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DEPARTMENT OF ZOOLOGICAL SCIENCES

STUDIES ON PESTICIDE USE KNOWLEDGE AND PRACTICES OF SMALL-SCALE ONION PRODUCING FARMERS IN CONTROLLING ONION THRIPS, *THRIPS TABACI* LINDEMAN (THYSANOPTERA: THRIPIDAE), ON ONION, *ALLIUM CEPA* L, AND ANALYSIS OF ORGANOCHLORINE AND ORGANOPHOSPHATE PESTICIDE RESIDUES IN ONION IN KEWET DISTRICT, CENTRAL ETHIOPIA

BY:

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MAY, 2022

ADDIS ABABA, ETHIOPIA

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Dedicated to

My beloved Father Late Tsegaw Zenebe, My beloved Mother GomezheShewa Mengistu

My beloved Uncle Late Shambel Zemedkun Chekol, My beloved Son Yeabsra Abnet

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ABBREVIATIONS AND ACRONYMS

AChE…………… acetylcholinesterase enzyme

ADI………………acceptable daily intake

AOAC**……………**Association of Official Analytical Chemists

APP………………Acute Pesticide Poisoning

ARfD…………….acute reference dose

ASE………………Accelerated Solvent Extraction

C_{18}………………..Octadecyl

CCPR……………..Codex Committee on Pesticide Residues

ChE………………cholinesterase enzyme

CMD……………. common mental disorders

CNS……………... central nervous system

Codex…………….Codex Alimentarius Commission

CSA………………Central Statistical Authority of Ethiopia

DBARC…………..Debre Birhan Agricultural Research Center

DDD……………... Dichlorodiphenyldichloroethane

DDE………………Dichlorodiphenyldichloroethylene

DDT……………....Dichlorodiphenyltrichloroethane

DNA…………….. Deoxyribonucleic acid

d-SPE…………….Dispersive Solid Phase Extraction

ECD………………Electron Capture Detector

ECPA…………….European Crop Protection Association

EFSA……………..European Food Safety Authority

ENAO……………Ethiopian National Accreditation Office

EC………………..European Commission

EPA……………...Environmental Protection Agency

EU………………..European Union

EWG……………. Environmental Working Group

FAO……………...Food and Agriculture Organization of the United Nations

FAO/WHO……….Joint Food and Agriculture Organization of the United Nations and World Health Organization

FID……………….Flame Ionization Detector

FPD………………Flame Photometry Detector

GAP……………...Good Agricultural Practices

GCB……………...Graphitized Carbon Black

GC………………..Gas Chromatography

GC-MS (GC/MS)...Gas Chromatography-Mass Spectrometry

GC/MSD…………Gas Chromatography/Mass Selective Detector

GC/MS-MS………Gas Chromatography tandem Mass Spectrometry

g/l………………...gram per litre

α-HCH……………Hexachlorocyclohexane (α isomer) β-HCH……………Hexachlorocyclohexane (β isomer)

HPLC…………….High Performance Liquid Chromatography

IEC……………….International Electrotechnical Commission

IPM………………Integrated Pest Management

ISO……………….International Organization for Standardization

IYSV……………..Iris Yellow Spot Virus

JMPR…………….Joint FAO/WHO Meeting on Pesticide Residues

L…………………Litre

LC………………..Liquid Chromatography

LC-MS…………...Liquid Chromatography-Mass Spectroscopy

LC-MS/MS………Liquid Chromatography tandem Mass Spectroscopy

LGE……………...Liquid-Gas Extraction

LLE………………Liquid-Liquid Extraction

LMIC…………….Low- and middle-income countries.

LPE………………Liquid Partition Extraction

LSE………………Liquid-Solid Extraction

MARC…………...Melkassa Agricultural Research Center

mg/kg……………milligram per kilogram

μg/kg……………microgram per kilogram

μL………………microlitre

mL/min…………millilitre per minute

MOA……………Ministry of Agriculture

MRL……………Maximum Residue Limit

MS……………..Mass Spectrometry

MS/MS………...tandem Mass Spectrometry

MSD…………...Mass Selective Detector

MSPD…………Matrix Solid Phase Dispersion

ng/ml…………..nanogram per millilitre

NPD……………Nitrogen Phosphorus Detector

NZFSA………...New Zealand Food Safety Authority

OCPs…………..Organochlorine Pesticides

OECD…………Organization for Economic Cooperation and Development

OPIDP………...organophosphate-induced delayed polyneuropathy

PAN…………...Pesticide Action Network

PHI……………pre-harvest interval

PPE…………....Personal Protective Equipment

PSA……………Primary Secondary Amine

QuEChERS……Quick, Easy, Cheap, Effecttive, Rugged and Safe

rcf……………....relative centrifugal force

SIM…………….Selected Ion Monitoring

SPE…………….Solid Phase Extraction

SPME………….Solid Phase Microextraction

STMR………….supervised trials mean/median residue (level)

TLC…………….Thin Layer Chromatography

TOF-MS………..Time of Flight Mass Spectrometry

TSWV………….Tomato Spotted Wilt Virus

TYFRV………...Tomato Yellow Fruit Ring Virus

UAAIE…………Upper Awash Agro Industry Enteprises

UHPLC…………..Ultra-High Performance Liquid Chromatography

UHPLC-MS/MS…Ultra-High Performance Liquid Chromatography tandem Mass Spectrometry

UN……………….United Nations

USA……………...United States of America

USDA……………United States Department of Agriculture

USEPA…………...United States Environmental Protection Agency

UV………………..Ultrviolet

v/v………………...volume by volume

w/v………………..weight by volume

WHO……………..World Health Organization

ABSTRACT

Synthetic chemical pesticides especially synthetic chemical insecticides have been widely and tremendously used in agriculture in the world including Ethiopia to safeguard crops from pest damages. However, there is a growing global perspective and concern on the extensive, excessive, indiscriminate and inappropriate use and unsafe handling and application of pesticides with inadequate knowledge, technical support and equipment, and its consequent adverse effects and potential threats to human health, food safety (quality of food) and the environment. The main objective of the present study was to assess and evaluate levels of synthetic chemical pesticide (synthetic chemical insecticide) use knowledge and practices of small-scale onion cultivating farmers in controlling onion thrips on onion, and analysis (analytical determination and evaluation) of organochlorine and organophosphate pesticide residues in onion in Kewet district, central Ethiopia. In the quantitative field survey research, a total of 385 smallholder onion producing farmers selected randomly from three purposively selected administrative 'kebeles' (a 'kebele' is the lowest administrative *structure) in Kewet district were included for the interview and data were collected using a standardized structured questionnaire administerd in in-depth face-to-face interview during 2020. In the analytical experimental study, analysis (analytical determination and evaluation) of concentration and contamination (pollution) levels of thirteen organochlorine and two organophosphate pesticide residues in onion samples taken from Shewa Robit (Shewa Robit is the main town and the major market place in Kewet district) in accordance with sampling procedures of Codex and European Commission were performed using Quick, Easy, Cheap, Effective, Rugged and Safe (QuEChERS) sample preparation method and gas gromatography (GC) coupled with mass selective detector (MSD) analytical instrumednt. In the survey study, all (100%) respondent farmers reported that onion thrips is the major and serious insect pest of onion attacking in every growing season (year), and all (100%) of them used synthetic chemical pesticides (synthetic chemical insecticides) to control onion thrips on onion; however, none of the study participants have ever received any formal training and technical support on the appropriate and safe use, handling and application of pesticides and pesticide use safety measures (safety precautions and safety practices of pesticide use) like use of personal protective equipment (PPE) during pesticide use and application.*

Knowledge, awareness and understanding of the participant farmers on the appropriate and safe use, handling and application of pesticides and adverse effects of inappropriate and unsafe pesticide use, handling and application to human health and the environment is very low where only about one third (34.8%) of the respondents perceived that exposure to pesticides could have some harmful effects to human health, while only about a liitle more than a quarter (29.1%) of them thought exposure to pesticides could have some negative impact on the environment. Most (93.8%) of the study subjects do not have any knowledge and awareness of the importance of wearing PPE during pesticide use (when handling and application of pesticides), and none of them used any PPE when handling (purchasing, storing, preparation (mixing), application (spraying)) of pesticides and disposal of pesticide wastes including empty pesticide containers. The most (96.9%) respondent farmers discarded empty pesticide containers on-farm (in the open field), and none of the study participants were aware of the pesticide legislations of Ethiopia. In the analytical experimental study, four pesticide residues were detected in onion samples, namely, α-HCH (0.004 mg/kg), β-HCH (0.001 mg/kg), heptachlor epoxide (0.007 mg/kg), and DDE (0.008 mg/kg) out of the pesticides analysed for their residues. And, all the pesticide residues detected were below the maximum residue limits (MRLs) established by Japan, EU, Codex (FAO/WHO) and USA. The investigations of the survey study demonstrate that onion farmers in the study area are in overall lack of knowledge, awareness and understanding of the appropriate and safe use, handling and application of pesticides and pesticide use safety measures, and the farmers have been adopting and operationalizing inappropriate pesticide use practices against proper pesticide use safety behaviours. The farmers' *overall lack of knowledge, awareness and perception of the appropriate and safe use, handling and application of pesticides and their improper pesticide use practices adversely affect human health, the environment and food safety (quality standard of food). The study emphasizes on urgently developing and formulating holistic pesticide policy and pesticide use intervention strategies and intervention measures including designing comprehensive formal educational training programs and stable technical support and advisory platforms on appropriate and safe use, handling and application of pesticides and pesticide use safety measures (safety precautions and safety practices of pesticide use) and on harmful effects of inappropriate and unsafe* *pesticide use, handling and application to human health, quality of food (food safety) and the environment, and immediately addressing and delivering at least to the farmers, pesticide vendors, agricultural extension workers (agricultural extenstion professionals) and beyond, presenting to them on continuous and regular basis to elevate their levels of knowledge awareness, understanding and perception of this alarming and threatening issue (pesticide use challenges) in Ethiopia encompassing the study area and taking the present research as a case study. Importantly, necessary amendment (making inclusive) and stringent enforcement of the national pesticide laws of Ethiopia at all levels is promptly required. The results of the analytical experimental study do not demonstrate an unacceptable health outcome for onion consumers in the study area; however, this may not imply a guarantee to human health as pesticides analysed for their residues in onion are fixed. Periodic (regular) and continuous monitoring, surveillance and analyses (analytical determination and evaluation) of pesticide residues and pesticides particularly of currently commonly used ones including organophosphates in onion must be urgently expanded at national level in Ethiopia encompassing the study area and taking the present analytical experiment as a case study with advanced pesticide residue analysis laboratories (with advancing pesticide residues and pesticides monitoring laboratory facilities). Regular (periodic) and continuous investigation (testing) and monitoring of the health status of the farmers, the agrarian communities and the public at large is promptly required. Promotion and use of pesticide use minimizing or non-pesticide use pest control and management alternative methods such as good agricultural practices (GAP), integrated pest management (IPM), biological control methods, cultural control practices and organic farming are quite urgently necessary, and insights (research) into new environmentally friendly pest control and management approaches and methods is required.*

***Key words**: Pesticide, Onion thrips, Pesticide use knowledge and practices, Pesticide residue, QuEChERS method, GC/MSD, Kewet district, onion, Ethiopia*

1 INTRODUCTION

1.1 Background of the Study

Onion, *Allium cepa* L., belongs to the family Amaryllidaceae (Alliaceae), and it is predominantly the most important monocotyledonous vegetable bulb crop in human food in most parts of the world (Rabinowitch & Currah, 2002; Brewster, 2008). Onion has been cultivated for 4700 years or more and does not exist as a wild species (Brewster, 2008). It is believed that onion was probably first domesticated in the mountainous regions of Turkmenistan and north Iran (Brewster, 2008)**.** Hence, south-west Asia is regarded as being the primary centre of domestication and variability (Brewster, 2008). Other regions of great diversity like the Mediterranean are considered secondary centres (Brewster, 2008). The introduction of onion crop to Africa in general and to Ethiopia in particular was not well known. However, it has been suggested that it was introduced to Ethiopia by foreigners in the early 1970s (Tadesse, 2008).

Currently, onion is produced throughout the world across a wide range of latitudes in Asia, Europe, North America and Africa (Rabinowitch & Currah, 2002; Tadele & Mulugeta, 2014). According to FAO STAT (2012), the world total onion production is about 742.51 million tons per annum, and out of this, China, India and USA, being the major world onion producing countries, shared 205.08 million tons, 133.72 million tons and 33.21 million tons respectively. In Africa, Egypt is the leading onion producing country (FAO STAT, 2012; Habtamu, 2017).

In Ethiopia, though believed to be introduced recently to the country, onion is rapidly becoming acceptable by producers and consumers than the traditionally grown shallot (Tadesse, 2008; Habtamu, 2017). Currently, it is widely grown and produced in different parts of the country including Kewet district, the study area, mainly by small-scale farmers and mostly under irrigation. Onion is a very important food and cash crop in Ethiopia (Tadele *et al*., 2013). Onion is becoming a popular and high-value crop because of its yield potential per unit area, the ease of propagation method both by seed and bulb, and the presence of high domestic and export markets (Tadele & Mulugeta, 2014; Sara *et al*., 2015; Habtamu, 2017). Onion has been the most indispensable crop used as condiments, food flavoring and seasoning of daily stews, for different vegetable food preparations in most Ethiopian cuisine and in therapeutic medicine (Tadele *et al*., 2013).

During the main cropping season of 2013/2014 of/in Ethiopia, the total production of onion bulb in the country was about 219,735.2 tons, but in the crop calendar of 2014/2015 the production has raised to about 230,745.2 tons, and the average productivity of onion was increased from 9 to 10.1 tons/hectare (t/ha) (CSA, 2015). In the cropping year of 2017/18, the total area under production reached over 31,673.21 hectares and the production was estimated to be over 2,938,875.85 quintals (MOA, 2018a). These some crop calendars show that volume of onion production in Ethiopia may seem in some increasing trend. However, the average production and productivity of the crop (about 10.02 t/ha) is far below the world average (19.7 t/ha) in spite of its year-round production scenarios (Habtamu, 2017).

Among (the) troublesome constraints challenging quantity and quality of onion production are insect pests, the major one being onion thrips (*Thrips tabaci* Lindeman). Onion thrips is a phytophagous, invasive and multivoltine insect pest and vector of onion. It is considered to be the most economically important cosmopolitan pest of onion which causes significant yield losses globally (Lewis, 1997; Trdan *et al*., 2005). It is reported that if onion thrips is not managed properly, it may cause yield losses of 6 to 63% with an average loss of 31% (Rueda, 2000**;** Haidar *et al*., 2014). According to Ibrahim (2009), onion thrips are the most severe pests of onion that can totally destroy young plants. In Kenya, onion thrips are present in all onion growing areas and can cause up to 59% loss in yield (Waiganjo *et al*., 2008). Onion thrips can also serve as a vector for Iris yellow spot virus (IYSV) ((Bunyaviridae: *Tospovirus*), an economically important disease causing pathogen in onion seedlings across the world (Reitz *et al*., 2011). Importantly, onion thrips feeding can reduce bulb yields by 30-50% and losses can be exacerbated if onion thrips infect the crop with IYSV or create damage that permits other pathogens to infect the crop (Brain, 2006). Diaz-Montano *et al*. (2011) reported that *Thrips tabaci* becomes a global pest of increasing concern in commercial onion fields because of its development of resistance to insecticides, ability to transmit plant pathogens and frequency of producing more generations at high temperatures.

In Ethiopia, including Kewet district, th study area, onion thrips is an important insect pest of onion that affects onion yield by direct feeding as well as reducing the quality and quantity by rasping the leaves and other tissues of onion crops to release the nutrients (Tsedeke, 1985; Yeshitila, 2015). Onion fields can be destroyed by onion thrips, especially in dry seasons (Tadele *et al*., 2013). Tsedeke (1983) and Yeshitila (2015) reported onion bulb yield losses of 26-57% due to onion thrips in Ethiopia. Similar studies at Upper Awash Agro Industry Enterprises (UAAIE) revealed yield losses of 10 to 85% due to onion thrips (Ferdu and Tsedeke, 2006). It is a serious insect pest of onion which mainly affects the leaf parts of the plant that reduces the yield and productivity (hinders photosynthesis) of the crop (Habtamu, 2017).

1.2 Statement of the Problem (Statement of Purpose)

Synthetic chemical pesticides especially synthetic chemical insecticides have been widely, extensively and excessively used for the control and management of pests of crops in agriculture in general and on horticultural crops (vegetables, fruits, flowers, spices) in particular in small-scale and large-scale (commercial) farming systems globally. And, the most common management tactic for onion thrips infestations on onions in the world including Ethiopia is the use of synthetic chemical pesticides (synthetic chemical insecticides) (Tsedeke, 1983; Tsedeke & Gashawbeza, 1994; Casida & Quistad, 1998; Harsimran *et al*., 2015). In Kewet district, the study area, onion cultivating farmers rely only on synthetic chemical pesticides (synthetic chemical insecticides) to control onion thrips on onion, and they have been using (applying) the chemical pesticides (chemical insecticides) excessively, extensively, indiscriminately and inappropriately without any pesticide use safety measures (without any safety precautions and safety practices of pesticide use) in controlling onion thrips on onion. It was reported that 58% of smallholder vegetable farmers in Kuwait overused pesticides (Jallow *et al*., 2017; Mustapha *et al*., 2017). Pesticides, by their nature, are potentially toxic to humans and many other living organisms other than their target audience; therefore, they must be used safely, and their waste should be disposed of appropriately (Cevik *et al*., 2020), and according to the World Health Organization (WHO) standards (WHO, 1986), only pesticides that are (relatively) safe to farmers and farm-workers should be used (Tambe *et al*., 2019). However, it has been reported in many earlier studies that particularly small-scale farmers use chemical pesticides (mostly synthetic insecticides) excessively, indiscriminately, extensively and improperly with disregard to recommended safety measures and without recognizing harmful consequences especially in the third world (developing) countries (Wesseling *et al*., 1997; Ecobichon, 2001; Mohanty *et al*., 2013; Abbas *et al*., 2014; Bakhtawer & Afsheen, 2021), and chronic, excessive and unsafe use of chemical pesticides outcomes in a serious risk to human health, the environment, and quality of food (Reigart & Roberts, 1999; Mohanty *et al*., 2013; Buralli *et al*., 2020) due to uptake and accumulation of these toxic pesticide compounds in the food chain and drinking water (Adesuyi *et al*., 2015; Adesuyi *et al*., 2016; Njoku *et al*., 2017; Adesuyi *et al*., 2018). Consequently, worldwide work-related and environmental pesticide poisoning has increased, especially in less-developed countries (Litchfield, 2005; Tambe *et al*., 2019), and there is an alarming/a worrying global surge in the incidence of occupational and environmental pesticide poisoning with an estimate of about 25-41 million people, mostly farmers and agricultural workers, experiencing unintentional (and intentional) pesticide poisoning and suffering health problems from exposure to pesticides around the world occurring annually (Jeyaratnam, 1990; PAN International 2007; Alavanja, 2009; Tambe *et al*., 2019; Buralli *et al*., 2020), resulting in an annual estimated deaths of 200,000-300,000 people from pesticide poisoning, mainly (99%) affecting low-and middle-income (developing) countries (LMIC) (Jeyaratnam, 1985; WHO, 2009; UN, 2017; Adesuyi *et al*., 2018; Alice *et al*., 2019; Buralli *et al*., 2020). And, it is (also) estimated that approximately 1-5 million cases of pesticide poisoning, and nearly 20,000 deaths occur per year among farmers and agricultural workers caused by chemical pesticides, mostly in developing countries (Abdou & Hend, 2018; Taghdisi *et al*., 2019; Cevik *et al*., 2020). Likewise, it is estimated that 99% cases of human pesticide poisoning fatalities occur only in developing countries, although these countries account only for (use only about) 20–30% of the total global pesticide consumption (WHO, 1990; Dinham, 1993; Wesseling *et al*., 1996; Ncube *et* *al*., 2011; Mohanty *et al*., 2013; De Jong *et al*., 2014; Mwabulambo *et al*., 2018; Cevik *et al*., 2020), and Africa consumes about 4% of the total pesticides produced in the world (Abdelbagi *et al*., 2006; Mwabulambo *et al*., 2018). The risk to human health comes from direct contact and exposure to pesticides and pesticide residues, or indirect exposure to pesticides due to pesticide residues in primary or derived agricultural products when consumed (Jeyaratnam, 1990; Mohamed *et al*., 2020). Particularly farmers and agricultural workers directly involved in the handling of pesticides are at a high risk of exposure to pesticides and hence pesticide poisoning health problems through direct contact to pesticides due to unsafe handling, storage and disposal practices during transport, dilution, mixing and application of pesticides, and contact with pesticide residues on treated crops (Manyilizi *et al*., 2017; Adesuyi *et al*., 2018; Cevik *et al*., 2020; WHO, 2020). Poor maintenance of spraying equipment and lack of protective clothing or failure to use it properly are another form of exposures (Matthews, 2008; Adesuyi *et al*., 2018). There is also a high risk of human poisoning due to exposure particularly to highly toxic pesticides through lack of protective gear, leaky spray equipment, from mixing and applying pesticides with bare hands and storage of pesticides near food (WHO, 1985; U.S. General Accounting Office, 1989; WHO, 1990; Ncube *et al*., 2011).

Human exposure to pesticides can occur through the mouth, skin, inhalation into the lungs and the eyes (Desalu *et al*., 2014; Mustapha *et al*., 2017; Adesuyi *et al.,* 2018). Inhalation exposure can occur while mixing granular and powder forms of pesticides, spraying of the solvent and during the burning of empty pesticide containers (Adesuyi *et al.,* 2018), and this inhalation exposure provides the fastest route of exposure into the bloodstream (Desalu *et al*., 2014; Adesuyi *et al.,* 2018). Specifically, about 10% of total pesticide exposures in agricultural occupations occur through the respiratory tract, the rest through dermal absorption or digestion (Ye *et al*., 2013; Cevik *et al*., 2020).

Human short-term (acute) exposure to pesticides due to direct and immediate contact and exposure to pesticides can lead to occupational acute pesticide poisoning (APP), and long-term (chronic) (prolonged) direct exposure to pesticides and consumption of agricultural food commodities (food items) contaminated with pesticides and pesticide residues (indirect human exposure to pesticides) outcomes in chronic human health problems, and particularly farmers, agricultural workers, and also agricultural communities in general are at high risk of facing several forms of APP and chronic health problems due to such short-term (acute) and long-term (chronic) pesticide exposures.

Pesticide poisoning is a major public health concern, especially in developing countries where the most persistent and hazardous pesticides are used by untrained farmers (WHO, 1985; U.S. General Accounting Office, 1989; Ncube *et al*., 2011). Moreover, pesticides that are banned, unregistered or suspended in developed countries due to their toxicity and harmful health effects are often exported to developing nations (Weir & Schapiro, 1981; U.S. General Accounting Office, 1989; Ncube *et al*., 2011). Many of these highly toxic pesticides are applied by people with minimum or no training in safe application or storage of pesticides, and without suitable protective gear (WHO, 1985; U.S. General Accounting Office, 1989; Ncube *et al*., 2011). Many developing countries do not have effective monitoring systems in place to assess the extent of pesticide poisonings and the majority of cases are unreported (Ecobichon, 2001; Ncube *et al*., 2011). Occupational acute pesticide poisoning (APP) emerges as a serious public health problem, particularly in developing countries, due to unsafe pesticide application (Cevik *et al*., 2020; WHO, 2020), and despite the high burden of APP in developing countries, there is substantial under-reporting suggesting that the burden of disease due to APP is frequently underestimated (London & Bailie, 2001; Lekei *et al*., 2014). In developed countries, the annual APP incidence rate in full-time agricultural workers is 18.2 per 100,000 (Thundiyil *et al*., 2008; Cevik *et al*., 2020).

Short-term (acute) human pesticide exposure can lead to temporary acute negative health effects and serious illnesses that can be acutely manifested as headache, body aches, coughing, stomach ache, rashes, disorientation, shock, nausea, vomiting, respiratory problems (respiratory failure), skin and eye irritation, dizziness, impaired vision, excessive salivation, diarrhoea and even death (Moses, 1989; Reigart & Roberts, 1999; Calvert *et al*., 2008; Ncube *et al*., 2011; Mohanty *et al*., 2013; Okoffo *et al*., 2016; Mustapha *et al*., 2017; Adesuyi *et al*., 2018). And, chronic (long-term) human exposure to pesticides are commonly and widely reported to have adverse health effects on thyroid function, cause low sperm count in males, birth defects, increase in testicular cancer, reproductive malfunction, immune system disruption (immune malfunction), genotoxicity, endocrine system disruptions, dermatitis, behavioural changes, cancers, impaired fertility, neurotoxicity, immunotoxicity, neurobehavioral and developmental disorders, effects on the central nervous system (CNS) like restlessness, loss of memory, convulsions and coma, and also effects on the parasympathetic and sympathetic nervous system, such as respiratory paralysis, and can result in reproductive, neurologic and skin diseases (WHO, 1990; Savitz *et al*., 1997; Garcia, 1998; Sanborn *et al*., 2007; Hopping *et al.*, 2008; Kesavachandran *et al*., 2009; Alavanja *et al*., 2013; Mohanty *et al*., 2013; Mhauka *et al*., 2014; Okoffo *et al*., 2016; Adesuyi *et al*., 2018; Mwabulambo *et al*., 2018; Mohamed *et al*., 2020). Particularly, farmers and agricultural workers especially in developing countries face chronic negative health effects from chronic exposure to pesticides (Antle & Pingali, 1994; Ncube *et al*., 2011), and chronic exposure can increase the risk of developmental and reproductive disorders, immune system disruption, endocrine disruption, impaired nervous system function and development of certain cancers (WHO, 1990; Ncube *et al*., 2011). Other harmful (health) effects of human pesticide exposure include alopecia, pulmonary edema, and bronchopneumonia and muscle spasm (Azman & Abdullah, 2011; Mohanty *et al*., 2013). Furthermore, in LMIC, the occupational human exposure to pesticides has been associated with gastrointestinal, musculoskeletal, respiratory, allergic, and nervous system negative health effects (Manyilizu *et al*.,2017; Muñoz-Quezada *et al*., 2017; Hutter *et al*., 2018; Negatu *et al*., 2018; Buralli *et al*., 2020), and common mental disorders (CMD) such as depression, anxiety, and suicide (Poletto & Gontijo, 2012; Faria *et al.*, 2014; Campos *et al*., 2016; Buralli *et al*., 2020). Self-inflicted poisonings are also a serious public health problem in many parts of the world, with ingestion of pesticides being one of the most common methods of suicide deaths and suicide attempts (Mehrpour *et al*., 2018; Cevik *et al*., 2020; WHO, 2020), because pesticides are easily accessible to people both in urban and rural settings. It is stated that the most problematic poisoning circumstance is suicide (Lekei *et al*., 2014). And, pesticide intake in sufficient amounts can lead to acute poisonings and be so severe; it can cause coma and death (Sumi *et al*., 2008; Marlene *et al*., 2017); this is most often seen in connection with suicides or by occupational exposure (Jørs *et al*., 2006; Marlene *et al*., 2017) although it might happen by accidents among consumers as well (Sumi *et al*., 2008; Marlene *et al*., 2017). On the other hand, it is stated that most of the adverse effects in consumers are caused by long-term intake of pesticides and pesticide residues in food (Oates *et al*., 2014 Marlene *et al*., 2017).

Pesticide residues studies in different matrices, for instance in Jamaica, have detected high levels of pesticide residues particularly residues of organochlorine insecticides such as endosulfan, dichlorodiphenyltrichloroethane (DDT), aldrin, endrin and di-eldrin (Mansingh & Wilson, 1995; Robinson & Mansingh, 1999; Witter *et al*, 1999; Ncube *et al*., 2011). Organochlorine pesticides (organochlorine pesticide residues) affect the nervous system causing convulsions, tremors, seizures and fatalities (Reigart & Roberts, 1999; Ncube *et al*., 2011). Other pesticides such as chlordane and DDT are associated with cancer (Zahn & Blair, 1992; Ncube *et al*., 2011), and alachor, altrazine and diazinon are associated with low semen quality (Swan *et al*., 2003; Yucra *et al*., 2006; Ncube *et al*., 2011). According to a UN report, the potential cost of pesticide-related illness in sub-Saharan Africa between 2005 and 2020 could reach $90bn (£56bn) (The Guardian, 2012; Alice *et al*., 2019).

Dietary pesticide and pesticide residues exposure assessment combines food consumption data with data on the concentration of chemicals (pesticides and pesticide residues) in food, and the resulting dietary pesticide and pesticide residues exposure estimate may then be compared with the relevant health-based guidance value for the food pesticide and pesticide residues (chemical) of concern, if available, as part of the risk characterization (Szpyrka *et al*., 2015). Assessments (evaluations) and analyses of pesticides and pesticide residues in food commodities (agricultural food commodities) may be undertaken for acute or chronic human pesticide exposures, where acute exposure covers a period of up to 24 h (hours) and long-term exposure covers average daily exposure over the entire lifetime (FAO/WHO, 2009; Szpyrka *et al*., 2015).

Studies in developing countries of farmer's knowledge and practices have reported low to moderate levels of knowledge about pesticides (Ibitayo, 2006; Nalwanga & Ssempebwa, 2011), non-usage of personal protective equipment (PPE) (Sivayoganathan *et al*., 1995; Ajayi & Akinnifesi, 2007), unsafe pesticide storage at homes (Ngowi, 2002; Ajayi & Akinnifesi, 2007), poor disposal of empty pesticide containers (Ibitayo, 2006), misuse of pesticides and relatively low knowledge about pesticide safety labels (Ajayi & Akinnifesi, 2007; Lekei *et al*., 2014). A study on farmers' safety practices in Ethiopia reported non-usage or use of worn-out PPE (Mekonnen & Agonafir, 2002).

These inadequate and poor pesticide use knowledge and practices of pesticide users particularly of farmers (pesticide handlers (pesticide end-users)) lead to occupational acute pesticide poisoning (APP) health problems of humans due to direct and immediate contact and exposure to pesticides (insecticides) (short-term insecticide exposure poisoning), chronic health problems to humans (the public at large) because of long-term (prolonged) exposure to pesticides, and raises questions and concerns in food safety (quality of food) issues due to pesticide residue accumulation and contamination in/on agricultural food commodities including onion, development of resistance in the insect pest, reduce the number of useful insects including natural enemies, outbreak of secondary pests, and environmental pollution (Abbas *et al*., 2014; Bakhtawer & Afsheen,2021). Particularly organochlorine insecticides, which have been used for agriculture and public health purposes since 1950, are very stable compounds and, therefore, extremely persistent in the environment because of their resistance to natural breakdown processes though the uses of some of them have since been severely restricted or banned altogether because of their recognized toxicity to non-target species, including humans (Greenpeace, 2015).

Poor farmers' education, inadequate training and awareness about/on pesticide use (pesticides and pesticide use) and disposal (disposal of pesticide wastes), insufficient information on hazards, and inadequate regulation (inadequate regulatory framework) and regulatory enforcement, particularly in developing countries, are major factors responsible for poor management, handling and application of pesticides, which could thus bring about (result in) increased acute (short-term) pesticide exposure poisoning (short-term (acute) pesticide exposure and poisoning) (APP)) human health hazards and risks (problems) (human health outcomes) due to direct and immediate pesticide contact and exposure (exposures) (because of acute (short-term) pesticides and pesticide use exposures), and chronic (long-term) human health problems (human health outcomes) because of chronic (long-term or prolonged) human exposure (exposures) to pesticides, the entry and accumulation of pesticide residues (pesticides) on/in agricultural food commodities (produce) including onion, and contamination (pollution) of the agricultural food commodities (produce) by these pesticide residues (pesticides), and pesticide environmental contamination (pollution) (Sharafi *et al*., 2018; Alice *et al*., 2019). Recena and Caldas (2008) have also opined that low educational levels of farmers contribute to higher exposure (exposures) to pesticides.

Pesticide wastes have been defined as any kind of useless material containing pesticide, such as surplus spray solutions, pesticide solution leftover in the spray equipment, pesticide-contaminated water and materials produced after cleaning up spray equipment (rinsate), empty pesticide containers, old pesticide products (old pesticide stocks), and obsolete pesticides (obsolete pesticide stockpiles) (Nesheim and Whitney, 1989; Shimelis, 2014). Disposal of pesticide wastes (liquid or solid) into nearby water bodies, burning or dumping of empty pesticide containers around the farm (Ntow *et al*., 2006; Oluwole and Cheke, 2009; Jones, 2014) are common poor practices reported among farmers in the developing countries (Alice *et al*., 2019). Worse still, some farmers re-use the empty pesticide containers for storing food and drinking water (Coppola *et al*., 2007; Mengistie *et al*., 2016; Huici *et al*., 2017). After they have been used and emptied, if not rinsed properly, pesticide containers are considered hazardous due to residual pesticides retained in them (Elfvendahl *et al.*, 2004; Buczynska & Szadkowska-Stanczyk, 2005; Ntow *et al*., 2006; Huici *et al*., 2017; Alice *et al*., 2019), and can cause damage to human health and the environment (Alice *et al*., 2019).

According to Pesticide Registration and Control Proclamation of Ethiopia (Proclamation No. 674/2010) “obsolete pesticide” means a pesticide: the use of which has been banned or severely restricted for environmental or human health reasons by applicable provisions of the Basel Convention (1989), Rotterdam Convention (1998) or the Stockholm Convention (2001); that has deteriorated as a result of improper or prolonged storage and can neither be used in accordance with its label specifications nor easily reformulated for use; or that cannot be used for its intended purpose,

According to Food and Agriculture Organization of the United Nations (FAO) (1999), obsolete pesticides have been defined as those pesticides (stocked pesticides) that can no longer be used for their original (intended) purpose or any other purpose and therefore require disposal (must be disposed of). Such pesticides can no longer be used because their use has been banned, because they have deteriorated, or because they are not suitable for the use purpose originally intended and cannot be used for another purpose, nor can they easily be modified to become usable, i.e., these include, among others, banned, outdated, and deteriorated pesticides.

These days, there is a growing global perspective and concern including in international trade on the adverse effects of unsafe use of pesticides, which is particularly exacervated by inappropriate use of hazardous pesticides, to the environment, human health, and food safety on/in agricultural food commodities in general and vegetables including onion in particular, partly due to vegetables' most morphological features exposure to pesticides during pesticide application, and vegetables are usually consumed raw in most parts of the world especially in developing nations (regions). Many governments around the world have been enacting and enforcing national pesticide use legislations and attempt regulating use of pesticides in their countries, and international and international intergovernmental organisations (the international communities) such as Food and Agriculture Organization of the United Nations (FAO) and United Nations Environmental Programme (UNEP) have been formulating international chemical pesticide conventions including the Basel Convention (1989), the Rotterdam Convention (1998) and the Stockholm Convention (2001) to provide information and facilitate information exchange among nations (among parties) across the globe, and support regulating movement and transactions of pesticides in international trade. And, international intergovernmental organisations such as Codex Alimentarius Commission (Codex) (Codex is an intergovernmental food standards-setting body established by FAO and World Health Organisation (WHO) in 1963), regional and national organisations have been establishing maximum residue limts/levels (MRLs) of pesticides in agricultural food commodities (food) though it is hardly emphasized in Ethiopia. Particularly Codex has been establishing Codex maximum residue limits (Codex MRLs) and serves as an important international reference point in developing food associated standards (food standards) (Codex, 2009, 2011; FAO, 2009).

Studies on pesticide use knowledge and practices, and analysis (analytical determination) of levels of pesticide residue (residues) concentrations and contaminations (pollution) in agricultural food commodities including vegetables is very limited (rare) in Ethiopia. Thus, pesticide residue (residues) contamination status of vegetables including onion generally (at all) is unknown. This calls for an extensive and expanded study (analysis (analyses)) of the status of pesticide residues in agricultural food products. In Kewet district, the study area, although onion growing farmers excessively, extensively, indiscriminately and irrationally use chemical pesticides (synthetic chemical insecticides) against onion thrips on onion, there had been no previous studies done on chemical pesticide (synthetic chemical insecticide) use knowledge and practices of onion producing farmers in controlling onion thrips on onion, and analysis (analytical determination) of levels of pesticide residues concentrations and contaminations (pollution) in onion. Hence, the present study hypothesized that onion growing farmers in the study area use chemical pesticides (synthetic chemical insecticides) inappropriately with inadequate knowledge and awarenwess, risky safety behaviours and practices without preventive and protective measures (without safety measures (without safety precautions and without safety practices)) of pesticide usage (application) (unsafe use of pesticides) which could pose problems to the environment and human health (the health of humans and the health of the environment) (which could pose health problems to the environment and humans (which could pose health problems to humans and the environment)), and (the) extensive use and application of these pesticides including the historical use of some of the persistent organochlorine pesticides (particularly persistent organochlorine insecticides) on onion could have an outcome (could have outcomes) in contamination (pollution) of onion by the residues of the (these) pesticides. Therefore, with this main theme in mind, the present study was initiated with the following objectives.

1.3 Study Objectives

1.3.1 General Objective

The main objective of the present study was to assess and evaluate levels of synthetic chemical pesticide (synthetic chemical insecticide) use knowledge and practices of small-scale onion producing farmers in controlling onion thrips on onion, and analysis (analytical determination and evaluation) of the concentration and contamination (pollution) levels of organochlorine and organophophate pesticide residues in onion in Kewet district, central Ethiopia.

1.3.2 Specific Objectives

- To assess and evaluate synthetic chemical pesticide (synthetic chemical insecticide) use knowledge and practices of onion cultivating farmers in controlling onion thrips on onion including their chemical pesticide purchase ways and storage conditions, farmers' knowledge and awareness of appropriate and safe use (correct and safe use, handling and application) of pesticides and pesticide use safety measures (safety precautions and safety practices of pesticide use) like use of personal protective equipment (PPE) during pesticide use and application, their knowledge and understanding of adverse effects of inappropriate and unsafe pesticide use to the environment and human health, and onion farmers' disposal ways of empty pesticide containers in the study area.
- To analyze (to analytically determine and evaluate) the concentration and contamination (pollution) levels of thirteen organochlorine and two organophosphate pesticide residues in onion in Kewet district.
- Comparison of the concentration levels of pesticide residues analyzed in onion in the present study with maximum residue limits (maximum residue levels) (MRLs) of onion established by internationally recognised (international) MRLs setting bodies such as Codex (FAO/WHO).

1.4 Significant of the Study

Findings of the present study could have the following significances (outcomes):

- The results obtained from the present research can be used as background information (background source of information) in education and as a reference for research on similar subjects (themes).

- It can be used as pre-information for policy makers to urgently develop, formulate and implement sound, appropriate and comprehensive (holistic) national pesticide and pesticide use and associated occupational health and environmental health and safety (occupational health and environmental preservation) policies, policy recommendations and strategies, and for regulatory body to review and amend (make inclusive) the existing national pesticide legislations of Ethiopia to enhance and advance healthy and sustainable agricultural production.
- The findings of the present study can be used by the Ministry of Agriculture (MOA) and other collaborating bodies, development partners and stakeholders in the country to elevate particularly the agrarian communities' knowledge and awareness on the appropriate and safe use (on proper and safe use, handling and application) of pesticides through urgently and continuously developing pesticide use interventions strategies and intervention measures including promptly and regularly designing and implementing formal educational training programs (formal education and training programs) and enhanced information dissemination services such as advanced agricultural extension delivery system that aimed at preventing, reducing (minimizing and limiting) and eliminating environmental health and human health hazards and risks caused by and associated with pesticide use in Ethiopia encompassing the study area and taking the present research as a case study.
- It can be used as baseline information for developing and establishing (setting) maximum residue limits (MRLs) (MRL standards) of pesticide residues (pesticides) in onion in Ethiopia inspiring further work (research) on the subject to protect consumers (the public at large (the society)) from acute and chronic health problems caused by and associated with consumption of pesticide residue (pesticide) contaminated agricultural produce.
- It can also contribute for the economic development of the country awaring and warning the negative impact of pesticides and pesticide residues in export agricultural produce and hence on foreign export earnings.
- It may provide insights on the trend of pesticide use and its impacts on public health and the environment.

2 LITERATURE REVIEW

2.1 Onion

2.1.1 General Biological (Botanical) Description and Importance of Onion

Onion (*Allium cepa* L.) is one of the most important vegetable bulb crops belonging to the family Amaryllidaceae (Alliaceae) which is widely grown and produced throughout the world. The crop is highly cross-pollinated, and intensity of cross-pollination varies between 30 and 90% depending on availability of pollinators. Usually, the pollen sheds before the female part is receptive (proto-andry) and this makes self-pollination difficult. Onion is monocotyledonous, having diploid chromosomes number 2n (2n=16), herbaceous biennial crop (and also perennial depending on cultivars) cultivated as annual (WHO, 1999; Rabinowitch and Currah, 2002; Lemma and Shimeles, 2003**;** Brewster, 2008**;** Tadele and Amin, 2014). The plant has shallow adventitious fibrous roots, bulb, and tubular leaves. The leaves are long, hollow with widening, overlapping bases. The tubular leaf blades are flattened on the upper surface and the stem is a flattened disc at the base of the plant and occurs below the soil surface. At the center of the stem is the shoot apex from which all new leaves and roots are produced. Each leaf is made up of a blade and a sheath. It is the leaf sheaths that appear to be the stem of the plant above the soil level but is in fact a false or pseudo stem. As the leaf sheath develops, it surrounds the growing point and forms a tube enclosing the youngest developing leaves and near the base of young leaves where new roots form (Ranjitkar, 2003; Bosekeng, 2012). The green leaves of the plant are an extension of the outer food storage leaves.The inflorescence is umbel-like and develops from a ring-like apical meristem. The umbel is the aggregation of flowers at various stages of development, and it contains 200– 600 small individual flowers, although this number can range from 50 to 1000. It is composed of white or greenish-white small flowers which grow at the tip of the stem in the second year of the plant (Ross, 2001). In Ethipia, under Melkassa conditions and depending on cultivars, for instance, the number of flower stalks produced by a single onion dry bulb varied from 3-12 flower stalks and it produces about 250 to 1000 flowers per umbel (Lemma and Shimeles, 2003).

Roots arise from the bottom of the growing bulb. Leaf initiation stops when the plant begins to bulb. The base of each leaf becomes one of the “scales” of the onion bulb, so the final bulb size depends in part on the number of leaves present at bulb initiation. The leaf base begins to function as a storage organ at bulb initiation, so the size of the leafy part of the plant also influences bulb size. Thus, the more leaves present and the larger the size of the plant at the onset of bulb initiation, the larger will be the bulbs and the greater will be the crop yield (Hamasaki *et al*., 1999).

Onion is a biennial crop. It is grown as annuals for bulb, but it takes two seasons for seed production. It produces dry bulb the first growing season and flower stalk the second season. The bulb is a fleshy structure serves as storage organ, which contains simple and compound sugars, protein, sulfur and nitrogen containing flavor precursors and a considerable volume of water in the swollen cells that make up the bulk of the bulb scales produced (Voss, 1979). During bulb development process, leaf bases get enlarged some leaves thicken and become storage organ, later lateral buds or multiple centers which varies from one to several lateral buds per plant are developed (Currah and Proctor, 1990). Physical protection is given by the dry outer papery scales, which form s closely fitting coat around the bulb. Onions are highly favored for their pungency. Pungency in onions is due to the presence of a number of sulfur-containing organic compounds in their juice, which releases the volatile flavor components when the onion tissues are damaged. The enzyme aliinase, which is present in the vacuole of the cells, then hydrolyses the alkyl or alkenyl cysteine sulphoxides, which are held in the cytoplasm (Lancaster and Collin, 1981; Lemma and Shimeles, 2003).

Onion can be grown in a wide range of climatic environments, but it thrives best at mild climate without excessive rainfall or extremes of heat and cold. The optimum altitude range for onion production is between 700 and 2200 m.a.s.l. Onion is a cool season crop that has some frost tolerance but is best adapted to an optimum growing temperature lying between 15 and 23^0C. Optimum temperatures for early seedling growth are between 23 and 27^0C; growth is delayed at temperatures above 30^0C. On the other hand, acclimatized plants are able to tolerate some freezing temperature. Best production is obtained when cool temperature prevails over an extended period, permitting considerable foliage and root development before bulb formation starts. After bulb formation begins, high temperature and low relative humidity extending into the harvest and curing period are desirable. Onion prefers well-drained sandy loam soil with high content of organic matter (Jilani *et al*., 2010; MOA, 2018).

Onion is recognized as one of the most important vegetable crops in the world including Ethiopia. It is grown mainly for its distinct flavour which is due to the presence of sulfur-containing compounds (thiosulfinates) from precursors of flavour compounds (alkenyl cysteine sulfoxides) (Brewster, 2008). It has wide benefits in humans' daily food requirements. Onion is primarily used as food flavouring agent. Also it is used as cuisines and value addition for different dishes and as a source of food (Brewster, 2008; Habtamu, 2017). The mature bulb contains some starch, appreciable quantities of sugars, some protein, and vitamins A, B, and C (Elhag and Osman, 2013). Onion is one of the richest sources of flavonoid in the human diet and consumption of flavonoid has been associated with a reduced risk of cancer, heart disease and diabetes, and also, organosulphur compounds, anthocyanins and fructo-oligosaccharides found in the onion are considered as medicinal and health benefits to fight these and other diseases (Goldman, 2011; Sara *et al*., 2015; Habtamu, 2017). Moreover, onion is potentially considered as a medicinal plant, and it is known for its anti-bacterial, antiviral, anti-allergic and anti-inflammatory potential and used as preservative (Saha, 2013; Sara *et al*., 2015).

Onion is important for its distinct pungency or mild flavor and form of essential ingredients of many dishes. Onion bulb is rich in phosphorus, calcium and carbohydrates. The mature bulbs contain some starch, appreciable quantities of sugar, some protein, vitamins A, B, C and supplying minor constituents such as minerals and trace elements (Elhag and Osman, 2013). It is pungent due to sulphuric compounds and it is an appetizer, stimulant and source of energy (Haidar *et al*., 2014). Onion is characterized by the remarkable sulfur-containing compound (alkenyl cysteine sulphoxides), which give them their distinctive smell and pungency. This substance has been extensively used as precursor of the flavor compounds in food processing industries and used as a medicine to prevent heart disease, cancer, diabetes, anti-bacterial, antiviral, anti-allergenic, anti-inflammatory and other ailments in humans

(Saha, 2013). Onion bulbs are boiled and used in soups and stews, fried or eaten raw (Geremew *et al*., 2010). In parts of West Africa, leaves still green at bulb harvest are pounded and then used to make sundried and fermented balls, which are used later for seasoning dishes. In France, immature flower heads are also popular food item (Holland *et al*., 1991). Consumption of onion has been increasing significantly in the world partly because of the health benefits it gives (Wang *et al*., 2006). It is consumed universally in small quantities and used in many home almost daily, primarily as a seasoning for flavoring of dishes, sauces, soup, and sandwiches in many countries of the world. The World Health Organization (WHO) also supports the use of onions for treating poor appetite and to prevent atherosclerosis. Onion is one of the most important vegetable crops in Ethiopia which is used almost daily as a spice and vegetable in the local dish regardless of religion, ethnicity and culture (CSSE, 2006).

2.1.2 Onion Production in Ethiopia

2.1.2.1 Acclimatization

Temperature is considered to be as one of the most important environmental factors that affects onion dry bulb and seed production in Ethiopia like in many countries of the world. The crop requires cool condition during early development and warm conditions during bulbing, bulb maturity, harvesting and curing stages. Onion bulbs have specific temperature requirements for seed and bulb production. In Ethiopia, onion can grow between 500- 2400 meter above sea level, but the best growing altitude so far known is between 700 - 1800 m (Lemma et *al,* 1994). It is grown under wide range of climatic conditions but it succeeds best in mild seasons without great extremes of heat or cold or excessive rainfall. Optimum temperatures of 18^{o}C - 24^{o}C day and 10 - 12^{o}C night are ideal for bulb production. High temperature favors bulbing and accelerates maturities (Robinson, 1971) resulting in small bulbs, split, double with consequence of low yield and quality. At lower temperature, there will be a delay in bulbing and maturity at least by 2-3 weeks and yield will be low. However, low temperature is required for flower stalk development, and then warm and dry conditions for seed maturity and harvest. It is important to emphasize on optimum climatic conditions favorable for high yield and quality of dry bulb and seed production. Onion can grow in all types of soils; however, highest yield will be obtained from freely drained friable loam soil with P^H of 6-6.8 (Lemma and Shimeles, 2003).

2.1.2.2 Production Trends and Challenges

Onion is a new and rapidly expanding crop in the agriculture community of Ethiopia, and it is produced in many parts of the country by small farmers, private growers, and state enterprises mainly in the Awash Valley and Lake Region where the bulk of dry bulbs and seed are produced. The research centers located in different agroecologies in the country also demonstrated diverse production potential belts in the country (Lemma and Shimeles, 2003).

The establishment of Horticultural Development Enterprises in the late 1980s has significantly contributed to the rise in onion production in the country. The initial supply of basic seed of recommended cultivar *Adama Red* from Melkassa Agricultural Research Center (MARC) by the selection of onion materials imported from Sudan in the 1980s to the newly established Horticultural Development Enterprises was the starting point for extensive production of onion in the country, and onion production was nationally become an important development component since then. Since the local markets were familiar only with the traditional shallot, in the first 3-4 years consumers were reluctant to accept the new crop variety (bulbs of onion) even free of charge because of considering it non-edible crop to human being. Nowadays, it is significantly an important crop in the national economy almost replacing shallot in many production belts for its diverse cultural and economic benefits mentioned above. It has become an important crop in many markets and in daily life of the people. It has benefited various small farmers, state enterprise, private enterprises, exporters and various local dealers. There is also a great scope for increasing the production of the crop through strong research support. Today, this crop is produced in different administrative regions in small and large-scale farms. With the realization and advance/advances in expansion of irrigation projects in the country, it is becoming an important cash crop even in areas where bulb crop production was not commonly practiced either in small pockets or large scale commercial farms under rain fed and irrigated conditions. However, the bulk of the production is in the rift valley areas (Lemma and Shimeles, 2003).

CSA (Central Statistical Authority of Ethiopia) (2002) statistical data indicated that the total hectare under onion was about 10,500 hectares with total production of 1.40 million quintals dry bulbs. The overall national onion yield is about 10 tons/hectare (t/ha) compared to the 15t/ha and 13t/ha of world and Africa onion production respectively (FAO, 1995). During the main season of 2013/2014 the total production of onion bulb in Ethiopia was about 219,735.2 tons, but in the year of 2014/2015 the production has increased to about 230,745.2 tons and the average productivity of onion was increased from 9 to 10.1 t/ha (CSA, 2015). In the cropping season of 2017/18, the total area under production reached over 31,673.21 hectares and the production was estimated over 2,938,875.85 quintals (MOA, 2018a). These (some) crop calendars may show that volume of onion production in Ethiopia seems in some increasing trend.

Despite the immense merits of onion to farmers, its production has been constrained by a myriad of biotic and abiotic factors as well as institutional limitations. In a survey report, disease and pests attack, weeds, shortage of quality seed, lack of pesticide, lack of irrigation water and pump for irrigation were indicated as major constraints of onion production (Bewuketu *et al*., 2016). According to the same study, about 77.78 % of onion growing respondents ranked insect attack as the most important production problem followed by disease attack of about 75%. Similarly, a survey in Rift Valley (major onion growing area) confirmed that pests and diseases, coupled with a low level of improved agricultural technology, recurrent droughts, and decreases in soil fertility levels are some of the major contributors to the low and unstable crop yields in Ethiopia (Eshetu *et al*, 2006).

2.2 Onion Thrips

2.2.1 Taxonomy, Origin and Geographical Distribution of Onion Thrips

Onion thrips was first described by the Russian Entomologist Karl Eduard Lindeman in 1888 (Lindeman, 1889). *T. tabaci* belongs to the order Thysanoptera, suborder Terebrantia, family Thripidae, and subfamily Thripinae (Mound &Walker, 1982; Diaz-Montano *et al*.; 2011). Onion thrips is believed to be a native of the Eastern Mediterranean region but has become a major pest of agricultural crops throughout most of the world (Mound and Walker, 1982;

Mound, 1997). Currently, it is found in Europe, North America, South America, Africa, Asia, and Australia, and severe damage to various crops has been reported in these regions including Australasia (Mound, 1997; Boateng *et al*., 2014). Onion thrips is a global pest of onion grown between sea level and 2000m (Lewis, 1973). In Ethiopia, onion thrips is distributed throughout the country being a major insect pest of onion in most onion growing areas (Tadele & Amin, 2014).

2.2.2 Biology and Ecology of Onion Thrips

Adult onion thrips are elongated with body color varying with temperature from yellow to brown (Murai and Toda, 2002). Adult females have fully developed wings but males are extremely rare and wingless (Diane, 2008). The forewings and hind wings are fringed with hairs and colored pale yellow to dark-brown in adult, white to pale yellow in immature stage. The wings are very different from other insects. They have a single longitudinal vein, where there are several hairs connected perpendicular to the vein. Mouthparts are piercing-sucking, antennae are 7-segmented, and eyes are gray (Lewis, 1997; Rueda and Shelton, 2003; Patel *et al*., 2013; Gill *et al.*, 2015). Generally, adult females and males are 1.0–1.3mm and 0.7mm in length respectively (Orloff *et al*., 2008; Harsimran *et al*., 2015). Adults often fly to and land on clothes or exposed skin because of the thrips attraction to white and yellow colors (Rueda and Shelton, 1995). Adult longevity varies from 28–30 days on onion (Patel *et al*., 2013).

Onion thrips can reproduce asexually through parthenogenesis and sexually. The most common parthenogenesis reproductive mode is thelytoky in which females are produced from unfertilized eggs. Onion thrips also reproduce via arrhenotoky, a parthenogenesis in which males are produced from unfertilized eggs; females are produced from fertilized eggs. Onion thrips that reproduce via thelytoky differ genetically from those that reproduce via arrhenotoky (Toda and Murai, 2007; Kobayashi and Hasegawa, 2012).

It was observed that there are biological differences between onion thrips populations that reproduce via arrhenotoky and thelytoky. For instance, when arrhenotokous and thelytokous onion thrips populations developed on either onion or cabbage, the arrhenotokous population performed better on onion than on cabbage, whereas the opposite was true for the thelytokous population (Li *et al*., 2014). Arrhenotokous onion thrips that developed on onion produced more progeny and the population developed significantly faster on onion than on cabbage (Li *et al*., 2014). Another difference observed between arrhenotokous and thelytokous populations of onion thrips was the ability to transmit tomato spotted wilt virus (TSWV), a Tospovirus closely related to IYSV (Chatzivassiliou *et al*., 2002). In Greece, only arrhenotokous onion thrips populations successfully transmitted TSWV (Chatzivassiliou *et al*., 2002). In the United States, Jacobson and Kennedy (2013) demonstrated that thelytokous populations of onion thrips also could transmit TSWV; however, populations varied in their ability to do so ranging from 0 to 45%. Transmission efficiency of IYSV to onion within and among populations of arrhenotokous and thelytokous onion thrips is not known (Harsimran *et al*., 2015).

Onion thrips go through six stages in their developmental life cycle, viz. the egg, first larval stage (first instar), second larval stage (second instar), prepupa, pupa, and adult. The rate at which thrips pass through their developmental cycle is highly dependent upon environmental conditions, including temperature and nutrient quality of their food source (Morse, 2005). Females exhibit a 1-week preoviposition period and can lay eggs up to 3 weeks (Alston and Drost, 2008). Females have a saw-like structure that helps to make an incision in plant tissue for egg laying. About 60 to 200 eggs per female are placed singly just under the epidermis of succulent leaf, flower, stem or bulb tissue with a sharp ovipositor. Eggs are elliptical or kidney-shaped and microscopic in size. On onion, the average length and width of eggs are 0.23mm and 0.08mm respectively (Patel *et al*., 2013). They are whitish or yellow at deposition and change to an orange tint (tinge) as development continues, and eventually reddish eye spots become evident. Incubation period is 4-5 days on onion (Fekrat *et al*., 2009). Hatching occurs in 2-3 days under laboratory conditions while it may take 5-10 days under cooler field conditions as reported in Utah (Alston and Drost, 2008; Pourian *et al*., 2009)

Besides the adults, the first and the second instars are active feeding and damaging stages. The first instar is small, 0.35–0.38mm in length, semitransparent and dull white, changing later to yellowish white. The second instar is larger and yellow, 0.7–0.9mm in length with red eyes. The abdomen is divided into eight distinct segments and has a large posterior segment that is conical in shape. Duration of the first instar varies from 2 to 3 days, and the second instar can range from 3 to 4 days (Pourian *et al*., 2009; Patel *et al*., 2013). Larval development is completed in about 9-10 days. The prepupa and pupa generally range 1.0–1.2mm in length, are relatively inactive and nonfeeding stages. They do not feed and occur primarily in the soil. Pupation normally takes place at the base of the onion's apical meristem or within the soil (Rueda and Shelton, 1995). The average length of the prepupa is 0.9mm and its width is 0.23 mm. The prepupa is whitish-yellow and lasts for 1–3 days. In completely formed pupae, the antennae are folded back over the head and wing pads are well developed. The pupae are yellowish white, changing to yellow before adult emergence. The pupal period varies in different geographical regions and combined prepupal and pupal development is completed in 3–10 days. The entire life cycle (egg to adult) requires about 19 days (Brain, 2006; Diane, 2008; Patel *et al.* 2013). Generations of onion thrips per year may vary across regions of the world including in USA. In New York, there are six to eight generations per season (Hoffmann *et al*., 1996). In Kentucky, development time from egg to adult is estimated to be 20 days with six to eight generations per year (Bessin, 2004). Carter and Sorenson (2013) reported five to eight generations per year in North Carolina.

Previous studies showed that thrips numbers were highest in the hotter parts of the year (February through April), and lowest in the rainy seasons (June through August) (Tsedeke, 1986). Relatively high temperatures and lack of rainfall have been associated with increase in onion thrips population, while high relative humidity and rainfall reduce thrips population (Hamdy, 1994). In addition to their effect on thrips activity, temperature and relative humidity further influence the intrinsic rate of natural increase of the thrips (Murai, 2000). The rate of development of *T. tabaci* is positively affected by increased temperature and decreased by increased relative humidity (Hamdy, 1994). Onion thrips also can reproduce on other cultivated crops and weedy plants (Diaz-Montano *et al*., 2011). Large onion thrips populations are able to develop quickly under dry weather conditions where there are many overlapping generations throughout the year (Brain, 2006). Hot and dry weather can lead to an increase in onion thrips populations and the severity of thrips injury to onion. The reason behind this is likely a combination of factors including a shorter generation time and a reduction in mortality from rainfall. Heavy rains have been shown to wash onion thrips from plants (Harris *et al*., 1935; North and Shelton, 1986). In addition, water stress may impact the nutritional quality of onion plants and also increases the attractiveness of the plants to thrips (Lewis, 1973). However, when the conditions are unfavorable, onion thrips undergoes diapauses either as fully-grown larva or as adult and the number of generations is reduced during this time. Diapausing may occur in the crevices of soil, leaf litter and also over seasoning in the bulbs (Soni and Ellis, 1990).

The adult stage of onion thrips overwinters in the soil in onion fields and in small grain and hay fields (Shelton and North, 1987; Larentzaki *et al*., 2007). Adults are more mobile than immature and pupal stages because they can fly (Rueda and Shelton, 1995). Onion thrips adults emerge from overwintering sites in the spring and may fly to colonize weed hosts and volunteer onion plants before subsequent generations infest onion crops (Larentzaki *et al*., 2007, Hsu *et al*., 2010; Smith *et al*., 2011). Winged adults are weak fliers but can fly from plant to plant or be carried long distances via wind (Carter and Sorenson, 2013).

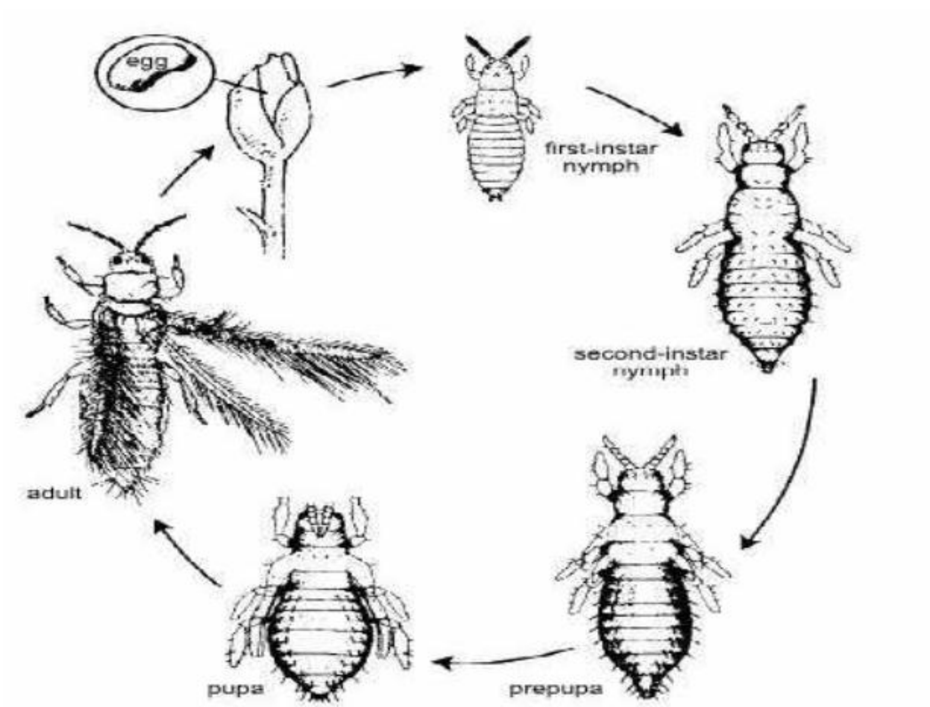

Figure 1. Life cycle of onion thrips (Source: University of California, 2004)

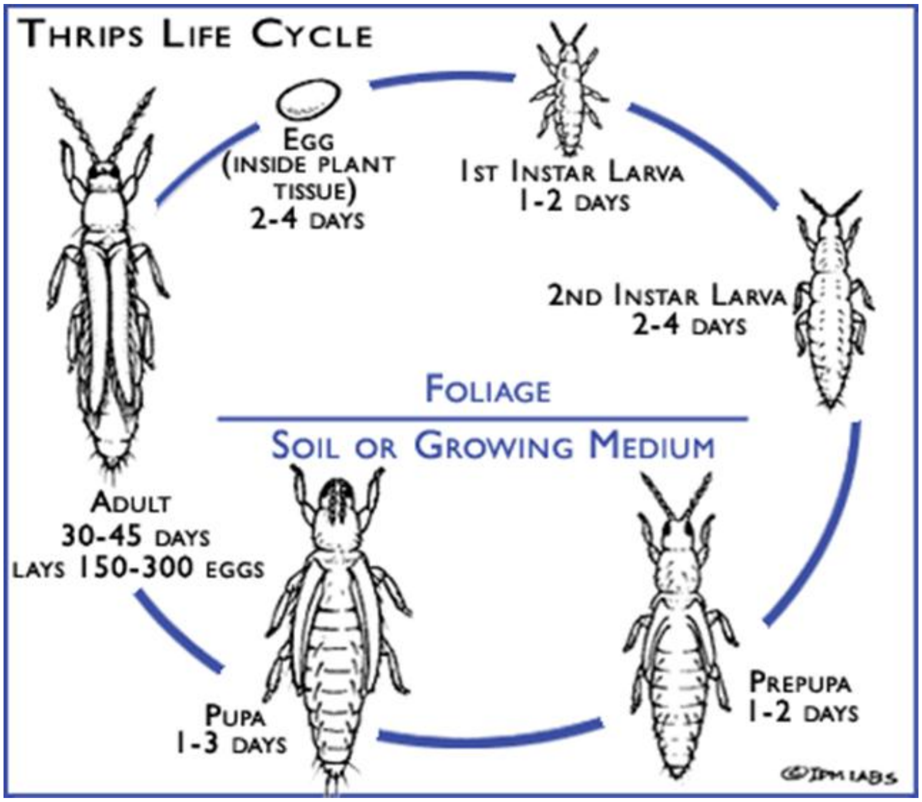

Figure 2. General life cycle of thrips (Source: IPM Laboratories, Inc., 2020 (USA))

2.2.3 Host Range of Onion Thrips

It has been reported that onion thrips have an extremely wide host range compared with other thrips species. *T. tabaci* is considered a pest of significant economic importance on different plant species during dry weather in temperate and subtropical regions (Morison, 1957). Reports of their host range vary from more than 140 plant species in over 40 families to more than 355 species of flowering plants (Morison, 1957; Ananthakrishnan, 1973). Some onion thrips populations exclusively utilize a single plant species like tobacco, while other populations may establish on hosts from multiple plant families (Brunner *et al*., 2004; Nault *et al*., 2014).

In addition to onion, onion thrips may attack such crop plants as alfalfa (*Medicago sativa*), asparagus (*Asparagus officinalis*), bean (*Phaseolus vulgaris*), beet (*Beta vulgaris*), blackberry (*Rubus fruticosus*), cabbage (*Brassica oleracea*), carrot (*Daucus carota*), cauliflower (*Brassica oleracea* L. var. *botrytis* L.), celery (*Apium graveolens*), cotton (*Gossypium* spp.), cucumber (*Cucumis sativus*), garlic (*Allium sativum*), kale (*Brassica alboglabra* L.H. Bailey), leek (*Allium ampeloprasum* var. *porrum*), lettuce (*Lactuca sativa*), parsley (*Petroselinum crispum*), pea (*Pisum sativum*), pineapple (*Ananas comosus*), potato (*Solanum tuberosum*), pumpkin (*Cucurbita maxima*), squash (*Cucurbita* spp.), strawberry (*Fragaria ananassa*), sweet potato (*Ipomoea batatas*), turnip (*Brassica rapa* var. *rapa*), tomato (*Solanum lycopersicum*), and practically all small grains (Pergande, 1895; Parella and Lewis, 1997; Cranshaw 2004; Shelton *et al*., 2008). Notably, the extent and frequency by which onion thrips damage crops varies across plant species. Onion is its preferred host and is one of the crops it damages the most. In contrast, onion thrips attack potato, sweet potato, and mustard, but none are damaged to a level that would routinely cause economic damage (Harsimran *et al*., 2015). Despite its large host range, onion is a favorite host and is one of the few crops attacked by the same species in different parts of the world (Lewis, 1973, 1997b).

2.2.4 Economic Damage of Onion Thrips on Onion

Onion thrips is a polyphagous insect pest and have been recorded on more than 300 species of plants (Straub, 1992). *T. tabaci* is considered to be the most economically important cosmopolitan pest of onion grown between sea level and 2,000 m which causes significant yield losses globally (Lewis, 1973, 1997, 1997b; Trdan *et al*., 2005). The pest status of onion thrips can be attributed to its polyphagous nature, high reproductive rate, short generation time, high survival of cryptic (nonfeeding prepupa and pupa) instars, ability to reproduce without mating (parthenogenesis), ability to transmit plant pathogens, and development of resistance to insecticides (Morse and Hoddle, 2006; Diaz-Montano *et al*., 2011).

Onion thrips possess unique asymmetrical mouthparts made up of a single mandibular stylet and paired maxillary stylets. They use this single mandible to pierce through the cell membrane upon which they retract the mandible and insert their maxillary stylets (Chisholm and Lewis 1984). Pre-digestion substances are released into the plant which help break down leaf tissue (Boateng *et al*., 2014). Onion thrips use a tube formed by the maxillary stylets to draw up and consume mesophyll cells by cibarial pumping (Chisholm and Lewis 1984). This unique feeding style is often referred to as "punch and suck" (Lewis 1991). Thrips damage can be characterized by silvery leaf spots that turn into white blotches along the leaves, a result of the loss of chlorophyll from feeding (Bailey, 1938). Thrips feeding stresses onion plants through the destruction of the leaf tissue ultimately reducing the photosynthetic ability of the plant (Molenaar, 1984; Parrella and Lewis, 1997). In severe cases damage by onion thrips has caused yield reductions of up to 60% in bulb weight (Kendall and Capinera 1987; Fournier *et al*., 1995; Rueda *et al*., 2007; Waiganjo *et al*., 2008; Diaz-Montano *et al*., 2010). The feeding damage on leaves caused by onion thrips can also create an entry point for plant pathogens (Orloff *et al*., 2008; Ari, 2017).

Onion thrips have very distinctive feeding behaviors by punching through the leaf surface and then extracting sap from plant cells. During this process, thrips release substances that help predigest the tissue. After this, they siphon off the plant contents and consume mesophyll cells, which eventually results in a loss of chlorophyll and reduced photosynthetic efficiency (Boateng *et al*., 2014). Damage appears as silvery patches or streaks on the leaves (Rueda and Shelton, 1995). Severe feeding injury by onion thrips is also associated with tiny black "tar" spots, which is excrement from thrips (Cranshaw, 2004).

Generally, onion is most sensitive to onion thrips feeding injury when plants are young and when bulbs are rapidly enlarging. Water loss from damaged leaf surfaces may cause stress and reduce plant growth and may accelerate leaf senescence, both of which may shorten the period bulbs enlarge. *T. tabaci* still causes significant yield loss despite decades of research on control strategies worldwide (Lewis 1997b). Onion thrips feeding can reduce onion bulb weight (Kendall and Capinera 1987; Fournier *et al*., 1995; Rueda *et al*., 2007; Diaz-Montano *et al*., 2010) and cause up to 60% yield loss (Waiganjo *et al*., 2008). Young onion plants are more susceptible and prone to be killed by high *T. tabaci* infestations (Lewis 1973), and are relatively insensitive to onion thrips feeding late in the season; however, the damage increases with water stress (Parrella and Lewis, 1997). Besides damage to the onion crop, *T. tabaci* adults and larvae can also feed on flower pedicels and buds and reduce seed yield in onions grown for seed production (Elmore, 1949). In USA, a 30–50% reduction in bulb yield (small bulb sizes) can occur due to severe thrips damage (Nault and Shelton, 2008). In

Kenya, thrips are present in all onion growing areas and can cause up to 59% loss in yield (Waiganjo, 2008). Thrips also may feed on onion bulbs following harvest and during storage, and this can cause scars that reduce the aesthetic appearance and quality of bulbs (Mayer *et al*., 1987).

In Ethiopia, onion thrips is an important insect pest of onion that affects onion yield by direct feeding as well as reducing the quality and quantity by rasping the leaves and other tissues of onion crops to release the nutrients (Tsedeke, 1985). Onion fields can be destroyed by onion thrips, especially in dry seasons and are the major problem on onion crops in Ethiopia. Tsedeke (1983) and Yeshitla (2015) reported 26-57% onion bulb yield losses due to onion thrips in Ethiopia. Similar studies at Upper Awash Agro Industry Enterprises revealed yield losses of 10 to 85% due to onion thrips in the country (Ferdu and Tsedeke, 2006).

Extensive feeding by onion thrips not only results in plant stunting and reduced bulb weight, but it also predisposes onion plants to various fungal, bacterial and viral pathogens that further decrease yield. Onion thrips transmits Iris yellow spot virus (IYSV), which further exacerbates the damage it causes and can ultimately result in complete crop failure (Harsimran *et al*., 2015). Thrips are the only vectors of tospoviruses and onion thrips is the principal and the only confirmed vector of the tospovirus IYSV (Bunyaviridae: *Tospovirus* spp.; IYSV) in onion; hence onion thrips is not only damaging insect pest of onion by direct feeding of it but also becoming an economically important indirect pest of the crop (as a vector) (Kritzman *et al*., 2001; Ari, 2017).

IYSV is the most common virus that affects onion. It was originally identified in Brazil but has spread to other major onion producing areas of the world (Hall *et al*., 1993; Pozzer *et al*., 1994; Gent *et al*., 2006; Ari, 2017). In USA, IYSV was first detected in Idaho in 1989, and by 2000 it was confirmed in most onion-producing areas in the United States and Canada. IYSV is not transmitted via onion seeds (Gent *et al*., 2004), nor is it successfully transmitted mechanically (Gent *et al*., 2006). First larval instars can acquire the virus from an infected plant and the acquisition rate decreases as the larva matures. Once acquired, tospoviruses can be propagated in the vector's body and transmitted in a persistent and circulative manner

(Ullman *et al*., 1992; Wijkamp *et al*., 1993). Viruliferous (virus carrying) adult thrips are capable of transmitting IYSV for life (Harsimran *et al*., 2015). Symptoms of IYSV appear as lesions along the edges of leaves which reduce bulb size and cause yield loss (Pozzer *et al*., 1999; Gent *et al*., 2004, 2006). IYSV causes straw- to tan-colored lesions on onion leaves and spindle- to diamond-shaped lesions on the scapes (leafless flower stalks). In severe cases, IYSV may cause leaves to become necrotic and plants to mature prematurely. In such situations, yield losses in individual fields can range from insignificant to 60% and even up to 100% (Mohan and Wilson, 1989; Pozzer *et al*., 1999). Onion thrips is also known to transmit tomato spotted wilt virus (TSWV), and tomato yellow fruit ring virus (TYFRV) (Wijkamp *et al*., 1996; Golnaraghi *et al*., 2007)

Onion thrips may also serve as a vector of *Alternaria porri*, the fungus that causes purple blotch. *A. porri* typically enters onion leaves through stomata and the epidermal cell layer, but fungal penetration becomes easier when the leaf surface has been damaged by onion thrips. Therefore, measures against onion thrips should also be considered while planning control of *A. porri* (Thind and Jhooty, 1982). Recently, onion thrips was shown to transmit a bacterial pathogen, *Pantoea ananatis*, to onion. It is reported that *P. ananatis* causes center rot in onion and has caused substantial economic losses in the United States (Dutta *et al*., 2014; Harsimran *et al*., 2015).

2.2.5 Monitoring

Early detection of a pest problem is a key element for designing integrated pest management strategies. It is suggested that in many cases, infestation of onion thrips begins along field edges rather than other parts of the field (Nault and Shelton, 2012). To make management decisions for onion thrips, field inspection including in situ examination of the onion plant is required. It is recommended that onion growers shouldmonitor their fields regularly to determine the density of onion thrips and time insecticide applications accordingly. Onion thrips adults and larvae can be visually observed (identified) and counted more easily by opening the neck of the onion plants (Shelton *et al*., 1987). The younger leaves are a preferred feeding site for onion thrips, and hence, they should be the focus area of examination. Inspection should primarily be concentrated on the youngest leaves in the lowest center part of the neck, which is a more preferred feeding site for onion thrips (Rueda and Shelton, 1995). Older leaves that have been folded over may also be a preferred feeding site for the pest (Paibomesai *et al*., 2013).

It is important that scouting onion fields for onion thrips and sampling of onion thrips should start at an early phenological stage, particularly at the 4-5-leaf stage in the season, and plants are checked weekly throughout the growing season, especially if weather conditions are ideal for onion thrips development as onion thrips population at this time may increase rapidly (Rueda and Shelton, 1995). Others, less commonly used methods of monitoring for onion thrips include plant dissection and plant beating (Mautino *et al*., 2012). Plant dissection consists of collecting plants from the field and dissecting and examining them leaf by leaf to detect onion thrips. Plant beating consists of beating plants into a plastic tray and counting the onion thrips in the tray. While plant dissection and plant beating are less accurate methods of onion thrips sampling compared to visual sampling they still can be used in practice to adjust the number of onion thrips per plant recorded (Mautino *et al*., 2012; Ari, 2017).

Recommended number of sampling sites within an onion field varies in accordance with field size. For large onion fields (>2 ha), 10 sampling sites with five plants per site (total of 50 plants per field) has been recommended (Rueda and Shelton, 1995). Additionally, thrips infestations tend to be higher near the field borders early to mid-season, and then they eventually disperse within the field. Early in the season, control measures can target crop borders, which may slow spread of the pest to the entire field and save money because the entire field is not treated (Shelton *et al*., 1987).

In laboratory-based methods, onion thrips activity can be monitored using sticky cards (Kuepper 2004; Trdan *et al*., 2005). Sticky cards are collected from the field after a certain period and then examined under a microscope to assess the presence and species of onion thrips. Onion thrips densities on onion plants can be determined by removing plants from the field and taking them to the laboratory where plants can be immersed in ethanol or soapy water for a few minutes followed by filtering the contents through a fine mesh sieve. Onion thrips on the mesh are visualized using a hand lens or a microscope and then counted. Alternatively, the onion leaves can be cut into pieces and then placed in a funnel connected with a collection vial. A cotton wick containing a few drops of turpentine can be placed on the top of plant material. Turpentine will repel the thrips into the collection vial, where they can be counted. These methods are more accurate for determining the number of immatures in a sample because adults may have flown away during collection (Mo, 2006; Harsimran *et al*., 2015).

2.2.6 Action Threshold Level

An action threshold for onion thrips is defined as the average thrips number per plant that will cause economic yield loss if the infestation is not controlled (Nault and Shelton, 2010; Harsimran *et al*., 2015). Under favorable conditions, onion thrips populations can rapidly increase due to their short developmental time and high fecundity making them difficult to control (Diaz-Montano *et al*., 2011; Ari, 2017). Economic action thresholds are necessary to indicate when control measures need to be implemented (Fournier *et al*., 1995). The determination of economic action thresholds depends on factors such as weather conditions and insecticide efficacy (Pedigo *et al*., 1986; Nault and Shelton, 2010); therefore, no uniform economic threshold exists for onion thrips on onion (Fournier *et al*., 1995). In most cases economic injury thresholds are region specific, such as 30 thrips per plant in California (Kuepper, 2004), 1 thrips per leaf in Texas (Edelson *et al*., 1989) or 5 thrips per 50 plants in Auckland, New Zealand (Jamieson *et al*., 2012). Action thresholds may also vary with season or weather conditions. For example, Canada has a 0.9 onion thrips per leaf threshold during early and severe drought conditions and a 2.2 onion thrips per leaf threshold under no or slight water deficit (Fournier *et al*., 1995).

Knowledge of action thresholds for onion thrips can help onion growers optimize insecticide applications and other management tactics. It is important to consider geographic and environmental factors when determining an appropriate economic action threshold for onion thrips. If proper monitoring is implemented and the correct thresholds are followed, onion thrips control can be optimized allowing onion growers to make fewer applications, save time and money, and potentially mitigate insecticide resistance development (Gill *et al*., 2015; Harsimran *et al*., 2015). Coviello (1993) noted that reliable treatment threshold levels for onions are speculative. Action thresholds for onion thrips may vary depending on geographic region, cultivar, plant stage, plant architecture, and insecticide efficacy. It is reported, for example, in California that an action threshold of 30 onion thrips per plant during mid-season has been effective for dry bulb, fresh-market onion (Kuepper, 2004). This threshold value is adjusted based on plant age in that fewer onion thrips are tolerated on young plants and more onion thrips are tolerated on mature plants (Kuepper, 2004). It is recommended that action threshold is higher for tolerant varieties as compared with susceptible ones. For instance, an action threshold level of 30 or more onion thrips per plant is suggested for the onion thrips-tolerant varieties, whereas a lower level of 15–30 onion thrips per plant is suggested for susceptible cultivars (Cranshaw, 2004). Plant architecture may also impact action thresholds; for example, cultivars with flat sided leaves and compact growth habits harbor more thrips as compared with cultivars with openly spaced leaves (Harsimran *et al*., 2015).

Action threshold for onion thrips on onion also vary with insecticide efficacy. More recently, in New York, USA, specific action thresholds were determined for different insecticides' efficacies, and it was reported that action thresholds for onion thrips on onion vary from one to three onion thrips larvae per leaf depending on insecticide efficacy (Nault and Shelton, 2010). For example, spinetoram (Radiant SC) can effectively manage onion thrips at a threshold level of three thrips larvae per leaf. In contrast spirotetramat (Movento), methomyl (Lannate LV), and abamectin (Agri-Mek SC) are effective at one thrips larva per leaf and need to be applied at this action threshold level to manage infestations (Nault and Shelton 2010, 2012). In Ethiopia it was recommended application of insecticide when threshold of 5 onion thrips per onion plant is exceeded (Tsedeke and Gashawbeza, 1994). Thus, it is important to consider all influential factors before selecting an action threshold to use in making onion thrips control decisions (Harsimran *et al*., 2015).

2.2.7 Management Options of Onion Thrips on Onion

2.2.7.1 Cultural Control Practices

Proper soil and water management for onions that keep onion plants healthy and non-stressed will increase the crops immunity to onion thrips feeding injury. Cultural practices ought to be the first line of defense against onion thrips (Alston and Drost, 2008). Adult onion thrips may overwinter in crops like alfalfa and small grains, and their proximity to onion could increase their likelihood to disperse into onion fields. Similarly, onion thrips populations can build up rapidly on other hosts like carnations, crucifers, cucurbits, roses, and strawberries. Hence, onions grown near other hosts for onion thrips will be more vulnerable to attack (Carter and Sorenson, 2013). Plant health through removal of volunteer onion plants and weeds around the cultivated fields and crop rotation would be useful in minimizing onion thrips populations in an onion field. Field sanitation by removing or destroying debris and volunteer onion plants after harvesting eliminates potential overwintering sites. If left on the soil surface, onion plant matter can harbor onion thrips that might successfully overwinter and infest the crop the following year. Inspection of onion transplants for presence of onion thrips and discarding the infested ones may also be useful (Larentzaki *et al*., 2007; Waiganjo, 2008).

Gachu *et al*. (2012) reported that intercropping onion with spider plant and carrot reduced onion thrips population by up to 45.2% and 21.6%, respectively. In Egypt, intercropping of onions and garlic with tomato reduced the onion thrips infestation by 80% (Afifi and Haydar, 1990). In England, mixed plantings or intercropping of carrots and onions effectively decreased onion thrips populations by 50% (Uvah and Coaker, 1984), and in this case, both crops can be harvested because onion thrips injury to carrots is not economically damaging. It has been shown that other crops such as carrot, crucifers, cucurbits, and some flowers including carnation and chrysanthemum are highly attractive to onion thrips, and can be planted in strips or patches to attract onion thrips. It has been suggested that this approach might only work if the trap crops are large and more attractive than the onion plants. When onion thrips populations reach a certain threshold level, then the trap crop could be sprayed with an insecticide or disked under (Alston and Drost, 2008; Harsimran *et al*., 2015). Additionally, modification of planting date of onion and trap crops, and different cultivars of onions could help reduce onion thrips populations (Harsimran *et al*., 2015).

Transplanting and selecting early-maturing cultivars of onion, or both have also been suggested to expedite the period between planting and harvest, thereby truncating the period that onion thrips are able to infest the crop (Kisha, 1977; Harsimran *et al*., 2015). In New York, USA, transplanted onion fields are often colonized by onion thrips before direct-seeded onion fields (Hsu *et al*., 2010).

It has been indicated that lack of adequate soil calcium invites higher population of onion thrips (Mishra *et al*., 2014). In another study, reductions in nitrogen levels in plants have reduced populations of insects (Mattson, 1980), and this has been shown to be true for onion thrips in onion (Harsimran *et al*., 2015). In Utah, USA, adult onion thrips populations in a reduced nitrogen treatment (one-third the standard rate) were 23 to 31% lower than in a standard nitrogen rate treatment (402 kgN/ha) (Buckland *et al*., 2013). In the same study, onions grown following corn rather than wheat in a 1-year rotation reduced the onion thrips population because corn removed more nitrogen from the soil than wheat and the lower levels of nitrogen were shown to reduce onion thrips densities (Buckland *et al*., 2013).

In a study in Pakistan, different rates of nitrogen (50 to 250 kg/ha) were applied to onion to evaluate the effect it had on onion thrips populations. Application of the lowest (50 kg N/ha) and optimum level (150 kg N/ha) had no effect on onion thrips abundance. However, onion thrips abundance increased 74% in the highest nitrogen level treatments (200 and 250 kg/ha) and onion thrips damage led to reductions in onion yield (Malik *et al*., 2009). Excessive application of nitrogen fertilizer on onions has been shown to increase the number of onion thrips (Alston and Drost, 2008).

Overhead irrigation and heavy rainfall have been suggested to reduce onion thrips populations on onion plants (Harris *et al*., 1935; Passlow, 1957). The physical action of water washing onion thrips off the plants and water droplets standing on leaf surfaces are inhibitory to onion thrips. In addition, sprinklers used for water application may promote a crust on the soil surface, which reduces the access of pre-pupae and pupae to seek shelter in the soil.

Cranshaw (1994) reported that besides their effects on plants, frequent irrigation by flooding of the onion field at the soil surface reduced the density of onion thrips on the crops as pre pupae and pupa were killed in the soil. It has also shown that drought stress increases the susceptibility of onions to onion thrips damage. Adequate irrigation throughout the growing season is a critical factor in minimizing damage (Fournier, 1995).

Mulches have many benefits including weed suppression, conserving soil moisture, increasing soil temperature, and reducing soil erosion. In some studies, it is reported that straw mulch has been used to reduce onion thrips infestations in onion (Larentzaki *et al*., 2008; Schwartz *et al*., 2009). Field experiments in Colorado also showed that straw mulch application to the center of onion beds at early to mid-bulb growth reduced onion thrips densities to 33% compared with nontreated plots of transplanted onions. Another field studies in New York produced similar results, showing that colonization of adult onion thrips was delayed one to two weeks and fewer onion thrips larvae developed in straw covered plots of onions compared with those with no mulch (Larentzaki *et al*., 2008; Harsimran *et al*., 2015). The fact that thrips are color-sensitive suggests that colored mulches may be effective in their control. Louisiana, USA, researchers conducted a study to see whether aluminum-coated mulch would repel the pest (Quarles, 1990). The reflective mulch repelled 33 to 68% of the onion thrips. