ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
DEPARTMENT OF ZOOLOGICAL SCIENCES

Insecticide Testing and Assessing Farmers' Knowledge of Pests, Pesticides, and Method of Application on Tomato (*Solanum lycopersicum* L.) against Tomato Leaf Miner *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) in the Central Rift Valley of Ethiopia at Bora

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A Thesis Submitted to The Department of Zoological Sciences of Addis Ababa University in Partial fulfillment of the requirement for the degree of Master of Science in Zoology (Insect Science)

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Declaration

I, Sintayehu Bonsa, the undersigned, declare as this thesis is my original work, and it is not presented in any University on behalf of any similar degree award. And all materials used in this thesis work were properly acknowledged and referred to according to regulations and practices accepted internationally.

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APPROVAL SHEET

A Thesis Submitted to The Department of Zoological Sciences of Addis Ababa University in Partial fulfillment of the requirement for the degree of Master of Science in Zoology (Insect Science).

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Table of Contents

List of Figures

Figure **Page**

List of Tables

Table **Page**

Abbreviations/ Acronyms

ADI	Acceptable daily intake
A.I	Active ingredient
CRVE	Central Rift Valley Ethiopia
CSA	Central Statistical Authority
DAs	Development Agents
DAT	Days After Transplanting
DDT	Dichloro-diphenyl-trichloroethane
ESA	Ethiopian Standard Agency
GDP	Gross Domestic Product
IPM	Integrated Pest Management
IRAC	Insecticide Resistance Action Committee
MOANR	Ministry of Agriculture and Natural Resource
MRC	Mean Round Count
SAS	Statistical Analysis Software
SPSS	Statistical Package for the Social Sciences
TLM	Tomato leaf miner
WHO	World Health Organization

Abstract

The tomato (*Solanum lycopersicum*) is an economically important vegetable in Ethiopia, and the crop is vulnerable to attacks from insects, mite, and disease pests. Among these pests, the South American tomato leaf miner (*Tuta absoluta*) is a serious, new, and exotic pest affecting tomato production in Ethiopia. Tomato leaf miner *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), which is the biggest challenge for tomato production in Ethiopia, was first encountered in February 2013 in the Central Rift Valley (CRV) areas of Ethiopia. Studies were conducted in Bora Wereda in April 2021 to understand pesticide use practices and to test the effectiveness of some selected insecticides against *T. absoluta* on tomato plants. A total of 100 farmers were interviewed using a structured questionnaire. Six treatments of five insecticides; Super Jet 300SC (chlorfenapyr 100 g/l + thiamethoxam 200 g/l), Tutan Plus 410SC (chlorfenapyr 36% + cyromazin 5% SC), Tutan 360 SC (chlorfenapyr 36% SC), Emma 19.2 Ec (emamectin benzoate 19.2 g/l), and Ravan (chlorfenapyr 180 g/l + indoxacarb 120 g/l) from different insecticide classes, one non-registered, were screened for their efficacy against *T. absoluta* along with the untreated control using a randomized complete block design with four replications. Insecticides were tested in three rounds at the recommended rate based on the economic threshold level of the larval count. The larval count data were analyzed (ANOVA) using SAS version 9.0. The survey results showed that ninety-two percent of farmers in Bora Wereda had not received formal training on using pesticides properly. A hundred percent of the respondents believed that the frequency and rate indicated on the label were ineffective in controlling the insect. Twenty-eight percent of the farmers used smuggled insecticide and found it effective. Tutan 360 SC, Tutan Plus 410 SC, and Super Jet 300 SC were significantly better than untreated check in reducing pest population with a p-value of < 0.001 after the second spray round. Marketable yield weight showed significant differences ($P = 0.035$) between the Super Jet 300 SC and the control. This study suggests the importance of registering new insecticide molecules with diverse modes of action and using rotational insecticide application techniques.

Keywords: *Insecticides, Pesticide use, Tomato, Tuta absoluta.*

1. Introduction

1.1 Background of the study

Vegetables are an essential source of dietary fiber, vitamins, minerals, and food with high nutritional value. Additionally, they contain phytochemicals that lessen the risk of contracting dangerous diseases and other health issues. Nearly 200 countries have good agronomic conditions for growing vegetables (Silva Dias, 2011). Asia accounts for approximately 74.7% of global vegetable production. Out of this, more than 50% of the world's vegetable production comes from China (Silva and Ryder, 2011). Following potatoes (*Solanum tuberosum* L.), tomato (*Solanum lycopersicum* L.) is the second most popular vegetable consumed worldwide (Nicola et al., 2009).

Tomato is one of the world's most economically and nutritionally significant vegetables. It was initially cultivated in Mexico but is thought to have originated in South America, most likely in Peru and Ecuador. Spanish conquistadors brought tomatoes from southern and eastern Asia, Africa, and the Middle East to Europe in the sixteenth century. Tomato belongs to the family Solanaceae, and this family includes common species like potatoes, tobacco, pepper, and eggplant (Naika et al., 2005).

Most tomato production occurs in temperate regions with long summers and winter precipitation, but different countries have different cultivation practices (Costa and Huevelink, 2007). According to FAOSTAT, in 2019, roughly 123 million tons of tomatoes were produced from a total production area of about 4.5 million ha. China, the United States, Turkey, and the European Union (EU-25) are the top tomato producers.

One of the vegetable crops that are most frequently grown in Africa is tomato. In 2007 it occupied an area of 660,215 ha with a total production of roughly 14,918,554 tons (Fufa et al., 2011). According to Isaac (2007), tomatoes' production helps enhance the African nations' GDPs by creating jobs, generating income for rural and peri-urban residents, and improving the livelihoods of small-scale growers.

Ethiopia's economy depends on agriculture, which accounts for 40 percent of the GDP, 80 percent of exports, and an estimated 75 percent of the country's workforce (USAID, 2020). Two percent of the nation's total crop production is made up of vegetables. Tomato is one of

Ethiopia's widely grown fruity vegetables, and it comes in fourth of all the vegetables produced, behind cabbage, red pepper, and green pepper. Tomato yields in the country average around 6.2 tons per hectare, below the global average of 34.84 tons per hectare (Delalegn Ragassa et al., 2016). Tomatoes are one of the nation's top-priority vegetable crops due to their high production, economic growth potential, and nutritional value (Dube et al., 2019).

Despite its economic, social, and health benefits, tomato crop is vulnerable to attacks from insects, mite, and disease pests. The major pests that attack tomato fruit include fruit borer, common armyworm, beet armyworm, whitefly, and spider mites. Among diseases, the germini-virus transmitted by whitefly, bacterial spot, bacterial wilt, damping-off, early blight, late blight, fusarium wilt, southern blight, and black leaf mold are the major ones that call for management interventions (Srinivasan, 2010).

Ethiopia's total crop output losses from pests (insects, diseases, and abiotic stressors) are estimated to be between 30% and 40%. Insects alone result in losses to cereal crops of 32%–60%, pulses of 19%–63%, citrus of 2%–9%, cotton of 36%–60%, and vegetables of 24%–49 (Dagne Mojo and Lema Zemedu, 2022). Damage caused by diseases and insect pests is Ethiopia's major biotic factor constraining tomato production (Belay Tizazu, 2017).

The two main insect pests that attack tomatoes in Ethiopia are the potato tuber moth (*Phthorimaea operculella* Zeller) and the African bollworm (*Helicoverpa armigera* Hubner). Beyond its capacity to spread the virus that causes tomato yellow leaf curl, the tobacco whitefly (*Bemisia tabaci* Gennandius) is a significant sucking insect pest. The red spider mite (T*etranychus cinnabrinus*, Boisduval) has recently become a substantial issue in the Rift Valley (Lemma Desalegne, 2002). *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), commonly called the tomato leaf miner, adversely affects tomato production in Ethiopia and spreads fast into major tomato-producing regions (Gashawbeza Ayalew, 2015).

The tomato leaf miner, *T.absoluta*, the most significant global challenge for tomato production, has invaded most Afro-Eurasian nations. The pest is uncontrollable with chemical pesticides, and biological and biotechnological control methods are also more expensive. Several solutions have been developed and put into practice to control this pest, and much progress has been made in fundamental and applied research. While insecticide resistance is a growing concern, biological control via releasing or conserving arthropod natural enemies and sex pheromone-based biotechnical control is the most successful management practice to control *T.absoluta*. Additionally, agronomic control-related research is a developing field where soil irrigation, fertilization, and breeding resistant cultivars may all be used to improve the efficiency of Integrated Pest Management (IPM) programs for controlling the pest (Desneux et al., 2022).

Following a severe infestation of tomato fields by the pest in the Central Rift Valley of Ethiopia (CRVE) regions, the first cases were verified in the country in February 2013. The pest has a high reproductive potential, up to 12 generations per year and 260 eggs per female. Despite the application of many locally accessible insecticides used to treat other vegetable insect pests, *T. absoluta* destroys tomato plantations costing some farmers their entire crops (Gashawbeza Ayalew, 2015).

Tomato protection in Ethiopia depends on applying insecticides (Kariathi et al., 2016). The most widely used insecticides (pyrethroids, organophosphates, and organochlorines) are outdated and have various side effects. According to Gashawbeza Ayalew (2015) reports, many insect pests have already resisted these families of pesticides.

In Ethiopia, the Pesticide Registration and Control Proclamation No.674/2010 was enacted in August 2010. The Ethiopian government mandated the Plant Health Regulatory Directorate of the Ministry of Agriculture (MoA) to (i) regulate pesticide management relating to importation, distribution, transportation, storage, retailing, and use; (ii) adopt regulations; (iii) promote the correct use of pesticides and search for alternatives to chemical pesticides; (iv) raise awareness and provide technical support when the need arises; (v) participate in monitoring and evaluation of stakeholders; and (vi) evaluate the competence of companies that are engaged in pesticide imports.

Vegetable crop cultivation serves as a source of livelihood for farmers in Ethiopia. Most farmers in the CRVE use synthetic pesticides to control *T.absoluta* on tomatoes. The relatively low cost and high potency of insecticides make them attractive to tomato farmers. Due to the knowledge gap and indiscriminate use of insecticides in terms of concentration and application frequency, the pests are believed to have developed resistance. Monitoring, observing economic threshold levels, and informed decision-making are the missing elements of pest management practices in those areas. Hence, investigating the level of pest awareness and knowledge on pesticide use among tomato grower farmers is essential for planning future pest control strategies and enhancing safety in all aspects of pesticide use. The main concern of this work is to assess the farmer's awareness of insect pests and pesticides and evaluate the efficacy of selected insecticides against *T. absoluta* on tomatoes.

1.2 Objectives of the study

1.2.1 General objectives

To identify the intervention area gaps in pesticide use by tomato grower farmers in CRVE, screen and recommend effective insecticides against tomato *T. absoluta*.

1.2.2 Specific objectives

- To assess insecticide use practices for pest control among tomato-growing farmers in the CRVE; and
- To screen effective insecticides against *T. absoluta* in Dugda Bora Wereda

2. Literature Review

2.1 Origin and cultivation of tomato

Wild tomato species are native to South America, now called Peru, Bolivia, Chile, and Ecuador. The first tomatoes cultivated by the ancient Incan and Aztec civilizations were little sour berries that grew on low bushes (Mehta, 2017). The tomato was introduced to Europe in the 16th century; the origin of its domestication still needs to be determined. Today, tomato is widespread worldwide and represents the most economically important vegetable crop (Bergougnoux, 2014).

Tomato is widely known for its taste, color, flavor, and nutrient contents. It is a source of vitamins A, B, and C, providing small amounts of vitamin B complex, such as thiamin, riboflavin, and niacin. It is also rich in minerals, essential amino acids, sugars, dietary fibers, iron, and phosphorus. Tomato fruit is consumed fresh and can be processed in industry. Fresh tomatoes are primarily produced and sold on the open market, while those for processing are produced under a contract agreement between growers and processing companies (Naika et al., 2005; Nicola et al., 2009).

