0.157*
Yes	80.63	69.17	100	85.42	0	0	55.87		
No	19.37	30.83	0	14.58	100	100	44.13		
When do you observe/recognize *A. tubercularis*								15.0	0.241*
For the past 10 years	19.37	0	0	0	0	0	3.23		
For the past 6 to 9 years	24.07	0	0	0	0	0	4.01		
For the past 4 to 5 years	23.29	43.61	0	16.67	0	0	13.93		
For the past 2 to 3 years	14.48	25.56	100	54.16	0	0	32.37		
Not observed	18.78	30.83	0	29.17	100	100	46.46		
Extent of *A. tubercularis* problem								18.0	0.263*
Sever	52.05	24.06	100	0.0	0.0	0.0	29.35		
Moderate	16.05	32.33	0	87.5	0.0	0.0	22.65		
Minor	8.41	9.02	0	12.5	0.0	0.0	4.99		
Not awarded/observed	23.48	9.00	0	0	100	100	38.75		

Note: **Statistically significant at P < 0.01

Severity levels varied, with 29.35% experiencing severe infestation. Infestation mainly affected leaves (46.05%), fruits (39.92%), and succulent twigs (14.03%) (Table 7). The symptoms observed on the plant parts are chlorosis and defoliation of leaves as well as drying up of twigs and pink blemishes on the fruits are the major one.

Table 7. Farmer's knowledge and awareness on the occurrence and infestation of *A. tubercularis* in the study Area

Characteristics	Percent (%) Response in different Regions						Mean %	χ^2	P-value
	Orom N=511	Amha N=133	BGum N=72	SWR N=48	HarRS N=48	DDA N=28			
Parts of mango trees get infested								15.0	0.164*
Leaves	46.05	41.58	51.72	49.23	0.0	0.0	31.43		
Branch/twigs	14.03	12.37	18.40	11.64	0.0	0.0	9.41		
Fruits	39.92	37.26	29.88	39.13	0.0	0.0	36.36		
Symptoms of *A. tubercularis* damage								12.0	0.147*
Chlorosis	29.26	18.42	31.42	28.35	0.0	0.0	17.81		
Defoliation	24.07	22.18	25.78	21.28	0.0	0.0	93.31		
Drying up of twigs	11.37	9.56	14.53	10.43	0.0	0.0	15.55		
Pink blemishes fruits	25.57	27.65	28.27	30.67	0.0	0.0	18.69		
Never seen	9.73	22.19	0.0	9.27	100	100	40.19		

Note: **Statistically significant at P < 0.01

Distribution, incidence, and severity status of *A. tubercularis*

The distribution of *A. tubercularis* covered almost all the majority of the mango-growing areas of the surveyed zones and districts. Among the 198 localities surveyed in 66 administrative villages of 32 districts, *A. tubercularis* infestation was confirmed in 168 localities of 56 (80%) administrative villages', which were distributed in 28 districts of the surveyed mango orchards in all cardinal directions of the country (Figure 2 and 3). The field survey result confirmed that *A. tubercularis* has already distributed from its original locus, RAILMCF (the 1st place of *A. tubercularis* emergence), to the neighboring and/or far away administrative zones up to the maximum air distance of 235, 277, 383, 380, and 436 km to the direction of western, southwestern, eastern, northwestern, and northeastern directions of the country, respectively.

Direction wise dispersal limit showed that *A. tubercularis* were not spread in the western direction beyond Algalea of Homosha district of Assosa zone, in the northern direction beyond Bati of Oromo special zone of Amhara Regional State, in the southwest direction beyond Bench Shako zone of Southwestern Regional State (SWRS) and in the east direction beyond UAAI of East Showa zone of Oromia Regional State. The distribution pattern and severity status of *A. tubercularis* within each administrative zone were found to be irregular as it can be rated as none, medium, high, and very high severity. Such irregular distributions were found to be more evident in Assosa, east and west Wollega, and east and west Shewa zones. The irregularity of *A. tubercularis* severity might be due to the difference in weather and climate of study areas, management practices used and different in mango cultivars grown, the time of pest introduction into the localities, agroecological and geographical landscape differences are among the reason of irregularity.

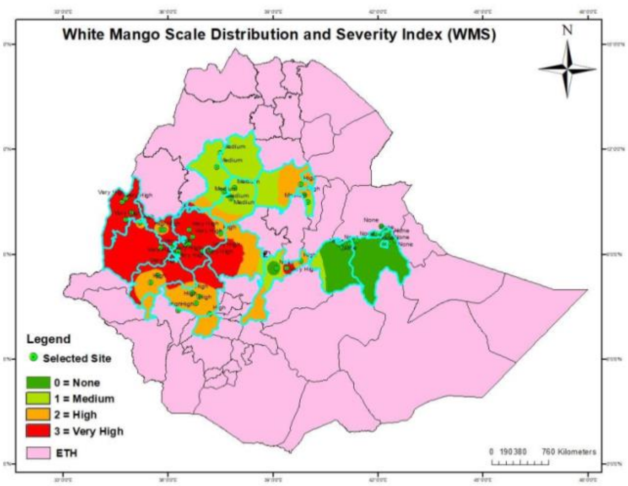

Figure 2. Map showing the distribution, incidence, and severity status of *A. tubercularis* in the study areas of western, southwestern, central rift valley, eastern, northwestern, and northeastern parts of Ethiopia

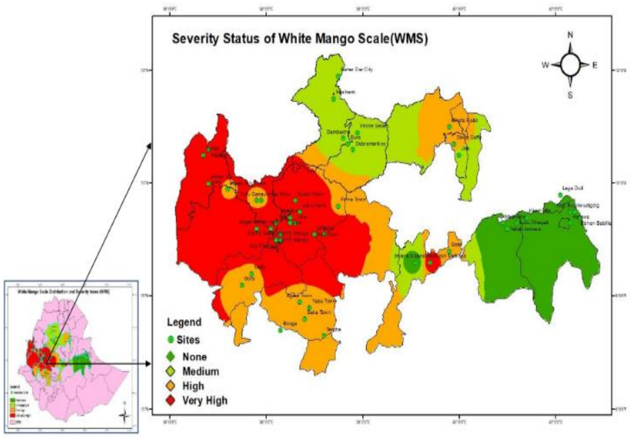

Figure 3. Map showing specific areas of *A. tubercularis* distribution, incidence and severity status in western, south western, central rift valley, eastern, north western and north eastern parts of the country

The distribution patterns and severity indices provide valuable insights into the extent and impact of *A. tubercularis* across diverse regions and agroecological landscapes. The irregularities observed underscore the complex interplay of factors influencing pest dynamics in mango orchards.

status of *A. tubercularis* in the study areas of western, southwestern, central rift valley, eastern, northwestern, and northeastern parts of Ethiopia

Severity status and percentage severity index of *A. tubercularis* clusters (ATCs)

The results of severity status and percentage severity index of ATCs formation are presented in Table 8. Among 17 geographic zones, one region and one city administration of Ethiopia assessed, the occurrence and prevalence of the insect were observed in 14 zones. *A. tubercularis* clusters formation was prevalent in all the surveyed zones with varying intensity, except East and West Hararge zones, Harari Regional State, and Dire Dawa City Administration, which were free of *A. tubercularis* infestation until the last survey time, June 2019.

The average incidence of ATCs formation in infested zones varied from 0–50.8 % with the greatest highest incidence recorded in Asossa (50.8 %) and the least severe incidence in the North Shewa zone (23 %). The incidence of the mango tree was significantly ($P<0.05$) higher in the Asossa zone followed by West Shewa, Buno Bedelle, East Wollega, and Jimma zones, respectively. The mean minimum and maximum incidence for the surveyed area was (±SE) 23.00±2.19 to 50.80±3.77 with a range of (±SE) 23.0 to 50.8 %, respectively. The survey result revealed that the *A. tubercularis* incidence and severity varied from locality to locality due to different geographical landscapes and prevailing environmental and weather conditions.

Table 8. Percentage incidence and severity status of *A. tubercularis* clusters (ATCs) on mango leaf in selected zones/regions of Ethiopia

Survey area	Average incidence (±SE)	Severity Status (±SE)	Severity Index
East Wollega	41.33±1.18a	95.80±0.39a	Very high
West Showa	47.00±2.19a	95.88±0.93a	Very high
West Wollega	32.17±4.95b	87.67±2.85b	Very high
Horo Guduru Wollega	39.50±3.50b	95.15±0.41a	Very high
Assosa	50.80±3.77a	97.7±0.25a	Very high
East Showa	29.25±7.37d	66.12±14.80d	High
Jimma	39.50±1.19b	96.35±0.69a	Very high
Buno Bedelle	46.50±2.50a	95.85±1.23a	Very high
Ilu Ababora	32.0±1.0b	87.71±0.86a	Very high
Keffa	32.0±1.0c	88.88±0.31b	Very high
Dawuro	28.0±3.0d	86.16±0.05b	Very high
Bench Sheko	26.50±2.50d	88.38±0.51b	Very high
West Hararge	0.0	0.0	None
East Hararge	0.0	0.0	None
Harari Region	0.0	0.0	None
Dire Dawa City Administration	0.0	0.0	None
West Gojem	23.25±3.37d	79.31±5.82c	Very high
Bahir Dar Special zone	24.67±7.51d	79.35±14.26c	Very high
Oromo Zone	30.00±1.13c	84.93±1.57b	Ver high
North Showa	23.00±2.19d	74.04±4.12c	High
Total	29.17±1.92	71.74±4.10	Very high

*Values in the same letters along the column are not significantly different ($P<0.05$), Tukey's studentized range test.

The severity status, severity index, and distribution (air distance in km from Loco, the scene of 1st record) of *A. tubercularis* in the western, southwestern, northwestern, northeastern, and central rift valley of Ethiopia are presented in Table 9

Table 9. Severity status of ATCs formation and air distance from scence of record in western, south western, central rift valley, eastern, north western and north eastern Ethiopia.

Zone/City	District	Locality	SI	Severity Status	Air distance from Loco (km)
East Wollega	Guto Gida	RAILMCF	4	Very high	Scene of 1st record
"	"	Uke	4	Very high	6.2
"	"	WUURF	4	Very high	10
"	Gida Ayana	Guten	4	Very high	30
"	"	Gendo	3	High	58
"	Diga	Arjo Gudetu	4	High	43
"	"	EWFWE	4	Very high	46
"	Sibu Sire	Jarso Sire	3	High	53
"	Gobu Sayo	Sombo Kejo	3	High	61
West Shewa	Bako Tibe	Bako	4	Very high	63
"	Ilu Gelan	Ijajji	4	Very high	95
"	Toke Kutaye	Guder	2	Mild	141
West Wollega	Ghimbi	Tole	4	Very high	57
"	"	Jogir	4	Very high	69
"	Nejo	Nejo	3	High	115
West Wollega	Kiltu Karra	Kiltu Karra	0	Not present	144
"	Mana Sibu	Wajati Kiltu Lubo	2	Mild	171
Assosa zone	Bambasi	Bambasi	4	Very high	203
"	Assosa	Assosa town	4	Very high	232
"	"	Amba 14	4	Very high	225
"	Homosha	Tumat	4	Very high	239
East Shewa	Lume	Sharra Dibandiba	0	Not present	293
"	Adama zuria	Adama (St.OTC)	4	Very high	314
"	"	ASTU	4	Very high	316
"	"	MARC	4	Very high	326
"	"	Wonji	4	Very high	318
"	Boset	Metehara-Merti	4	Very high	376
"	"	UAAI	3	High	380
Jimma zone	Agaro zuria	Agaro	4	Very high	163
"	Jimma Town	JUCoA	4	Very high	186

Table 9. Severity status of *A. tubercularis* …. cont.

Zone/City	District	Locality	SI	Severity Status	Air distance from Loco (km)
Buno Bedelle	Bedele zuria	Bedele	4	Very high	98
"	"	"	4	Very high	98
Ilu/A/Bora	Mettu zuria	Mettu	4	Very high	154
"	Gore zuria	Gore	4	Very high	170
Kefa	Bonga zuria	Bonga	3	High	229
"	"	"	3	High	229
Dawuro	Tercha zuria	Tercha	3	High	251
"	"	"	3	High	251
Bench Sheko	Mizan Teferi	Mizan	3	High	277
"	Mizan Tepi	Tepi	3	High	264
West Hararge	Chiro	Madhicho	0	Not present	478
"	"	Yabdo bobasa	0	Not present	476
"	Xullo	Lubu Dhaqab	0	Not present	505
"	"	Kira kufis	0	Not present	503
East Harage	Babille	Bishan Babille	0	Not present	638
"	"	Abdi Buci,	0	Not present	636
East Harage	Haramaya	Haramaya	0	Not present	632
Harari	Erer	Erer Woldiya	0	Not present	627
"	Sofi	Harawe	0	Not present	618
"	"	Awudigdig	0	Not present	616
Dire Dawa City	Dire Dawa	Laga Doll	0	Not present	593
"	"	Bake Hallo	0	Not present	599
West Gojam	Bure	Bure Town	3	High	252
Bahir Dar sp.z	Bahir Dar	Cherkacherk	3	High	269
Bahir Dar sp.z	Bahir Dar	Peda campus	3	High	267
"	"	Woramit	3	High	268
North Shewa	Shewa Robit	Shewa Robit	4	Very high	379
Oromo zone	Chefa Robit	Chefa Robit	3	High	401
Oromo zone	Dawa Caffa	Dawa Caffa	4	Very high	400
Oromo zone	Kamisie zuria	Kamisie	3	High	398
"	Bati	Bati	3	High	436
"	Jille Xumuga	Senbete	2	Mild	396
Oromo zone	Kamisie zuria	Kamisie	3	High	398
"	Bati	Bati	3	High	436
"	Jille Xumuga	Senbete	2	Mild	396
"	Artuma Fursi	Artuma	4	Very high	397

NB. SI= Severity Index; RAILMCF= Raj Agro Industry Loco Mango Commercial Farm; WUURF= Wollega University Research Farm, EWFWEM= East Wollega Forest, and Wildlife Enterprise Mango; JUCoA= Jimma University College of Agriculture; ASTU= Adama Science and Technology University; MACR= Mekasa Agricultural Research Centre; St. OTC= Sent Merry Orthodox Tewahido Church; UAAI=Upper Awash Agro Industry

***SI range**: 0= non infestation (n), 1= mild; 2= medium; 3= high; 4= very high

Cluster formation of *A. tubercularis* on infested mango leaves

In the study areas where *A. tubercularis* emerged, the severity status was found to be from medium to very high in most of the surveyed localities. The mean maximum average *A. tubercularis* cluster formation recorded was at the Assosa zone ±SE (39.24±0.73) and the minimum mean average clusters were recorded at the North Shewa zone ±SE (5.06±0.09). The average clusters and female adults of *A. tubercularis* recorded at UAAI were 8 and 16 per leaf, respectively. The severity status within the zones shows irregular means and standard deviations, which exhibited big variations. In the Administrative Zones of West and East Hararge, Harari Regional States, and Dire Dawa City Administration, there was no infestation observed in the surveyed localities. The cluster formation of *A. tubercularis* on the mango leaf that indicates its severity status is shown in Table 10.

Table 10. Mean numbers of ATCs recorded on mango leaf within each administrative zone in western, south western, central rift valley, eastern, north western and north eastern Ethiopia (N= leaf number)

Survey area	N	Mean ± SE	Values for 95% CI	
			Minimum	Maximum
East Wollega	720	22.43 ± 0.78b	12.2	40.8
West Wollega	720	17.58 ± 2.03c	1.5	49.5
Horo Guduru Wollega	720	29.14±0.82ab	14.5	48.7
West Showa	720	36.27 ± 1.78a	13.6	59.0
Assosa	720	39.24 ± 0.73a	22.6	52.6
Buno Bedelle	720	24.16 ± 1.06b	9.1	40.9
Ilu Ababora	720	14.35 ± 0.86c	3.3	35.6
Jimma	720	12.31 ± 0.49 c	5.4	25.4
Dawuro	720	13.08 ± 0.48c	7.3	24.2
Kefa	720	10.59 ± 0.36cd	6.1	18.9
Bench Sheko	720	12.23 ± 0.47c	5.3	22.4
West Gojem	720	8.21 ± 2.43d	4.7	14.8
Bahir Dar Special zone	720	8.05 ± 0.25d	4.5	12.7
West Gojam	720	5.72 ± 0.47d	3.9	6.7
Oromo Zone	720	10.05 ± 0.22cd	7.0	14.2
North Showa	720	5.06 ± 0.09d	3.8	6.2
East Showa	720	11.60 ± 0.72cd	2.2	26.8
West Hararge	720	0.00 ± 0.00e	0.0	0.0
East Hararge	720	0.00 ± 0.00e	0.0	0.0
Harari Region	720	0.00 ± 0.00e	0.0	0.0
Dire Dawa City Administration	360	0.00 ± 0.00e	0.0	0.0

*Values in the same letters along the column are not significantly different (P<0.05), Tukey's studentized range test.

N.B. HG = Horo Guduru; DDC Admin = Dire Dawa City Administration; BD = Bahir Dar

In highly infested areas of the study sites, mango trees resulted in discoloration of the leaves and the fruits, dieback of the tree, and in severe cases, total death of young twigs and leaves of mango trees (Figure 4-6). Such kinds of severe infestation were observed at Backo, Arjo Gudetu, Tole, Jogir, Uke, Guten, and Assosa (Amba 14 and Algelea) study areas.

Figure 4. Mango tree affected by white mango scale, *A. tubercularis* infestation in the study areas**:** Backo High School compound mango grove (a_1), and mango tree at Assossa, Homosha district Algelea kebele (b_1& b_2) leaves, branches and twigs severely infested were dried up, [Photo from field survey by Temesgen Fita, May 2018]

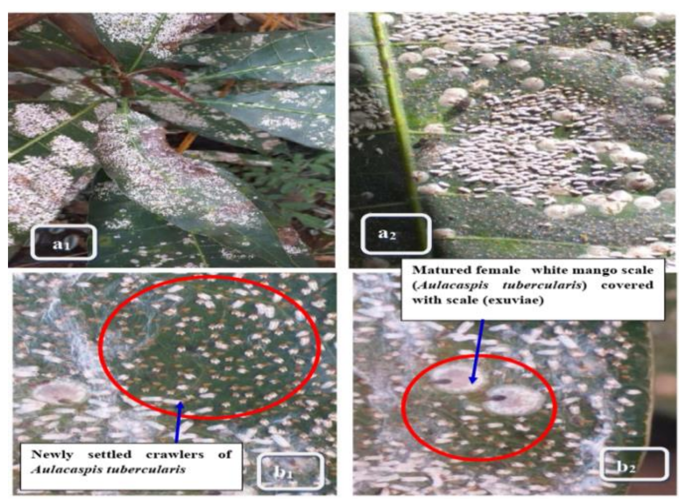

Figure 5. Young mango tree twigs and leaves severely infested by *A. tubercularis* adult females, males and the crawlers newly settled on leaf surface at Nekemte area: (a_1 & a_2) Mango twigs severely infested by sessile *A. tubercularis*; (b_1 & b_2) Mango leaves

severely infested by *A. tubercularis* [Photo from field survey by Temesgen Fita, June 2018]

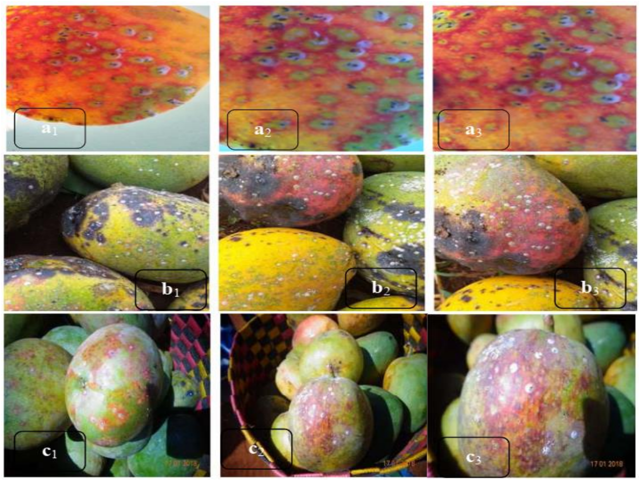

Figure 6. Mango fruits at different study areas severely infested by *A. tubercularis*: (a_1, a_2 & a_3) Mango fruits severely infested at Jogir kebele, Gimbi district; (b_1, b_2 & b_3) Infested mango fruits fallen down on to the ground at Arjo Gudetu; (c_1, c_2 & c_3) Mango fruits severely infested at Assosa zone Homosha district Algelea kebele on market for sale; [Photo from field survey by Temesgen Fita, January and April & May 2018]

From the field survey observation, the fruits were highly infested by the female *A. tubercularis* than the males and crawlers. The numbers of clusters and adult females of *A. tubercularis* recorded per infested 12 mango leaf samples showed big differences among the localities. The maximum was 73 clusters and 821 adult females at the Algalea locality in the Homosha district of the Assosa zone, while the minimum was 5 clusters and 38 adult females at the UAAI locality of the Bosset district, East Showa zone. The interviewed respondents and people in the market indicated that infested fruits were less storable, only for about three days than the none-infested ones, which can be stored for about two weeks. Infested fruits were hypersensitive to *A. tubercularis* attack and are less preferred on market by the buyers.

Farmers management practices of *A. tubercularis*

Among the respondents who participated in the interview, about 55.7 % (468) indicated that they attempted to manage *A. tubercularis* through different cultural practices like pruning, stem cutting, burning infested branches, and under-tree smocking to chase out the pest. From those who practiced control methods, 36.96 % practiced under-tree smoking, 19.87 % practiced pruning of infested dense branches, 22.86 % practiced both pruning and burning of infested branches and 0.85 % practiced uprooting of the infested trees and replacing them with annual crops. According to the idea of the respondents, there was no source and availability of chemicals for this pest and there were no respondents who practiced chemical or oil spray. Respondents' insight on management methods they applied for control of *A. tubercularis* is indicated in Table 11.

Those who completely uprooted their mango trees elucidated that because of *A. tubercularis* damage on mango fruits, they do not get income from their mango sale. Infested mango fruits were not attractive in color as well as due to their poor quality the mango fruits were not acceptable on market. They added that replacing the up-rooted mango land with an annual crop would be more beneficial to their livelihood than the income earned from mango sales. Growers who completely uprooted their mango trees changed the stems and the branches to firewood.

Table 11. Management methods used by mango growers to manage *A. tubercularis* in the study area (N=840)

Characteristics	**Percent (%) Response in different Regions**						**Mean %**	**χ^2**	**P-value**
	Orom N=511	Amha N=133	BGum N=72	SWR N=48	HarRS N=48	DDA N=28			
Management methods used by respondents to manage *A. tubercularis*								18.0	0.263*
Under-tree smoking	43.55	68.08	45.24	44.73	0.0	0.0	33.60		
Dense branch pruning	26.48	12.76	19.05	26.31	0.0	0.0	14.10		
Pruning & burning of infested branches	25.43	19.15	28.57	28.95	0.0	0.0	17.02		
Uprooting of infested mango trees	4.53	0.0	7.14	0.0	0.0	0.0	1.95		
Purpose of production								12.0	0.285*
For consumption	2.35	0.0	0.0	0.0	0.0	14.29	2.77		
Selling	5.09	0.0	0.0	0.0	0.0	0.0	0.85		
Both	92.56	100	100	100	100	85.71	96.38		

Note: **Statistically significant at $P < 0.01$

Discussion

In this study, we conducted a comprehensive survey of *Aulacaspis tubercularis*, covering major mango-growing areas in Ethiopia. Prior to our investigation, there was a lack of comprehensive studies detailing the distribution, incidence, severity status, and severity index of *A. tubercularis* in Ethiopia. Our findings reveal that the pest has expanded extensively from its initial record at Raj Agro Industry Loco Mango Farm (RAILMCF) to all cardinal directions in the country.

The spread of *A. tubercularis* was observed in various directions, with recorded air distances of approximately 239 km to the west ('Algelea' locality, Benishangul Gumuz Regional State), 383 km to the east (UAAI, 'Bosset' district, East Shewa administrative zone), 277 km to the south-west ('Mizan Teferi' locality), 269 km to the north-west ('The Bahir Dar' locality), and 436 km to the north-east ('Bati' locality). Notably, Ofgaa *et al*. (2019) reported slightly different distances, an air distance of 97, 98, 92, and 43 km to the east, south, west, and north directions, respectively, indicating the need for further investigation into the pest's dispersal mechanisms.

During 2018 field survey it was confirmed that in Amhara Regional State *A. tubercularis* recorded in Bahirdar area, some areas of west and east Gojam, North Shewa and Oromo zone. Melaku and Getie (2022) reported that *A. tubercularis* was 1st recorded in Bahir Dar area, Northern Ethiopia, in 2017, that means it took 7 years to arrive there from the original focal point of emergence. This study shows that the spreading nature of *A. tubercularis* in mango-growing areas of the country is somewhat fast but not at an equal speed in all cardinal directions of the country. In other corners of mango growing areas the pest occurred in short period and in other areas the occurrence was somewhat delayed. In this case the researcher noticed that the spreading mechanism of the pest is either mechanical or natural or both mechanisms. Calculating how fast the speed of spreading from its original locus of first-time emergence (since 2010) can lead to wrong calculation. If it is transported by mechanical means like by human's activities, animals and phoretic insects, then this calculation does not work, because transporting the insect to a new locality or area cannot be the only way for pest spreading, but the pest needs its host immediately after transported to new areas for its establishment, that means if there is no host available in that locality, the pest cannot be established. But if it is spreading by natural means like wind-jet, then one can calculate the speed of transmission, even though the target insect can be trapped by existing natural barriers like trees, shrubs, bushes and savanna grasses and even it can be hindered by geography of the land, like long kilometers with hot depressed lowland of savanna grass land, hills and mountains can block its spread and causes natural deaths before the pest reaches its new destination. It is, therefore, possible to notice that there are enabling novel biotic environmental conditions for *A. tubercularis* to disperse and establish its population in mango-growing areas of the four cardinal directions of the country, Ethiopia.

Our study also indicates there is variations in the speed and timing of *A. tubercularis* spread across different mango-growing areas. While some regions experienced rapid infestation, others encountered delayed occurrences. We propose that the dispersal mechanism involves a combination of mechanical and natural means. Mechanical transport, facilitated by human activities, animal movement, and phoretic insects, may contribute to initial introductions. However, successful establishment is contingent on the immediate availability of suitable host plants in the new locality.

Increased global connectivity accelerates rates of introductions of alien insect pest invasions such as *A. tubercularis*, while climate change may decrease the barriers to invader species' spread. In many situations, invasive insects face novel or non-analog environmental conditions, suggesting that invasion success should relate to general stress resistance and dispersal mechanisms (Renault *et al*., 2018). The impact of global connectivity on invasive species is highlighted in our study. Increased global connectivity, coupled with climate change, can potentially reduce barriers to the spread of alien insect pests. While the specific mechanisms of *A. tubercularis* spread within Ethiopia were not assessed, we suggest that human activities, such as the marketing of mango fruits, exchange of mango seedlings, and general movement of plant materials, could play crucial roles.

Reports from agricultural offices indicate that NGOs distributed mango seedlings from MARC *i.e.,* central rift valley area to farmers in Benishangul-Gumuz Asossa zone and Amhara Regional states 'Wara Kallo' districts, possibly contributing to the introduction of *A. tubercularis*. This aligns with previous studies linking the movement of infested plant materials by human beings to the dispersal of scale insect species. A related study by Abo-Shanab (2012) mentioned that the dispersion of *A. tubercularis* could occur by the transport of infested plant material to non-infested areas and by the presence of host plants. A related study by Jerom *et al*. (2019) and Michael *et al*. (2020) also mentioned that the movement of infested plant materials by human beings has been linked to the dispersal of scale insect species. Adam *et al*. (2020) suggested that the risk of sale dispersal is primarily during postharvest storage and distribution to retail outlets. Youngsteadt *et al*. (2015) and Frank and Just (2020) also stated that due to their obscure appearance and behavior scale insects (Hemiptera: Coccoidea) can persist and withstand pest control measures, and growing evidence of success under global change are excellent candidates for an invasion via the movement of plant material. However, evidence by Backe and Frank (2019) and Michael *et al.* (2020) suggests that this is not a primary mechanism for gloomy scale introduction to uninfected new areas. Their study mentioned that gloomy scales in the southeastern United States are likely to expand their range beyond and become pestilent in new areas with continued climatic warming and urbanization.

Magsig-Castillo *et al*. (2010) mentioned that the first instar nymphs of armored scales, called crawlers mobility could achieve the dispersal and colonization of new areas. Adam *et al*. (2020) also stated that the only mobile life stage, and thus the only stage that can infest new plant material, is the first instar nymph (or the crawlers). Few studies have considered the actual mechanisms by which crawlers disperse to new areas. Phoretic dispersal, where crawlers attach to other animals for transport (Timothy, 2011), and wind-mediated mechanisms are potential means of *A. tubercularis* dispersal. While crawlers are capable of short-distance wandering, longer-distance dispersal may involve hitching rides on insects or being carried by the wind (Magsig-Castillo *et al*., 2010). The difficulty in detecting *A. tubercularis* during inspections is highlighted, emphasizing the challenges posed by its small size and obscure appearance.

Crawlers can remain attached to flying insects for considerable periods, suggesting that this may be an important means of dispersal for armored scale insects (Magsig-Castillo *et al*., 2010). Another study by AGDAFF (2012) also stated that wind, birds, insects, and other animals including human activities could serve as accidental dispersal carriers for armored scale insect crawlers.

In the study area, the interviewed mango growers mentioned that they are not aware of when *A. tubercularis* entered their locality. They noticed the pest emergence on their mango after severe infestation. The study by Stocks (2013) mentioned that armored scales are notorious tramp species, primarily due to their small size and difficulty in finding them during inspections. Some species of scale insects are not detected at quarantine inspection points because of their small sizes, which open access for introduction to other locations (Watson, 2002; Bautista-Rosales *et al*., 2013). A related study by Michael *et al*. (2020) also mentioned that due to their small size and obscure coloration, gloomy scales insects are often not detected until they reach damaging levels. In general, armored scale insects are notoriously difficult and expensive to manage due to their morphology, which makes them difficult to detect and protect on the tree.

In the study areas where *A. tubercularis* infestation observed mango fruits were more highly infested by females than males and crawlers. Our findings reveal a notable impact of *A. tubercularis* infestation on mango fruit quality and storage. Infested fruits showed allergic-like lesions, increased susceptibility to secondary infections, and reduced storability. The significance of crawlers in dispersal and colonization is underscored by their association with the most severe infestations on leaves and succulent stems.

The leaves and succulent stems and branches were more infested by un immature males and crawlers. From field observation it was noticed that the very severe stage of leaf infestation was at deep green matured stages of the leaf and at fruit maturity and harvesting stages. A related study by Ofgaa and Emana (2015) portrays that female *A. tubercularis* infestation of mango fruit is at its peak when the fruit is ripe and ready for sale in western Ethiopia. During the field survey the matured/ripe fruits were observed fall down to ground from the tree and the fallen mango fruits show symptoms of allergic-like lesions on the infested fruits. Most of these fruits were rotted, and the reason behind might be the infestation by the scale insect may open the way for secondary infection like fungus and bacteria, which makes the fruit deteriorates within a short period. The interviewed respondents and people in the markets indicated that infested mango fruits were less storable, only for about three days than the none-infested ones, which can be stored for about two weeks.

A related study by Bakry (2009) and Abo-Shanab (2012) noted that the heavily infested plants encounter premature fruit dropping and the mature fruits became small in size, become lack juice, rotted, and unfit for commercial use. Banu and Aruna (2012) also observed a significant decrease in the nutrient content and biochemical parameter tested in the infected fruit as against the uninfected fruit. Given that the fruit would provide an ample food supply during transit, adults and crawlers are likely to survive storage and transported at the temperature of 8–10 °C and cause further damage in to the new locality (AGDAFF, 2012).

At UAAI, *i.e*., in the eastern parts of the central rift valley, the emergence of *A. tubercularis* was recognized in the summer of 2018. However, until the end of this survey *A. tubercularis* incidence was not detected in eastern parts of Ethiopia beyond the border of the UAAI fruits farm. The reason could be that the harsh environmental conditions (no novel abiotic conditions) and the geographical land escape along the road to Harar crosses long distances of the lowlands of Awash National Park (ANP). The savanna grasses and bushy trees present along this road can trap the wind-mediated and phoretic active crawlers of *A. tubercularis* that may allow for the natural deaths of the insect before arriving in the new environment. The study by Renault *et al*. (2018) stated that the geographic spread of invasive populations may occur in environments characterized by novel abiotic conditions and biological communities compared to the native range.

In the study areas where *A. tubercularis* infestations detected, their distribution pattern varies. Incidence in the infested zones varied from 60 to 100 %, with the greatest incidence (100 %) in the Asossa, West Shewa, East Wollega, Jimma, and Bunno Bedelle zones, respectively, while the least incidence was observed in East Shewa zone. Incidence and severity of *A. tubercularis* varied among zones, districts, and localities, suggesting differential environmental factors influencing pest populations. The association of high severity with un pruned mango trees, dense closed crowns, and shaded conditions further emphasizes the role of environmental factors in *A. tubercularis* development.

These conditions reduce light intensity and increase dense shades that favor the development and distribution of *A. tubercularis*. Moreover, there were differences in the severity status of the *A. tubercularis* infestation among the zones, districts, and localities, which may indicate the probable differences in biotic and abiotic environmental factors that may affect differently the populations of *A. tubercularis* at the local habitat level. In the most observed study areas, the very high severity status of *A. tubercularis* was localized at relatively lower altitudes, except the areas of Nekemte, East Wollega zone, and Bedelle areas of Buno Bedelle zone show high severity, which are located in mid altitudes that may need further study. Until the end of this study, among the surveyed areas of the country, the incidence of *A. tubercularis* was not detected in the eastern and southeastern parts *i.e*., East and West Hararge zones, Dire Dawa City Administration, Harari Regional State and major districts of Sidama Region and Gedeo zones (personal communication).

Among mango growers included in the current study, some of them recognized *A. tubercularis* as a pest of mango. However, there is considerable difference among them in understanding the extent of *A. tubercularis* severity and damages caused onto their mango crop and its impact on their income. This is probably due to a lack of knowledge in the identification of the pest and differences in the scouting system of their mango farm to distinguish *A. tubercularis* as a serious pest of mango to take action before it is conspicuous enough and causes remarkable damage. Mango growers' awareness and understanding of *A. tubercularis* varied, impacting their ability to implement control measures. Differences in observation timing and severity levels among farmers highlight the need for education and training initiatives. Commercial mango farms like RAILMCF and UAAI, implementing cultural and chemical control measures, serve as models for effective pest management.

In conclusion, our study sheds light on the complex dynamics of *A. tubercularis* spread in Ethiopia, emphasizing the interplay of human activities, environmental conditions, and pest biology. Further research is needed to elucidate specific dispersal mechanisms, enhance pest management strategies, and empower local farmers through education and training initiatives.

Conclusion

The study concludes that *Aulacaspis tubercularis* is spreading at an alarming rate, covering mango farms across extensive geographical areas in western, south-western, central rift valley (CRV), north-western, and north-eastern Ethiopia. The severity status of the infestation is high to very high in most localities, necessitating immediate action in implementing management methods and creating awareness among mango growers.

The spreading nature of *A. tubercularis* across the four cardinal directions serves as a critical warning for the formulation and implementation of effective control strategies. Although eastern Ethiopia remained free of *A. tubercularis* during the study, the risk of dispersal through the transportation of infested mango seedlings and fruits to un infested areas poses a potential threat, emphasizing the need for increased vigilance and preventive measures. Therefore, in light of the alarming spread of *A. tubercularis* across various mango-growing regions in Ethiopia, several key recommendations are proposed to mitigate the impact of this pest and safeguard un invaded areas:

Implementation of internal quarantine: Given the rapid spread of *A. tubercularis*, the implementation of internal quarantine measures by concerning bodies is strongly recommended. This entails restricting the movement of infested mango plant material and products within the country, particularly from infested to un-infested areas. Internal quarantine can serve as a crucial preventive measure to contain the further dissemination of *A. tubercularis* to regions currently unaffected by the pest.

Training for mango growers: Mango farmers in the affected and un- affected regions should undergo comprehensive training programs to enhance their ability to identify and manage *A. tubercularis* infestations. The training should focus on early detection through regular scouting of mango orchards. Farmers need to be equipped with the knowledge and skills necessary to recognize the signs of *A. tubercularis* infestation at its early stages, enabling timely intervention.

Cultural management Practices**:** Promotion and adoption of cultural management practices are paramount in affected areas in controlling *A. tubercularis* infestations. Consistent scouting, periodic inventory systems, and the timely pruning of infested branches are crucial components of an effective management strategy. The removal and proper disposal of infested branches through burning help minimize the pest's population and prevent further spread.

Periodic Inventory Systems: Implementing periodic inventory systems in mango orchards is essential for monitoring *A. tubercularis* infestations. Regular assessments of the pest's presence and severity will aid in identifying emerging hotspots and implementing targeted control measures. This proactive approach enhances the overall efficacy of pest management efforts.

Collaboration and Knowledge**:** Encouraging collaboration and knowledge sharing among mango growers, agricultural extension services, and research institutions is vital. Facilitating platforms for the exchange of experiences, successful practices, and the latest research findings can contribute to a collective effort in managing *A. tubercularis*. This collaborative approach fosters a community of practice dedicated to combating the pest.

Continued Research and Monitoring: Investment in ongoing research and monitoring programs is crucial to understanding the evolving dynamics of *A. tubercularis* infestations. Continuous surveillance, scientific studies, and field trials will provide valuable insights into the pest's behavior, contributing to the refinement and adaptation of management strategies over time.

By implementing these recommendations, Ethiopia can proactively address the challenges posed by *A. tubercularis*, protect un-invaded regions, and foster sustainable mango production practices.

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Conflict of Interest

The research was conducted without any commercial or financial relationships that could be perceived as a potential conflict of interest. The author affirms that there are no conflicts of interest associated with this study.

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