Tomato is a warm-season crop. Although cultivated as an annual crop, it is a perennial plant. A temperature of 70^{O}F to 85^{O}F during the day and 65^{O}F to 70^{O}F at night is considered ideal for tomato cultivation. Higher or lower temperatures can adversely affect fruit setting and quality (Sumner et al., 2010). Tomato can grow in different climatic conditions. Though tomatoes have a high-water requirement, a water surplus may cause fruit rot and bacterial wilt. It is most sensitive to water shortage during the flowering stage; buds and flowers may drop if there is a prolonged dry period (Ha, 2015). Tomato should ideally be grown in fertile, well-drained soil rich in organic matter. Sandy loam and clay loam soils with a pH of 5.5–8.0 are the most suitable (Cubero and Baquiran, 2017).

2.2 Tomato production in the world

Tomato is grown worldwide in almost every country and makes up a significant portion of the human diet in different parts of the world. It grows in outdoor fields, greenhouses, and net houses. The leading tomato-producing countries in the world are China, India, the USA, Turkey, Egypt, Iran, Italy, Spain, and Brazil (Sawant, 2018). From 2001 to 2011, global tomato production increased by 47%, and Asia took the lion's share, accounting for about 85% of the production increase (Malherbe and Marais, 2015).

Tomatoes are Africa's most consumed vegetable crop in their raw and processed forms, and it is a common ingredient in many soups, stews, sauces, and dishes. African countries that are the biggest producers of tomatoes are Egypt, Nigeria, Tunisia, and Morocco. Unfortunately, many countries on the continent do not produce enough tomatoes to meet their own needs. To satisfy this demand, countries import from outside the mainland, especially China, now the world's biggest exporter of tomato products (Rwomushana et al., 2019). Tomato production in Africa increased significantly from 3.11 million to 20.8 million tons between 1969 and 2018, with a maximum annual increase rate of 19.47% in 1975 and then decreasing to 0.32% in 2018 (Figure 1).

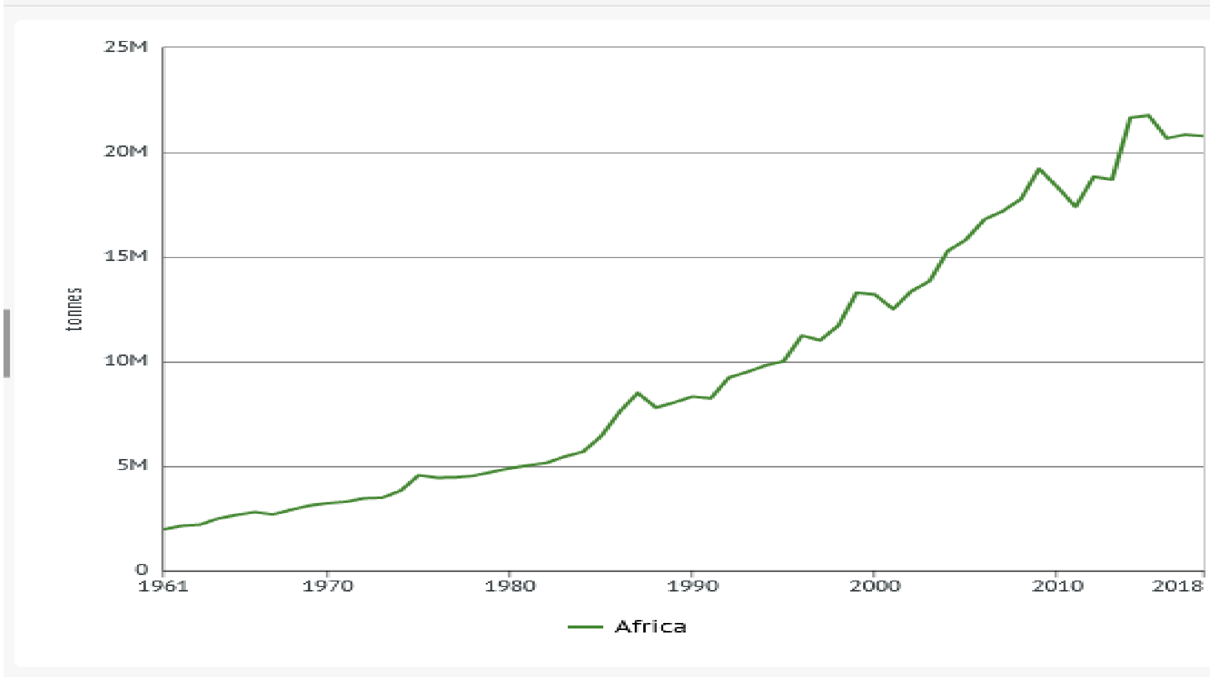

Figure 1: Tomato production in Africa (1961-2018) (https://knoema.com /FAOPRDSC2020/ production-statistics- crops-crops-processed)

In Ethiopia, tomato is one of the most economically important vegetable crops. According to the Central Statistical Authority of Ethiopia (CSA, 2012), the country is the 84th producer of tomatoes worldwide, with a total annual production of 81,738.05 tons. Smallholders have been growing tomatoes for a long time for their livelihood needs, and their needs were focused on more improved tomato varieties and better-applied production management practices. The demand for hybrid tomato seeds is very high in the country. More than 20 commercial hybrid tomato varieties have been verified to meet the market and are under production in Ethiopia, as shown in Table 1 (Tesfa Binalfew et al., 2016).

Table 1. Commercial hybrid tomato varieties registered in Ethiopia

No	Variety	Year of Registration	Responsible Company
1	Galilea	2011	Axum Greenline PLC.
2	Briget 40	2011	
3	Eden	2011	Makubou PLC
4	Barnum	2011	Markos PLC
5	Topspin	2011	CropGrow
6	Awasssa	2015	MEKAMBA PLC
7	Awash river	2015	
8	Momtanz	2015	SYNGENTA PLC
9	Chibli	2015	
10	Monica	2015	DAWNT PLC
11	Tasha	2015	GREEN LIFE PLC
12	Venise	2015	MARKOS PLC

*Source: Tesfa Binalfew et al., 2016

2.3 Tomato cultivation

2.3.1 Requirements for successful cultivation

2.3.1.1 Climate and Soil

Temperature and light

Tomato requires a relatively cool and dry climate for optimum production and premium quality. However, it is adaptable to various climatic conditions, from temperate to hot and humid tropics. The ideal temperature for most tomato varieties is between 21°C and 24°C. The plant tissues are damaged at prolonged temperatures below 10°C and above 38°C (Naika et al., 2005). On the other hand, tomatoes are day-length neutral plants that require 400-500 µmol.m s of light intensity for optimal growth and development, and high light intensity may cause fruit damage (Ha, 2015).

Water and humidity

There should be at least three months of rain to grow tomatoes in the area. Water stress and extended dry periods will cause the buds and flowers to drop off and the fruits to split. If there is high rainfall and humidity, the growth of mould will increase, and the fruit will rot. The occurrence of cloudy skies will slow down the ripening of tomatoes. However, adapted cultivars are available on the market (Naika et al., 2005. The crop is grown in Ethiopia at elevations between 700 and 2000 meters above sea level, with an annual rainfall of between 700 and 1400 mm. It also thrives in many climates, growing seasons, types of soil, and levels of technology (such as furrow, drip, or spate irrigation), and it produces a range of yields (Kebebew Birehanu and Tilahun Ketema, 2010).

Soil

Tomato can be grown on different types of soils. However, well-drained, friable sandy loam soil with a pH of 6.7 is preferable for early and high fruit yield (Lemma Desalegne, 2002). Tomatoes should ideally be grown in deep, fertile, humus-rich, medium-textured soils, and sites that tend to stay wet are not considered suitable for production. Moreover, fields that have grown solanaceous crops within the last three to four years should rotate with other crop families. In field production, tomato plants need the soil for physical support, anchorage nutrients, and water. The degree to which the soil adequately provides these three factors depends upon the topography, soil type, soil structure, and soil management practices (William and George, 2017).

2.3.1.2 Choice of varieties

Varieties should be selected based on quality, market acceptability, adaptability, and disease and pest resistance or tolerance. Although yield is ultimately essential, it is not the only selection criteria. Selecting varieties and other inputs is an important activity to be undertaken several months before planting, and different varieties perform differently under various environmental conditions. Other characteristics to be considered include maturity, size, shape, color, firmness, shipping quality, and plant habit (Sumner et al., 2010).

In Ethiopia, smallholders have grown tomatoes for a long time for their household needs. Since the start of commercialization, the country's demand for commercial hybrid varieties has rapidly increased. The tomato takes the highest share among the 90 commercial hybrid vegetables registered in the country (Tesfa Binalfew et al., 2016).

2. 4 Major insect pests of tomato in Ethiopia

Several insect species are the major challenges facing tomato production globally. Different insect species feed on tomato, for example, thrips, whitefly, tomato fruit worm, leaf miner, aphid, tomato borers, and mites (Lazgeen et al., 2013). Recently, *T. absoluta* became a serious pest of the tomato crop in Ethiopia, where it causes significant damage to the crop. Due to a lack of natural barriers and quarantine regulations in Ethiopia, invasive species like *T. absoluta* can move from one ecological community to another through wind and human activities (Tadele Shiberu and Emana Getu, 2018a).

2.4.1 Aphids (*Myzus persicae* Sulzer)

Aphid (Homoptera) is an economically important insect pest for tomato production. Adults of this insect suck the contents of infested plant cells and, while feeding, excrete vast amounts of honeydew that reduce the plant's photosynthetic efficiency. Severe infestations of aphid may reduce plant vigor and growth, cause chlorosis, uneven ripening, or reduce yield (Nzanza and Mashela, 2012). Aphid is one of the major constraints limiting tomato production in Ethiopia, and several species of aphids attack tomatoes (Dessie Getahun and Birhanu Habte, 2017). *Myzus persicae* (Sulzer) is the most serious pest species to tomato crops among all the others (Saljoqi et al., 2019).

Aphids are very small, soft-bodied insects that feed by inserting their slender mouthparts into phloem cells. The nymphs molt four times. Aphids attack several major crops and are vectors of plant viruses that cause more damage than insects (Stern, 2008). Aphids cluster on flower buds, under leaves, and stems, reduce plant vigor and create mottling or leaf curl, gall formation, yellowing or speckling, and sooty mold. Natural enemies can regulate populations, but it is challenging to manage using insecticides due to their resistance to a wide range of chemical insecticides (Hodgson, 2007).

2.4.2 Whitefly (*Bemisia tabaci* Gennandius)

The whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), is known to cause significant yield loss in several crops worldwide. Both the nymphs and adults cause damage to plants during feeding. It is also a vector for germini virus like TYLCV (Tomato Yellow Leaf Curl Virus) (Sani et al., 2020). Whitefly is a common insect pest of tomatoes, best known for spreading the TYLCV disease, threatening commercial tomato production in the field and kitchen gardens. They can acquire TYLCV from infected pepper plants and transmit it to tomato plants (Alam et al., 2016).

Because the damage caused by *B.tabaci is* high, chemical control measures have been widely utilized to control this insect pest. Due to the overuse of pesticides, the insect has developed resistance to some insecticides, which has reduced their efficacy (Redouan et al., 2020).

In Ethiopia, sucking pests like whiteflies cause a very high level of damage (quantity and quality) to tomato crops if no control measures are practiced. Whiteflies cause severe damage to tomato crops by transmitting the tomato leaf curl virus disease in addition to direct feeding. Due to direct and indirect damage caused by whiteflies, yield losses were reported to be 20–100 percent (Tadele Shiberu, 2020).

2.4.3 Tomato fruit borer (*Helicoverpa armigera* Hubner)

H. armigera (Hübner) (Lepidoptera: Noctuidae) is a polyphagous and voracious plant feeder insect that forages on a wide variety of plants. It feeds on different plant species, including economically important crops like; cotton (*Gossypium hirsutum*), sorghum (*Sorghum bicolor*), pigeon pea (*Cajanus cajan* (L.)), chickpea (*Cicer arietinum*), maize (*Zea mays*), soybean (*Glycine max*), tomato (*Lycopersicum esculentum*), pepper (*Capsicum annum*), bean (*Vicia faba*), peas (*Pisum sativum*), sunflower (*Helianthus annus*), niger seed (*Guizotia abyssinica*) and many other horticultural crops (Tarekegn Fite et al., 2018).

Tomato is more susceptible to pests' attacks than other vegetable crops because of its tenderness (Sajjad et al., 2011). *H. armigera* causes 90% damage to fruit and reduces yield by 30–40%. Fruit damage results in disfiguration of the surface, which rots through secondary infection by bacteria (Rijal and Dahal, 2019). The adults lay eggs on the leaves and flower buds. The larvae, upon hatching, bore into the developing fruits, causing severe damage and reducing the marketable yield (Mandaokar et al., 2000).

H.armigera is also a significant barrier to cotton production and productivity in Ethiopia (Geremew Terefe and Ermias Shonga, 2006). The indiscriminate use of pesticides to control *H.*

armigera has led to resistance to many classes of chemicals. Thus, there is an increasing concern over developing sustainable management strategies that rely less on chemical pesticides (Rijal and Dahal, 2019).

2.4.4 Tomato leaf miner (*Tuta absoluta* Meyrick)

Insect pest invasions have been rapidly expanding worldwide. More invasive species are likely to invade various regions with the increased mobility of people and goods from one country to another. In Africa, the risk and rate of invasion have skyrocketed. These invasions represent a substantial risk on the continent, where agriculture provides household food security and nourishment for 70–80 percent of the population (Mutamiswa et al., 2017).

Tomato leaf miner (TLM) is mainly a pest of solanaceous plants. It is native to South America and was first described in Ethiopia in the CRV region in February 2013. The pest is believed to have come from Yemen and entered Ethiopia through the northern part of the country. This insect is one of the significant challenges observed in Ethiopian tomato production recently, causing 100% crop losses for some producers. Tomatoes infested by TLM quickly become red and rotten. Some tomatoes look better from the outside but shrink in size and harden. The pest also changes fruits' colors to a greenish black and makes the fruit fall from the stem before fully ripened (Gashawbeza Ayalew, 2015).

The larval stage is most important economically. Its larvae mine tomatoes' leaves, flowers, shoots, and fruits. After hatching, larvae penetrate apical buds, flowers, new fruits, leaves, and stems. Infestations are relatively easy to detect due to conspicuous irregular mines, galleries, and dark frass. Fruits can be attacked soon after they form, and the larvae's galleries can be colonized by pathogens that cause fruit rot. Larvae are difficult to control because they develop within the plant, making this species hard to control with pesticides. Resistance has resulted from the extensive use of pesticides to control pests (Abdel-Raheem and Abdel-Rhman, 2014).

2.4.4.1 Insect description and life cycle of *T. absoluta*

The insect was identified as the South American tomato leaf miner, *T. absoluta*, based on external morphology and male genital structure. *T. absoluta* is a small moth with a body length of 5–6 mm and a wing span of 8–10 mm. The adult moth is grayish or silvery gray, with darker patches on the forewings (Figure 2A). Appressed scales cover the vertex of the head, and the antennae are filiform, long, and banded with gray and dark brown (Figure 2B). The forewing is narrow, with an apex fringed and speckled with brown, silvery gray, and black patches. The hind wing is narrow, the margins are fringed with long hairs, the color is silvery gray, and the outer margin is concave posterior to the apex (Ajaya et al., 2018). Larvae in the first stage are creamy with dark heads, and the thorax shield of later instar larvae has a dark line (Figure 3). Pink abdominal segments are also found in fully-grown larvae (Kiliç, 2010).

Figure 2. External morphology of *T. absoluta* (A) Adult moth (B) Head vertex and antenna (source: entnemdept.ufl.edu)

Figure 3. Larval instars of *T. absoluta*

T. absoluta is highly likely to thrive in novel, variable thermal environments, even in global climate change. At 27 °C, the biological cycle takes 24–38 days on average, and females can lay 250–300 cylindrical, creamy yellow eggs, mostly singly on the host plant's aerial parts and young fruits. The eggs are very small, measuring about 0.36 mm long and 0.22 mm in diameter, cylindrical, and ranging in color from white to yellow (Abdel-Raheem and Abdel-Rhman, 2014). The eggs hatch into 0.5-mm yellow or green larvae after 4–6 days (Mutamiswa et al., 2017). The first-instar larvae are whitish, becoming greenish to light pink in the second and fourth instars according to food availability. The larval stage lasts 12–15 days and has four developmental instars. The first two instars have been observed mining between the leaf's epidermal layers, resulting in a reduction in photosynthetic area and premature senescence. After that, larvae in their third and fourth instars leave the mines, boring into stalks, apical buds, and fruits (Mutamiswa et al., 2017). The newly formed pupae are greenish and turn dark brown as they mature. On average, male pupae are 4.3 mm in length and 1.2 mm in width, and female pupae are 4.7 mm in length and 1.4 mm in width (Abdel-Raheem and Abdel-Rhman, 2014). The pupal period lasts between 6 and 12 days on average (Nayana and Kalleshwaraswamy, 2015).

2.4.4.2 Geographic distribution of *T. absoluta*

T. absoluta has a wide geographical distribution worldwide, attacking many host plants (Figure 4). The pest is characterized by its active dispersal ability. The history of invasion in Afro-Eurasia and Middle East countries suggests that *T. absoluta* can spread and rapidly colonize new areas without the assistance of humans (Desneux et al., 2011).

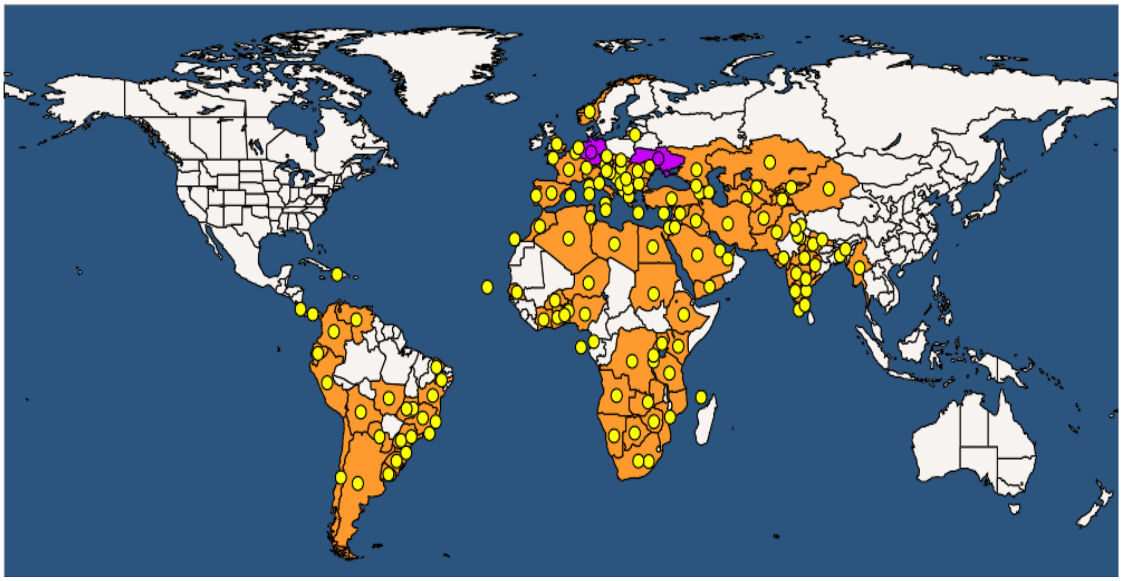

Figure 4. Geographic distribution of *T. absoluta* until 2020 (source: EPPO ttps://gd.eppo.int)

T. absoluta was first discovered in Africa, invading Morocco, Algeria, Tunisia, Libya, and Egypt in 2008 and 2009. It was first found in West Africa in Senegal in 2012 before spreading to most of the continent's other countries. It is now a well-established pest with a significant economic impact in North and Sub-Saharan Africa. In developing countries, the socioeconomic consequences of such a pest invasion are likely to be disastrous for food security and poverty alleviation (Konan et al., 2022). The most important routes for *T. absoluta* entry are importing tomato fruits intended for consumption from pest-infested countries and packing materials (Abeba Nigussie and Daniel Hagos, 2015).

T. absoluta is the most severe pest against the tomato plant in the Mediterranean Basin and Africa, and it has become much more abundant recently, particularly in Ethiopia (Gashawbeza Ayalew and Abiy Fekadu, 2013). In Ethiopia, the pest began infesting tomato farms in eastern Shewa, spreading to regions such as Oromia, Tigray, Amhara, and Gambela. The factors causing the pest's spread in Ethiopia are a need for solid quarantine regulations, poor enforcement of existing rules, and a lack of border inspection points (Tadele Shiberu and Emana Getu, 2018a).

2.4.4.3 Damage and symptoms

T. absoluta infests tomato plants throughout the entire crop cycle. Feeding damage is caused by all larval instars and throughout the whole plant. The larvae feed on the mesophyll tissue of the leaves, forming irregular leaf mines that can become necrotic later. Larvae can develop extensive galleries in the stems, affecting plant development. The larvae also attack fruit, and secondary pathogens use the entry points, causing the fruit to rot. The infestation's extent partly depends on the variety (IRAC, 2011).

2.4.4.4 Management of *T. absoluta*

Pest management entails reducing pest populations to manageable levels by changing practices, making habitat or structural changes, and using pesticides sparingly to kill pests only when necessary. Thus far, to control pests, many techniques and combinations of methods have been used with the sequence of inspection, habitat modification, pesticide application, and monitoring/follow-up. Pest management is a complex process that requires knowledge, special equipment, and technologies. There are four approaches to current structural pest management activities: prevention, reaction, extermination, and IPM. Pest management efforts may combine a few or all of these methods (Randall, 2000). Whichever combination is used, it must effectively control the target pest and not have a negative impact on non-target organisms, people, and the environment.

Integrated pest management (IPM) programs are often required to reduce pest population densities. IPM is a science-based decision-making process that allows for long-term control of insect pests while causing the least environmental harm. It can be implemented through timely pest monitoring to estimate pest densities, as well as judicious pesticide use and various "green" management methods such as trapping and the use of synthetic pheromones, biological control through the conservation and release of arthropod natural enemies, agronomic and cultural control through habitat manipulation, and the use of resistant crop varieties (Desneux et al., 2022; IRAC, 2011). With *T. absoluta* infesting the entire Ethiopian tomato growing region, there is an urgent need to understand the pest's management options in its invaded range and develop environmentally sustainable, economically sound, and effective IPM strategies (Tadele Shiberu and Emana Getu, 2018b).

2.4.4.5 Control methods

T. absoluta is a tricky pest to control due to its feeding habits, high reproduction capacity, and resistance to many insecticide classes, which might have resulted in gene mutation. Chemical pesticide application was once the sole control method, but its use has declined. *T. absoluta* is well controlled by a combination of practices that, when used alone, are ineffective. Leaf miners can be controlled using a variety of strategies. To effectively manage the pest, it is critical to combine all available control measures, including physical methods, cultural methods, biological control agents, and the proper use of recommended pesticides (Illakwahhi and Srivastava, 2017).

Physical controls

T. absoluta and other flying pests such as cotton bollworm, thrips, and whitefly can be physically excluded if the tomatoes are grown in greenhouses. Screening vents can reduce pest migration into greenhouses on the roof and sides of greenhouses and the disciplined use of double entry doors. Outward-facing fans inside the double-entry porch can blow back any flying insect pests that might otherwise be "sucked" into the crop on thermal currents when the outside door opens (Abeba Nigussie and Daniel Hagos, 2015; Caparros et al., 2013).

Biological control methods

Biological control plays an essential role in IPM programs. Biological control agents for pests and weeds have enormous and unique advantages; they are safe and permanent. Developing a biological control method could be a very beneficial tactic. It has been used to control crop pest insects such as Homoptera, Diptera, Hymenoptera, Coleoptera, and Lepidoptera. One possible solution to the *T. absoluta* crisis is biological control agents (living antagonists-natural enemies: predators, parasitoids, and pathogens). This strategy provides a more environmentally friendly and less expensive alternative to chemical use (Illakwahhi and Srivastava, 2017).

Predators

The natural enemies of *T. absoluta* have been reported from their origin (South America). *T. absoluta* has been preyed upon by at least 60 species of generalist arthropod predators from 26 families. More than 50 have been recorded in South America, with ten, mostly hemipterans, reported in newly invaded European countries (Desneux et al., 2022; Ferracini et al., 2019). Some species are essential in regulating *T. absoluta* populations in their natural habitat. Natural enemies of *T. absoluta* are commercially available and can be used for its control. However, current field results indicate that the intentional use of commercially available predators for biological control of *T. absoluta* has been successful only in early-invaded areas of Southern Europe. It is too early to tell whether similar predator-based biological control practices significantly impact other recently invaded areas. Two mired bugs, *Nesidiocoris tenuis*, and *acrolophus pygmaeus*, feed on eggs and larvae of *T. absoluta* when encountered outside mines and have emerged as critical biological control agents (Desneux et al., 2022).

T. absolutas' rapid spread in Ethiopia may be due to various factors, including its high biotic potential and the absence of co-evolved natural enemies. This may explain why pest population dynamics are faster in newly invaded regions than in newly invaded regions in native areas where natural enemies are more common. However, there is no silver bullet for *T. absoluta* control; instead, various management options exist for control. Furthermore, when the pest is established, it requires a survey of the local natural enemies recruited by it to identify effective ones (Abeba Nigussie and Daniel Hagos, 2015).

Entomopathogens

Entomopathogens that have shown efficacy against *T.absoluta* include *Metarhizium anisopliae* var. *anisopliae* (Metsch.) Soroki, *Beauveria bassiana* (Balsamo), *Vuillemin*, and *Bacil lus thuringiensis* (Berliner). *Basillus Thuringiensis (Bt)* is a soil bacterium, one of the essential microorganisms with entomopathogenic properties. It is safe for the environment and can be used extensively in an IPM strategy. Apart from Lepidoptera, *Bt* has been shown to have insecticidal effects on various insect orders, making it ideal for long-term integrated management. Efficacy studies on *T. absoluta* with *B. bassiana* and *B. thuringiensis* revealed that third-instar larvae were the most susceptible; their interaction effects were synergistic (Tarusikirwa et al., 2020). *B. thuringiensis* was highly effective in controlling *T. absoluta* in laboratory, greenhouse, and open-field experiments. The evidence suggests that first-instar larvae are the most susceptible to *Bt* and can potentially keep *T. absoluta* below economic thresholds (Molla and Gonza, 2011).

Parasitoids

Parasitoids are natural enemies that can control *T. absoluta* population growth in greenhouses and open-field tomato farms. In South America, where the pest originated, they are the most widely used natural enemies of *T. absoluta*. Parasitoids have been discovered parasitizing *T. absoluta* larvae in the Mediterranean region, and at least two *Necremnus* species have been identified. *Stenomesius* spp. is found in Spain's naturally-infested tomato plots, indicating that native parasitoids adapt to the new host. *Trichogramma acheae* has been identified as a potential biological control agent for *T.absoluta* eggs and is currently being released in commercial tomato greenhouses (Illakwahhi and Srivastava, 2017).

Cultural control methods

Crop rotation with non-solanaceous crops, plowing under, supplying adequate irrigation and fertilization, removal of infested plants during the growth stages, and complete removal of post-harvest plant debris and fruits are all good agricultural practices for *T. absoluta* control. The destruction of wild solanaceous host plants near the growing area is also encouraged, as these can host all stages of the pest, infecting the growing crop again. A variety of cultural control measures are available to aid in the management of this pest. Crop rotation and the selective removal and destruction of infested plant material are all essential cultural control practices for managing this pest in greenhouses. The wild host plants around the field or greenhouses should also be removed to prevent further spread and population growth (Abeba Nigussie and Daniel Hagos, 2015).

Chemical control methods

Chemical control, particularly in open-field tomatoes, is a dominant management strategy against *T. absoluta.* The pest attacks stem buds, followed by leaf-mining during canopy development and fruit infestation. This attack pattern affects the various plant parts throughout its development and protects the insect from insecticide sprays (Desneux et al., 2022). Furthermore, intensive application of insecticides lower growers' profits due to high insecticide purchase and application costs, negatively impact non-target organisms, result in the accumulation of insecticide residues on tomato fruits and the environment, and, most importantly, leads to the rapid development of resistance to available molecules (Abeba Nigussie and Daniel Hagos, 2015).

Despite the intensive search for alternative control methods, insecticide application remained the primary tactic against this pest species in both field and protected tomato production environments. Insecticide applications are only sometimes as practical as expected in controlling *T. absoluta*. When the insect population is well established before the tomato reproductive stage, insecticide efficacy is usually compromised (Guedes and Picanc, 2012). The risk increases significantly when pest management is solely based on chemical control, with only a limited number of effective insecticides available. This situation typically increases the frequency of application and, as a result, increases selection pressure for resistance (IRAC, 2011).

Early on, few active compounds were used against *T. absoluta* but reported losses in control efficacy. The detection of insecticide resistance in *T. absoluta* populations favored the registration of various active substances against this species. Until the 1990s, the insecticides against the pest included the organophosphate methamidophos, cartap, abamectin, and pyrethroids deltamethrin and pyrethroids permethrin (Guedes and Picanc, 2012). In Bolivia and Chile, the control efficiency of organophosphorus insecticides decreased, which could be adequately controlled by pyrethroids. Recently, resistance to organophosphates and pyrethroids has been reported in Chile, as well as resistance to abamectin, cartap, methamidophos, and permethrin in Brazil (Lietti et al., 2005). Higher LC50 values and resistance ratios indicate that the *T. absoluta* population in Ethiopia has developed resistance to the insecticides registered for its control. This suggests that new insecticide molecules should be screened regularly (Abiy Fekadu, 2019).

2.5 Insecticide resistance management

Insecticide resistance has been a problem in the chemical control of various insect pest species, including *T. absoluta*. As a result, applying the principles of insecticide resistance management (IRM) is critical for developing an effective and long-term pest management strategy for *T. absoluta* (IRAC, 2017). Resistance management should be part of IPM, which reduces pesticide use through alternative tactics such as cultural control and the conservation of natural control agents through the selective use of safer insecticides. The reduced susceptibility of various field-collected *T. absoluta* populations in the current study indicates the development of insecticide resistance, necessitating the prudent use of chemicals for its management. As a result, regular monitoring of the susceptibility of different populations exposed to other ingredients is required (Prasannakumar et al., 2021).

2.6 Insecticde classes, formulations, and mode of action

Pesticides are substances or mixtures of substances that have physical, chemical, and identical properties. As a result, they are classified based on these characteristics. Some pesticides are also classified into different classes based on their method of application, for example, EC, ULV, aerosols, dust, granules … Etc. Currently, the three most common pesticide classifications widely used are classification based on the mode of entry, pesticide function and the pest organisms they kill, and the pesticide chemical composition. Example: Pesticide toxicity was classified by the WHO into four categories: extremely dangerous, highly dangerous, moderately dangerous, and slightly dangerous. Based on chemical composition, pesticides are classified into organochlorines, organophosphorus, carbamates, and pyrethroids. Modes of entry refer to how pesticides come into contact with or enter the target organism or site. Examples include systemic contact, stomach poisons, fumigants, and repellents (Ishwar and Ningombam, 2017; Kaur et al., 2019).

2.6.1 Insecticides based on the chemical composition

Insecticides are mainly classified according to their chemical composition: Organochlorine (Endosulfan), Carbamates (Carbaryl), Organophosphorus (Monocrotophos, prophenofos, malathion), Pyrethroids (permethrin), Neonicotinoids (Imidacloprid), various pesticides such as Spinosyns (Spinosad), Benzolureas (diflubenzuron), and Antibiotics (Akashe et al., 2018).

Organochlorines

Organochlorine pesticides are generally persistent and toxic pollutants composed primarily of carbon, hydrogen, and chlorine. Because chlorine atoms prevent organic compounds from degrading rapidly in the environment, these pesticides remain active and persistent for a long time after application. Their use and applications are prohibited or restricted in some countries. Organochlorines are primarily used as insecticides, with applications ranging from pellets in field crops to sprays for seed coating and grain storage. Dichloro-diphenyl-trichloroethane (DDT) has gained popularity among Organochlorines due to its low cost, long duration, and effectiveness (Venelin and Stoyanka, 2019).

The compound is a stable pesticide that accumulates in fatty tissues and is highly persistent in the environment. Most of them were widely used as insecticides to control a wide variety of insects, and they have a long-term residual effect on the environment. These insecticides can potentially disrupt the nervous systems of insects in contact or ingested, resulting in convulsions and paralysis, followed by death. Among organochlorine insecticides, DDT, lindane, endosulfan, aldrin, dieldrin, and chlordane are some of the widely and long-used compounds for the control of an array of pests on cultivated crops, ornaments, and forests. Though the production and application of DDT were banned long ago in most developed countries, it is still used for vector control in most tropical countries where malaria occurs. Tomato, rape, lettuce, alfalfa, corn, rice, sorghum, cotton, and wood are preserved using them (Ishwar and Ningombam, 2017; Prieto et al., 2012).

Organophosphate

Organophosphorus pesticides are phosphoric acid derivatives considered broad-spectrum pesticides, consisting of various chemicals that control a wide range of insects. They are acetylcholinesterase inhibitors, which disrupt neurotransmitter transmission across a synapse. As a result, nervous impulses fail to move across the synapse, resulting in the rapid twitching of voluntary muscles and, ultimately, paralysis associated with death (Abubakar et al., 2020). Stomach, contact, and fumigant poison lead to nervous system poisoning. Organophosphorus insecticides are more toxic to vertebrates and invertebrates. However, these pesticides are biodegradable and cause little environmental pollution but promote pest resistance (Kaur et al., 2019).

Carbamates

Carbamates have a chemical structure similar to organophosphates, except that carbamates are carbamic acid derivatives, whereas organophosphates are phosphoric acid derivatives. Carbamate pesticides work similarly to organophosphate pesticides; they affect nerve signal transmission, resulting in the pest's death through poisoning. Insecticides in this category are used for vector control and include chemicals such as carbaryl, which is used for dusting livestock for flea control; propoxur, which is used against insect pests; and others for bee and wasp control. Stomach and contact poisons, as well as fumigants, are the modes of action. They degrade quickly in natural environments with little environmental pollution. Carbamates differ in their activity spectrum, mammalian toxicity, and persistence (Ishwar and Ningombam, 2017; Venelin and Stoyanka, 2019).

Pyrethroids

Pyrethroids are organic compounds extracted from naturally occurring pyrethrum flowers (*Chrysanthemum Coccineum and Chrysanthemum cinerariaefolium*). Pyrethroic acids are responsible for pyrethrin's insecticidal properties. These insecticides cause paralysis by interfering with the sodium channels. Permethrin, cypermethrin, deltamethrin, lethrin, furethrin, fenevelerate, and alphacyperamethrin are the most widely used synthetic pyrethroids. Synthetic pyrethroids are another type of pesticide that can be produced by mimicking the structure of naturally occurring pyrethrins. They are more stable and effective in comparison to natural pyrethrins. Pesticides containing synthetic pyrethroids are highly neurotoxic to insects and fish but less to mammals and birds. The majorities of synthetic pyrethroid insecticides are non-persistent and quickly degrade when exposed to light. They are the least harmful insecticides (Abubakar et al., 2020; Schleier and Peterson, 2011).

2.6.2 Insecticide mode of action

Insecticides differ in their action modes or how they act against a target pest. Mode of action is the most fundamental property of an insecticide, even more so than its chemical structure, because compounds with vastly different chemical structures can bind at the same target site and have the same mode of action. Insecticides are classified by the Insecticide Resistance Action Committee (IRAC) into groups with a standard mode of action and then into chemical subgroups within those groups. While consolidating the 50 or so chemical insecticide classes into modes of action groups is very useful. Further grouping the 26 recognized modes of action into four categories provides a broader understanding of this relationship. The four categories are neuromuscular toxins, which attack the nervous system or muscles; insect growth regulators (IGRs), which affect growth and development; respiratory poisons, also known as metabolic poisons, which affect energy metabolism; and gut disruptors, which destroy the integrity of the gut lining (Vincent, 2016).

Understanding the mode of action of insecticides is critical for developing a pest management strategy. Repeated application of insecticides with similar modes of action resulted in several vulnerable issues, such as resistance, resurgence, reduced sensitivity, Etc. Insecticides were designed to be broad-spectrum, regardless of the insect: mortality in exposed insects or toxicity after entry into the body. Environmental factors, such as non-target insect mortality and toxicity to beneficial insects, contribute to developing site-specific insecticides (Ghosal, 2015).

To act at its target site, an insecticide must enter the insect through one or more absorption routes, such as cuticle absorption, oral consumption of treated foliage or sap, or inhalation through the spiracles as a vapor. The active ingredient is absorbed into the body and distributed throughout to reach the target sites, which may only occur deep within specific tissues. At the same time, the insect's natural defense mechanisms are breaking down and excreting the insecticide molecules. These processes are absorption, distribution, metabolism, and excretion, which, together with the mode of action, determine the biological effect of the insecticide. Over 20 mechanisms, or modes of action, currently exist by which various commercial insecticides control insects by disrupting specific vital biological processes. However, not all these can be used against any particular pest insect. Despite the unreserved efforts of the crop protection industry, a new insecticide with different molecules and modes of action is introduced to the market every 5–10 years of research (Vincent, 2016).

2.7 Insecticides used in Ethiopia for the management of *T. absoluta*

Tomato growers in the CRVE tried cocktails of insecticides after the first outbreak of *T.absoluta* in Ethiopia. The efforts to control *T. absoluta* using locally available pesticides, which were used for managing other vegetable pests, were unsuccessful and resulted in a total crop failure in 2013. Familiar with many other African countries, most insecticides available on the local market for controlling vegetable insect pests are old and broad-spectrum (Gashawbeza Ayalew, 2015). The pest population established in Ethiopia and other countries is thought to have resisted these insecticides (Silva et al., 2011).

Though ineffective, the only management option used in Ethiopia is chemical control. More than 23 insecticides have been registered in Ethiopia against *T.absoluta.* However, their efficacy has remained low (Table 2) because synthetic insecticides developed resistance (Tadele Shiberu and Emana Getu, 2018b). Tomato growers in fruit worm-affected areas of the CRV have used a variety of insecticides, including reportedly effective and novel insecticides such as neonicotinoid and imidacloprid. This did not prevent pest damage and total crop failure, resulting in massive financial loss, exacerbated by the additional financial stress of pesticide costs (Gashawbeza Ayalew, 2015).

Table 2. Insecticides registered for the control of *T.absoluta* in Ethiopia

S/n	Trade Name	Common Name (Active Ingredient/s)	Agent (Registrant)
1	Absolute 36 SC	Chlorfenapyr	Girum Gebretsadik Zenebe
2	Adventure 150 SC	Indoxacarb + spinosad	Hortichem International Trading
3	Ampligo 150 ZC	Chlorantrniliprole +lambda-cyhalothrin	Syngenta Agroservices Ag. Ethiopia
4	Apachet	Emamectin Benzoate	Issachor Agro Input Importer and Distributor PLC.
5	Belt SC 480	Flubendiamide	Bayer Trade Representative Office
6	Benzer Plus 38.5 EC	Phenthoate + Emamectin Benzoate	Pharmachem Enterprise Importer
7	Bestfield 360 SC	Chlorfenapyr	Lions International Trading (Pvt) Co.
8	Beta 310 SC	Cyromazine + Abamectin	Pharmachem Enterprise Importer
9	Blanket	Indoxacarb	General Chemical and Trading Pvt. Co
10	Blastfill 240 SC	Chlorfenapyr	Garuman Trading Plc
11	Biotrine	Abamectin + Oxymatrine	General Chemical and Trading Pvt. Co
12	Coragen 200 SC	Chlorantraniliprole	Chemtex private ltd C.
13	Comb	Chlorfenapyr	Harvest General Trading

Table 2. Continued

S/n	Trade Name	Common Name (Active Ingredient/s)	Agent (Registrant)
14	Fire	Indoxacarb	MDD Chemical Products Importer
15	Kri-Star	Emamectin Benzoate	Issachor Agro Input Importer and Distributor PLC.
16	Lamdamectin 5% EW	Lambda-cyhalothrin + emamectin benzoate	Hortichem International Trading
17	Man	Indoxacarb 300 g/kg	Issachor Agro Input Importer & Distributor PLC.
18	Oberon Speed SC 240	Abamectin + Spiromesifen	Bayer Trade Representative Office
19	Radiant 120 SC	Spinetoram	Chemtex private ltd C.
20	Secure 24% SC	Chlorfenapyr	BASF Trade Representative Office
21	Tracer 480 SC	Spinosad (a mixture of spinosyn A & spinosyn B) 480 gm/lt	Chemtex private ltd C.
22	Windstorm 500 WDG	Lufenuron 400 g/kg + emamectin benzoate 100 g/kg	Cultivo trading plc
23	Uman	Indoxacarb 300 g/kg	Issachor Agro Input Importer & Distributor PLC.

Source: MoA

3. Materials and Methods

3.1 Description of the study area

The study was conducted in April 2021 at Dugda Bora Woreda, situated in the CRVE of Ethiopia (Figure 5). The area is part of the Great Rift Valley, where abundant use of pesticides exists. Dugda Bora is located 109 kilometers southeast of Addis Ababa. The district is found in the East Shewa Zone of the Oromia Region. It is bounded north by Lome and Liben Chukesa, west by Dugda, east by the Arsi zone, and south by the Dugda district. It has a latitude and longitude of 8° 18' N, 38° 57' E, and an elevation of 1,611 meters above sea level (asl).

This woreda had a total population of 58,748 according to the 2007 national census, of which 30,487 were men, and 28,261 were women. Approximately 19.41% of this population lives in cities. 18 kebeles make up Bora woreda. The main tomato-growing kebeles in the woreda are Dodo Wedera, Gora Lemane, Elene, and Tube Suti. According to Tsion Fikre (2016), Bora woreda often receives more than half of its annual rainfall (500 mm) in just two months (July and August); the soil type of the area is a light sand-type with a limited ability to retain moisture. Temperatures, on average, range from 12.9°C to 29.8°C.

Dugda Bora woreda is one of the major vegetable-producing areas of the Oromia region. In the woreda, vegetables are grown for market and domestic consumption. Small farmers near urban centers and urban youths who lease land for two to three seasons produce vegetables for urban markets year-round. The main vegetable crops of these kebeles are tomato, onion, shallot, garlic, potato, head cabbage, Ethiopian kale, and green peppers. At the same time, Swiss chard, lettuce, beetroot, eggplant, and watermelon are also produced in modest amounts under rain-fed and irrigated conditions.

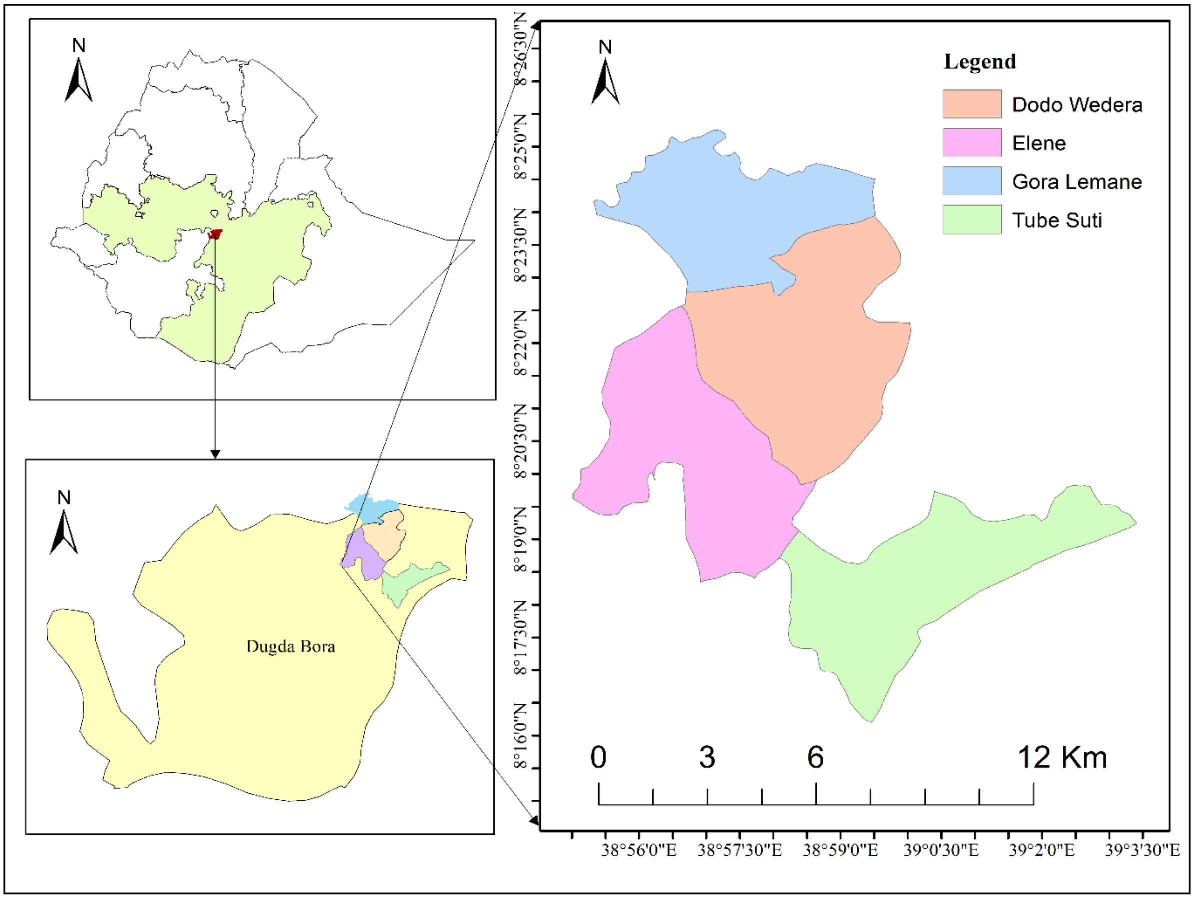

Figure 5. Map of survey locations for pesticide use practices against *T. absoluta*

3.2 Field survey

3.2.1 Sampling area and sample size

Twenty-five farmers from each of the four kebeles (Dodo Wedera, Gora Lemane, Elene, and Tube Suti) in the district known for their tomato cultivation were chosen purposefully for the interview in consultation with woreda offices of agricultural and development agents (Figure 5). During the survey, 100 farmers in total were interviewed. They had all been cultivating tomatoes for at least one or more years in the previous five years. Selected farmers were given a structured questionnaire that included questions about their knowledge of the pest, the type, and source of insecticides used to control *T. absoluta*, the application rate and frequency, the method of pesticide application, the growers' assessments of the effectiveness of insecticides, the use of non-registered insecticides in the area, and other related topics (Appendix 1 and Appendix 2). The answers to the questionnaires were then recorded and analyzed.

3.2.2 Data analysis

The analysis was done using statistical package for social sciences (SPSS) software version 26, and the descriptive statistics model was used to generate a percentage of responses given by respondents for each question. Unless indicated, percent values were based on 100 responses.

3.3 Field experiment

3.3.1 Experimental site

The experiment was conducted at Dodo Wodera in April 2021 (Figure 5). It is one of the four major tomato-growing kebeles of the Bora wereda in the CRVE, where tomato production has been seriously affected by *T.absoluta*.

3.3.2 Experimental field establishment

The experimental plots were set up in six rows of five meters long (Appendix 3). A hybrid tomato variety, "Galilea 39," obtained from Rainbow Colors Plc. The seedlings were planted in March 2021 and transplanted to the field after one month of growing on seed beds (Appendix 4). Di-ammonium phosphate (DAP) was applied at the time of planting at the rate of 200 kg per hectare, and urea was used at 100 kilograms per hectare in split applications three weeks after transplanting and at the early flowering stage. Fungicides (Pyribos38 SC) were applied against tomato leaf spots and downy mildew (Appendix 5). Depending on the crop stage, the experimental plots were irrigated one to two times weekly using the furrow-irrigation method. During the first month, treatments were irrigated every week (6 to 8 days) while becoming less frequent during the remaining growing stages. According to research recommendations, weeding was done every two weeks from the beginning of cultivation until fruit maturity (before the first harvest) (Tesfa Binalfew et al., 2016).

3.3.3 Experimental design and treatments

In the field experiment, six treatments were used and arranged in Randomized Complete Block Design with four replications. Among the treatments, four insecticides were selected from those registered in Ethiopia by the Ministry of Agriculture and Natural Resources (MoANR, 2022). One non-registered insecticide was employed to control *T. absoluta* based on farmers’ choices (Table 3). The untreated check (only water) served as the negative control. The plot comprised six rows of five meters long, with 1 meter between rows and 0.5 meters between plant spacing. Each plot and block had a 1-meter and 1.5-meter gap, respectively.

Table 3. Lists and some details of the tested insecticides

Treatment No	Trade Name	Common Name	Insecticide Class	Mode of Action	Application rate (ml/ha)	Legality of the products
1	Super jet 300SC	chlorfenapyr 100g/l + thiamethoxam 200g/l	A mixture of pyrroles & neonicotinoid	Stomach, systemic, and contact	675	Registered
2	Tutan Plus 410SC	chlorfenapyr 36% + cyromazin 5% SC	A mixture of pyrroles & triazine	Stomach, systemic and contact	500	Registered
3	Tutan 360 SC	chlorfenpyr 36%SC	Pyrroles	Stomach and contact	800	Registered
4	Ravan 300 SC	chlorfenapyr 180 g/l + indoxacarb 120g/l	A mixture of pyrroles & oxadiazine	Stomach, systemic and contact	500	Not registered
5	Emma 19.2 EC	Emamectin Benzoate 19.2g/l	Avermectines	Non-systemic	500	Registered
6	Water	Untreated check	-	-	-	

3.3.4 Larvae monitoring and treatment application

T.absoluta infestation on monitoring started two weeks after transplanting tomatoes and continued until crop maturity, and the final harvest was made, repeating every three days (Appendix 6). Treatments were applied when the economic threshold was attained. The economic threshold level of 2.87 larvae per plant was used following the recommendations of Tadele Shiberu and Emana Getu (2017). After three weeks of transplanting, the first round of treatment was applied based on the results of the second round assessment and continued through the third round of application. The insecticides were applied using a manual 20-liter backpack sprayer at the manufacturer’s recommended rate (Appendix 7).

3.3.5 Data collection and sampling techniques

Data on larvae count and yield was collected from the middle four rows. Each row had two plants sampled and tagged randomly, with eight plants in one plot. The upper, middle, and lower parts of tagged plants were examined. The total number of larvae per plant and plot was counted and recorded in the sheet (Appendix 8) using a hand lens. The assessment was made every seven days before the economic threshold level was reached and post-treatment three days after spray. At harvest, fruits were sorted into marketable and unmarketable classes; infested fruits were counted and weighed.

3.3.6 Data analysis

An analysis of variance (ANOVA) was performed using the SAS system version 9.0. Tukey's HSD test was used with a 5% significance level to separate treatment means for significant differences. Percent mortality was corrected using Abbott’s formula (Abbott, 1925).

4. Results

4.1. Field Survey

The results of a survey conducted on tomato growers' insecticide use practices in the CRVE for the control of *T.absoluta* are presented and discussed in this section under eight topics that summarize the major findings of the survey regarding growers' knowledge on the pest, practices/experiences in using chemicals and the challenges encountered during *T. absoluta* control.

4.1.1. Age and gender participation

The study covered 100 farmers from four kebele, with 25 participants from each locality, considered ideal for conducting focused group discussions. Age was categorized into four groups: 21–30 years (8%), 31–40 years (16%), 41–50 years (44%), and 51-60 (32%) of the whole population. As a rule of thumb, tomato production is male-dominated in the selected kebeles (Table 4). Therefore, only male respondents participated in the survey, and women mainly participated in weeding, harvesting, grading, and marketing tomatoes.

4.1.2. Education level

According to the finding, about 90% of the farmers have completed their primary education. Six percent have attended secondary schools, while only one person had the chance to complete college-level training. The remaining three percents are illiterates (Table 4).

4.1.3 Short-term training

About 92% of the respondents were not exposed to formal and informal training on tomato production, pest identification, management, pesticide spray, personal protection, or waste disposal. Only a few vegetable growers (8%) have been trained by chemical companies and development agents (DAs) (Table 4).

4.1.4. Experience in tomato production

Most respondents (97%) have worked on a farm in the area for more than two years and have gained some experience in tomato production and marketing (Table 4).

Table 4. Age, gender, education level, training, and tomato production experience of respondents

Background information	Number of respondents (n=100)	Percent respondents (100)
Age		
21-30	8	8
31-40	16	16
41-50	44	44
51-60	32	32
Gender		
Male	100	100
Female	-	
Education level		
Primary schooling	90	90
Secondary schooling	6	6
Higher education	1	1
No schooling (Illiterate)	3	3
Experience		
Two years	3	3
More than two years	97	97
Short term training		
With training	8	8
Without training	92	92

4.1.5. Knowledge of tomato pests

It was revealed that 51% of the respondents accurately described the various insect pests and tomato damage symptoms, and the remaining 49% couldn't describe the insect morphologically or use damage symptoms. Respondents' unanimously ranked first *T. absoluta* among insect pests attacking tomatoes. Only 31% and 4% of the respondents, respectively, described whitefly and aphids as significant insect pests of tomatoes, while 64% and 51% of respondents named African bollworms and thrips as the second and third most important insect pests of tomatoes, respectively, after *T. absoluta* (Table 5).

Table 5. Insect pests of tomato as identified by growers

Insect pest	Number of respondents (n=100)	Percent of respondents (100)
Tomato leaf miner (*T. absoluta*)	100	100
African bollworm	64	64
Thrips	51	51
Whitefly	31	31
Aphids	4	4

4.1.6. Source and farmers' preference for commonly used insecticides

Farmers in the woreda can obtain pesticides directly from agrochemical retailer shops, importers or their agents, agriculture offices, unions, and primary cooperatives. In the study area, pesticides can be purchased from retailers (86%), importers (9%), and the farmers' cooperative union (5%) (Figure 6).

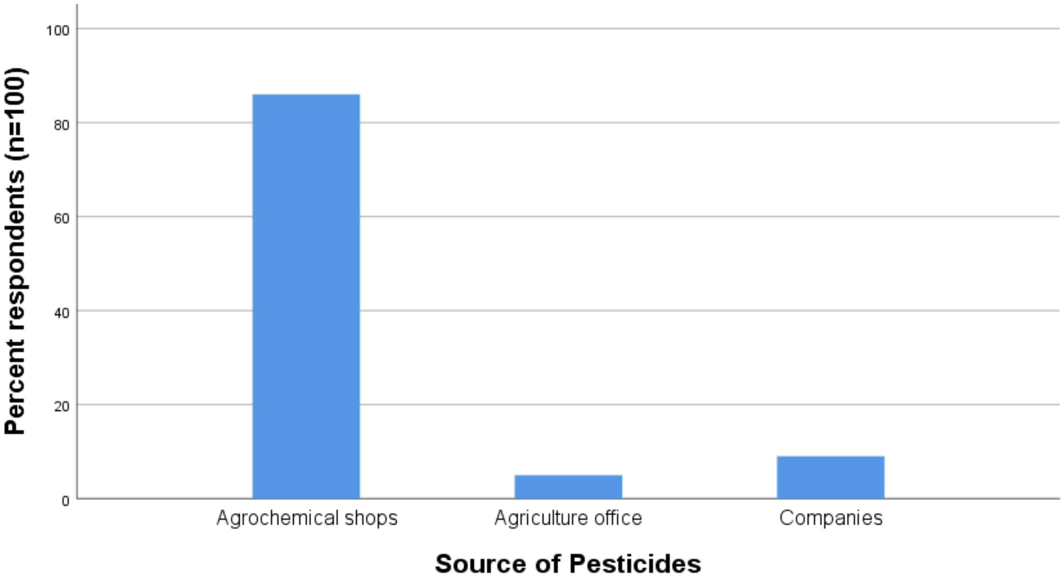

Figure 6. Sources of pesticides

4.1.7. Application rate and efficacy of insecticides

According to the result, 65% of respondents used recommended application rates, while the remaining 35% did so based on old experience (Table 6). Most respondents think that the frequency and rate were ineffective when used as directed by the manufacturers.

Table 6. Application rate and efficacy of insecticides used

Insecticides application practice and efficacy	Number of respondents (n=100)	Percent of respondents (100)
Application rate		
Based on recommendation	65	65
Based on experience	35	35
Efficacy based on recommended rate		
Effective	-	
Not effective	100	100

4.1.8. Trends in the use of unregistered pesticides to control *T. absoluta*

The legality and effectiveness of the insecticides used by the respondents to control *T.absoluta* were also evaluated. Sixty-five percent of respondents were unsure whether the product they used was legally registered. Twenty-eight percent knowingly used unregistered insecticides and found them much more effective against the insect than the registered insecticides (Appendix 9). The remaining seven percent did not use it (Table 7).

Table 7. Use of non-registered insecticides for *T. absoluta* control

Unregistered insecticides use	Number of respondents (n=100)	Percent of respondents (100)
Use unregistered insecticides	28	28
Don’t use unregistered insecticides	7	7
Not sure about	65	65

4.2 Insecticide testing against *T. absoluta*

4.2.1 Pre- and post-treatment larvae counts

After fifteen days of transplanting the tomato seedlings to the field, the first round sampling of *T. absoluta* larvae was conducted on May 14, 2021 (Mean Round Count 1). The second round count was made on May 22, 2021, and larvae number increased drastically and ranged between 3.4 and 3.8 on all plots, calling for insecticide application (MRC 2). Following treatment applications, there were fluctuations in population growth. After the initial spray, the larvae counts decreased at the end of May; however, they began to rise again after a week. At the end of May, the count was at its lowest; late in June, during the tomato blossoming and first fruiting periods, it was at its highest. The mean count in the second, fourth, and sixth rounds shows the larvae count before treatment application, whereas the third, fifth, and seventh-round is the mean count of larvae after spray (Table 8).

Table 8. Mean pre- and post-treatment larvae counts

	Mean Round Count Larvae						
Treatment	1st round (14 DAT)	2nd round (22 DAT)	3rd round (27 DAT)	4th round (34 DAT)	5th round (39 DAT)	6th round (46 DAT)	7th round (53 DAT)
Super jet 300SC	0.1	3.8	1.8	3.6	1	3.9	2.1
Tutan plus 410SC	0.1	3.6	1	3	0.7	4.7	2.3
Tutan 360 SC	0.1	3.8	1.5	3.5	0.4	3.3	2.4
Ravan 300 SC	0.2	3.4	1.9	3.4	1.8	5	2.4
Emma 19.2 EC	0.3	3.6	1.8	3.8	1.8	6.1	2.7
Water	0.2	3.5	3.2	4.2	2.5	6.5	3.5

DAT= Days After Transplanting

4.2.2 Effect of tested insecticides against *T. absoluta* larvae under field conditions

Five insecticides from various chemical groups were tested for their effectiveness against the tomato leaf miner larvae. There were no significant differences in the number of alive larvae among all experimental plots before treatment application in the three rounds, first ($P = 0.99$), second ($P = 0.48$), and third ($P = 0.18$). In each of the three rounds, there were significant differences between pre-and post-spray larval counts ($P < 0.001$). Except for the second round, no statistically significant difference existed among treatments (Table 9). A significant difference between treatments for larvae infestation was observed on records made after the second spray with a p-value of < 0.001. Insecticides Tutan 360 SC (chlorfenapyr 36%SC), Tutan Plus 410 SC (chlorfenapyr 36% + cyromazin 5% SC), and Super Jet 300 SC (chlorfenapyr 100 g/l + thiamethoxam 200 g/l) were applied against *T. absoluta* larvae at the rate of 800, 500 and 675 mlha^{-1}, respectively. The applied insecticides suppressed the level of infestation to different degrees in comparison to the control ($P = 0.001$, $P = 0.004$, and $P = 0.017$), respectively. The average score of larvae infestation between treatments following the second spray ranged from 0.4 to 2.5 larva/plant. The plots treated with Tutan 360 SC, Super Jet 300 SC, and Tutan Plus 410 SC had an average larval decrement of 3.1, 2.6, and 2.3, respectively, compared to the count before treatment application. The rest of the treatments, chlorfenapyr 180 g/l + indoxacarb 120 g/l (Ravan 300 SC) and Emamectin Benzoate 19.2 g/l EC (Emma 19.2 SC), did not differ significantly in the mean number of larvae between treatments (Table 9).

The results (Table 9) show a mean number of *T. absoluta* plant-1 and their respective percent mortality caused by insecticides after the first, second, and third rounds of spray. After the first round of spray, Tutan Plus 410SC caused 72.2 % mortality followed by Tutan 360 SC (60.5 %), Super jet 300SC (52.6 %), Emma 19.2 EC (50.0 %) and Ravan 300 SC (44.1 %). After the second round of spray highest percent mortality was recorded for Tutan 360 SC (88.6 %), followed by Tutan Plus 410SC (76.7 %), Super jet 300SC (72.2 %), while the lowest percent mortality was recorded for Emma 19.2 EC (52.6 %) followed by Ravan 300 SC (47.1 %), after the third spray, the lowest percent of mortality was recorded for all insecticides. It was very much fluctuation compared to the other two rounds.

Table 9. Insecticidal test against *T. absoluta* larvae under field conditions

Trt no.	Trade name of insecticide	Tomato infestation score											
		1st round spray			2nd round spray			3rd round spray			Overall effect		
		Mean of alive larvae before treatment	Mean of alive larvae after treatment	Efficacy (%)	Mean of alive larvae before treatment	Mean of alive larvae after treatment	Efficacy (%)	Mean of alive larvae before treatment	Mean of alive larvae after treatment	Efficacy (%)	Mean of alive larvae before treatment	Mean of alive larvae after treatment	Efficacy (%)
1	Super jet 300SC	3.8	1.8	52.6	3.6^{d}	1.0^{a}	72.2	3.9^{abc}	2.1^{a}	46.2	3.76	1.63	56.6
2	Tutan Plus 410SC	3.6	1	72.2	3^{cd}	0.7^{a}	76.7	4.7^{abc}	2.3^{ab}	51.1	3.76	1.33	64.6
3	Tutan 360 SC	3.8	1.5	60.5	3.5^{d}	0.4^{a}	88.6	3.3^{abc}	2.4^{ab}	27.3	3.53	1.43	59.5
4	Ravan 300 SC	3.4	1.9	44.1	3.4^{cd}	1.8^{abc}	47.1	5^{bc}	2.4^{ab}	52	3.93	2.03	48.3
5	Emma 19.2 EC	3.6	1.8	50.0	3.8^{d}	1.8^{abc}	52.6	6.1^{bc}	2.7^{abc}	55.7	4.5	2.1	53.3
6	Untreated check	3.5	3.2		4.2^{d}	2.5^{bcd}		6.5^{c}	3.5^{abc}		4.73	3.06	
MSD		3.01	0.52		1.84	1.1		4.27	1.61		2.76	1.83	
MSE±		1.31	0.22		0.8	0.48		1.86	0.7		1.01	0.67	
P-value		0.99	0.06		0.48	0.0002		0.18	0.13		0.66	0.07	
P-value (Time)			< 0.001			< 0.001			< 0.001			-	

P-value = the probability for at least one difference at P<0.05.

4.2.3. The effect of tested insecticides on tomato yield

A significant difference in the mean weight of marketable fruits was seen between treatments, with a p-value of 0.027 (Table 10). The weight of marketable fruits ranged from 27.6 to 43.9 tons per hectare. The highest marketable yield of tomato fruits was harvested from plots treated with Super Jet 300Sc (chlorfenapyr 100 g/l and thiamethoxam 200 g/l) compared to plots treated with water as a control (P = 0.035) (Table 10). The rest of the treatments were not significantly different (P> 0.05) from the untreated check. The unmarketable yield harvested ranged from 14.9 to 25.9 t/ha, but no statistically significant difference (P=0.27) existed between treatments. The highest marketable fruits (i.e., both in number and weight of fruits) were produced on plots treated with the insecticides chlorfenapyr 100 g/l + thiamethoxam 200 g/l (Super Jet 300 SC), chlorfenapyr 36% SC (Tutan 360 SC), and chlorfenapyr 36% + cyromazin 5% SC (Tutan Plus 410 SC), yielding 43.9, 43.3, and 42.4 tons per hectare, respectively. Plots treated with the other insecticides, such as Ravan 300 SC (chlorfenapyr 180 g/l + indoxacarb 120 g/l) and Emma 19.2 g/l (Emamectin Benzoate 19.2 g/l EC), produced low marketable yields of 39.5 and 33.5 tons per hectare, respectively, compared to the other three insecticides.

Table 10. Weight of marketable and unmarketable tomato fruits treated with insecticides

Treatment No	Trade Name	Marketable yield	Unmarketable yield
	Super jet 300SC	43.9^{a}	25.9
2	Tutan Plus 410SC	42.4^{ab}	19.65
3	Tutan 360 SC	43.3^{ab}	24.85
4	Ravan 300 SC	39.5^{ab}	21.17
5	Emma 19.2 EC	33.52^{ab}	24.45
6	Water	27.57^{b}	14.87
P-value		0.027	0.27

P-value = the probability for at least one difference at P<0.05.

5. Discussion

5.1 Pesticide use practices

The survey implemented in this study showed that *T. absoluta* is perceived as a key economically important tomato pest in the four main tomato-producing kebeles in Bora wereda. They noted from the survey that most farmers rely solely on chemical control to manage *T. absoluta*. The growers were aware of the key pests of tomatoes, although some did not describe morphologically or use damage symptoms. A similar finding was reported by Abiy Fekadu (2019), where the majority of participants (95%) described the pest using life stages and damage symptoms, while the remaining (5%) were unable to do so either morphologically or using damage symptoms. The author also noted that 93% of respondents ranked *T. absoluta* as the most important pest attacking tomatoes, with the remaining 7% mentioning red spider mites and African bollworms as more significant.

Recently the use of pesticides on vegetable crops has shown an increasing trend in Ethiopia. All commercial vegetable farmers in the CRVE use pesticides to manage pests because of their accessibility, simplicity, time-saving, and efficacy. In the study, Kebeles, the primary source of pesticides are retailers, importers, and the farmers' cooperative union. A similar survey by Belay Mengistie et al. (2015) in the CRVE showed that different types of commercial pesticides with different chemical compositions are readily available at wholesale stores (importers), farmers' unions, and pesticide retailers. Consequently, farmers are either unaware or unwilling to use alternative crop protection measures (Midekesa Chala, 2022).

This study has shown that in the study area, farmers think the frequency and rate were ineffective when used as directed by the manufacturer. Although the farmers have no records of pesticides sprayed, they explained that their spraying frequency varied depending on climatic conditions and crops. According to Belay Mengistie et al. (2015), most farmers apply increased dosages as, from experience, the recommended amount proved ineffective; they use higher than the dose. They intend to eliminate pests at once or reduce spraying frequency. In other East Shewa, Ethiopia studies, many respondents acquired knowledge of pesticide application through field experience. Such farmers need help in pesticide selection, reading and understanding the information conveyed through the labels, and stagger in proper implementation (Tebkew Damte and Getachew Tabor, 2015). A study in Ghana revealed that farmers frequently overdose on agrochemicals to control weeds or insect pests. The author also stated that farmers overdose on agrochemicals because most believe pesticides are less effective than labeled (Egbadzor and Sakyi, 2021).

The decline in the effectiveness of registered insecticides might have forced farmers to switch to using non-registered chemicals. Unpublished sources indicate that local pesticide retailers and some flower farms significantly supply non-registered products. This can be better understood by looking at the examples of Super til 300 SC, Prove 1.9 EC, and Ravan 300 SC, which is used for *T. absoluta* control on tomatoes without passing the necessary testing stages and getting approval. In a related study, Belay Mengistie et al. (2015) found that tomato farms use unregistered pesticides, some of which are class 1a (extremely hazardous) and imported exclusively for the flower industry. However, the Woreda agricultural office head claims that flower growers occasionally import large quantities of unregistered pesticides for their flower and vegetable farms. When the expiration date of some of these products is approaching, they are sold to small vegetable farmers at discount prices (Personal communication).

5.2 Tested insecticides

The results obtained in this study showed that the insecticides tested performed inconsistently in preventing *T. absoluta* infestation and reducing damage to tomato plants. However, plots treated with the insecticides Tutan 360 SC, Tutan Plus 410 SC, and Super Jet 300 SC in the second round of spraying have shown great effect with percent of mortality of 88.6%, 76.7%, and 72.2%, respectively. According to Sudo et al. (2019), the estimated mortality of a single active ingredient in reducing pest density is roughly 70–95%, indicating that the registered pesticide satisfies the "effective" criterion. These three insecticides have the active ingredient chlorfenapyr, which belongs to the insecticide class pyrroles, in common. Similar research on the effectiveness of insecticides against leaf minor revealed that chlorfenapyr was numerically the best treatment for controlling larvae and reducing the infestation (Dos Santos et al., 2011; Soliman et al., 2014). The poor performance of Emma 19.2 EC (Emamectin Benzoate 19.2 g/l) and Ravan 300 SC (chlorfenapyr 180 g/l + indoxacarb 120 g/l) compared to the control might be related to the emergence of insecticide-resistant populations. Recently, reduced efficacy and the highest resistance to specific insecticides were reported (Prasannakumar et al., 2021). After the first, except Tutan Plus 410SC, with a percent of mortality of 72.2 %, and third sprayings, the effectiveness of the tested insecticides' toxicity against *T. absoluta* larvae was insufficient to reduce the infestation compared to untreated plants. Overall, there were no statistically significant differences (P= 0.07) between treatments in the levels of *T. absoluta* control.

One aspect of the study that was unclear was the preference of farmers for the insecticide Ravan 300 SC (chlorfenapyr 180 g/l + indoxacarb 120 g/l) against *T. absoluta*, which is not legally registered in the country until March 2022 and performed poorly in terms of both larval infestation reduction and marketable yield increase. In this efficacy trial, a significant difference between treatments, including the control, was only seen after the second spray; there was no difference in the first and third rounds. According to a survey on the insecticides farmers use to control the pest, old molecules are still frequently used in managing this pest, probably because they are less expensive. Small-scale farmers often need more resources and financial means to buy costly insecticides.

6. Conclusion and Recommendation

6.1. Conclusion

The tomato growers in Bora Wereda have not received training on the proper use of pesticides for controlling *T.absoluta*. In the study area, farmers predominantly used insecticides to control the pest. They also use pesticides indiscriminately due to a lack of knowledge of pest identification and pesticide management. In this regard, most farmers applied increased dosages as, from experience. In addition, farmers were still determining whether their products were legally registered in the country. For instance, nearly 65% of the respondents were unsure of the product's legality.

In the insecticide efficacy test, four registered and one unregistered product were evaluated for use against *T. absoluta* in three spray rounds. Although generalization based on the results obtained from a single round application and experiment is challenging, Tutan 360 SC, Tutan Plus 410 SC, and Super Jet 300 SC were effective against *T. absoluta* and outperformed the untreated control. However, in the other two rounds, the first and third, all the tested insecticides showed no significant difference between treatments.

6.2. Recommendation

Updating farmers with new technologies and teaching on handling and applying pesticides safely should be given attention. Farmers also must be trained to identify pests correctly. Furthermore, a coordinated effort involving all actors in the pesticide value chain is required to prevent issues with the misuse and abuse of insecticides.

Tutan 360 SC, Tutan Plus 410 SC, and Super Jet 300 SC gave best results than all other insecticides in the second spray round; therefore, these insecticides are recommended against *T. absoluta* in Bora Wereda. Tomato should be regularly monitored for *T. absoluta* attack, and if the number increases to 2.87 larvae per plant, the crop should be sprayed with recommended insecticides on recommended dose. The spray can be repeated if the pest population exceeds this number.

There must be a need for multidisciplinary efforts involving research scientists to identify the problems and design strategies to prevent the spread of *T.absoluta* in Ethiopia, agricultural extensions to provide farmers with useful agricultural information; policymakers to establish applicable regulations. Comparable studies in other tomato or vegetable production regions are necessary to get a national perspective on pesticide use habits and determine the degree of insecticide sensitivity among *T. absoluta* strains nationwide.

The current level of protection by all pesticides applied against *T. absoluta* is unsatisfactory. Therefore, it is crucial to test and register new insecticide molecules with diverse modes of action. Thus, the general recommendation is to use rotational insecticide application techniques as an IRM strategy and implement an IPM program that fits the CRVE production system.

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8. Appendices

Appendix 1: Survey questionnaires format

Survey Questionnaire

Pesticide use in tomato production in Bora Wereda

Survey ID number: ☐ ☐ ☐

Name of interviewer: ________________________________

Date of interview: _________ Time started: __________ Time finished: __________

Region: ________ Zone: __________ Wereda__________ Kebele ________________

Full address of the contact: ____

Good morning/ afternoon. My name is_________, and I am from Addis Ababa University of Zoology Department (Insect Science stream). I am currently surveying insecticide use by farmers in the Bora Woreda. The purpose of this survey is to the different types of insecticides used by farmers in Bora Woreda for managing tomato insect pests.

It is for research purposes only. I assure you that your answers will always be kept strictly confidential and never disclosed to anyone else. I only request that you answer the questions truthfully, in the best possible way, and to the best of your knowledge. If you cannot answer some questions, say "NO,' or I do not know.

Do you agree to participate in this study? a. ☐ Yes b. ☐ No

If yes, continue the survey.

PART I: GENERAL INFORMATION OF THE FARM HOUSEHOLD

Part I.1 Respondent and household characteristic

1. Gender 1.☐ Male 2. ☐ Female

2. Age __________

3. What is the highest education level you have completed?

a. ☐ No schooling b. ☐ Primary (1-8 years of schooling)

c. ☐ Secondary (9-12 years of schooling) d. ☐ Higher education (diploma, BSC)

e. Other, specify ____________________________________

4. How many years have you been staying in this village? _________ Years.

If you have less than five years in this village, ask the following question:

4.1 Where did you stay just before coming to this village?

a. In another village, but the same wereda

b. In another wereda, but the same region

c. In another region

5. How long have you been working in farming? ______ Years.

If you have less than two years of working in farming, ask the following question:

5.1 What was your job before working in farming?

a. ☐ Doing non-farm activities

b. ☐ Being an office worker

c. ☐ Other jobs (please specify) ______________________

PART II: PESTICIDE USE IN TOMATO PRODUCTION

In this section of the survey, I would like to ask you questions about the use of pesticides on your tomato farm. Is there any pesticide used on your farm?

a. ☐ Yes b. ☐ No, If Yes: Continue the survey. If No: Please tell us why pesticides are not used on your farm:

Thank you very much for your participation in this survey. Your answers will be beneficial for our research. Again, I assure you that all your answers in this survey will be kept strictly confidential and never revealed to anyone outside our research group. Tell me your name, please.

Name of respondent: ______________________

Thank you very much, Mr. /Ms. ______________

1. Is tomato production profitable with the use of pesticides?

a. ☐ Yes, b. ☐ No

2. What time do you apply pesticides? (Please specify the cropping season and crop age)

3. What are the major insect pests attacking tomatoes in the kebele? (Please give ranks based on their importance based on % of loss).

No.	**Name of the insect pest**	**Very important (High loss)**	**Important (some loss)**	**Not so important**

4. Who is responsible for deciding which pesticide to buy?

a. ☐ The respondent

b. ☐ Other family members. Please specify________________________________

5. Do you buy the pesticides used in this farm from one or different retailers?

a. ☐ One b. ☐ Many

6. Do you always buy the same brands of pesticides or regularly change brands of pesticides?

a. ☐ Always the same b. ☐ Change regularly c. ☐ Change sometimes

If there is a change, then ask the following questions

6.1 What is the reason you regularly change brands of pesticides?

a. ☐ The new brand of other pesticide companies is better

b. ☐ The old brand is no more effective against insect pests

c. ☐ Following recommendations from retailers/ pesticides companies

d. ☐ Following recommendations from agricultural officials/research

e. ☐ Others (please specify) _____________________________________

7. When you buy pesticides, does it sometimes happen that the container(s) has no label?
a. ☐ Never happen b. ☐ It does sometimes happen c. ☐ Often

8. What action do you take if pesticides come without a level?

a. ☐ Buy b. ☐ Refrain from buying, c. ☐ Others specify

9. Do you check for the expiry date when buying pesticides? a. ☐ Yes, b. ☐ No

10. What types of pesticides do you commonly use on tomato farms?

a. ☐ Insecticides b. ☐ Fungicides c. ☐ Herbicides

d. ☐ Others (please specify) ---

11. Who is the primary person responsible for applying the pesticides?

a. ☐ The respondent

b. ☐ Hired & trained applicator,

c. ☐ Hired non-trained laborer,

d. ☐ Other family members

12. Record of commonly used insecticides in tomato farms

No.	**Name of insecticides**	**Target pest**	**Rate/ha**	**Unit price (Birr/lit/kg)**	**Registered/ Smuggled**	**Remarks**

Notes: 1. Name of insecticides: trade name, active ingredient concentration. Example: Farrate 5% EC; 2. Price per unit: using the cost of commercial products in birr/ lit or kg.

13. Do you mix the recommended quantity of product with the required amount of water?

a. ☐ Yes b. ☐ No

13.1 If YES, please specify the insecticides and the amount of water you used in the last tomato growing season

No.	**Name of insecticide**	**Amount of insecticide mixed(grams or ml)**	**Water volume used**

14. Did you change the dosage of insecticides per unit of land compared to the dosage you used for tomatoes on the same unit of land in the last two years?

a. ☐ Yes, b. ☐ No

14.1. If yes, a. ☐ Increased b. ☐ Decreased c. ☐ Both

14.1.1 If increased, why did you raise the dosage?

a. ☐ The target insects do not die anymore at the recommended dosage

b. ☐ New research/extension advice to increase the rate

c. ☐ Suppliers recommended doing so

d. ☐ More pest incidence after spray

e. ☐ Other (please specify) --------------------

14.1.2 If decreased, why did you reduce the dosage?

a. ☐ The insecticide killed everything, including natural enemies

b. ☐ New research/extension advice to decrease the rate

c. ☐ Suppliers recommended decreasing

d. ☐ To make sure that it works

e. ☐ Other (please specify) --------------------

15. Do you use any insecticide recommended for other crops for tomato insect pest control?

a. ☐ Yes b. ☐ No c. I do not know

15.1 If yes, list the insecticide you used and the crop it was initially recommended for

Name Insecticide	**Target crop specified on the label**

15.2 Please give a reason for such practice:

a. ☐ Suggested by research/extension (agriculture office)

b. ☐ Suggested by supplier companies

c. ☐ Suggested by local retailers

d. ☐ Acting on your own

e. ☐ Suggested by friends/neighbors

f. ☐ Suggested by NGOs

g. ☐ Imitating others

h. ☐ Others (please specify) --

16. Have you received any formal training on how to use pesticides?

a. ☐ Yes, b. ☐ No

17. When purchasing pesticides, are you usually supplied with information on the pesticide, such as pamphlets or instructions describing safety issues or procedures?

a. ☐ Yes, b. ☐ No

PART III: SOCIAL FEEDBACK:

1. Some people believe that some farmers use insecticides not legally registered in Ethiopia. I am not asking about you specifically, but could this happen in this village?

a. ☐ Yes, b. ☐ No c. ☐ I do not know

1.1 If the answer is yes, do the farmers in the village believe these insecticides are more effective than the legally registered ones?

a.☐ Yes, b. ☐ No

2. When you buy insecticides, do you know if the particular insecticides are legal to use in Ethiopia or not?

a. ☐ Yes, b. ☐ No

If yes, ask the following question:

2.1 How do you know whether or not insecticides are legal to use in Ethiopia? Explain____

3. To which criteria do you give attention when buying an insecticide? (Specify).----------

4. Please indicate the degree of importance of each of the following criteria when buying an insecticide

Criterion	**Very important**	**Important**	**Not so important**
Price of the pesticides			
Efficacy of the pesticides in controlling insect pests			
The clarity of explanation on how to use			
The legality of the pesticide			

5. Suppose that a farmer (not you in particular) has the choice between two insecticides: one legal and one illegal. Suppose the price of the illegal insecticide is much lower than the price of the legal one. How many farmers do you think would buy the cheaper but illegal insecticides?

a. ☐ Most farmers b. ☐ A few farmers c. ☐ No farmer d. ☐ I do not know

6. Have you any legal measures or actions against illegal insecticide use in the past growing seasons in your area?

a. ☐ Never b. ☐ A few c. ☐ Many d. ☐ I do not know

Thank you very much for your participation in this survey. Your answers will be beneficial for our research. Again, I assure you that all your answers in this survey will be kept strictly confidential and never revealed to anyone outside our research group. Please tell me your name.

Thank you very much, Mr. /Ms. ____________________

PART IV: INTERVIEWER DEBRIEFING QUESTIONS:

(TO BE FILLED OUT BY THE INTERVIEWER ONLY)

1. Are you confident that the interviewee was answering the questions honestly and truly?

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Very Uncertain	Moderately Uncertain	Neutral	Moderately Certain	Very Certain

Data entry operator (name): ___________________

Appendix 2 Conducting discussion with data collectors on a structured questionnaire

Appendix 3 The Layout of an experimental field

Appendix 4 Seedling of tomato in a seedling tray ready to transplant in the field

Appendix 5 Septoria leaf spot of tomatoes

Appendix 6 Pest scouting A) Using data collection form B) Using a hand lens.

Appendix 7 Insecticides application on tomato field for *T.absoluta* control

Appendix 8: Amharic version of data collection form

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Appendix 9 Unregistered insecticides in one of the pesticides shops in the area

A) SUPER TIL 300 SC B) RAVAN 300 SC C) PROVE 1.9 EC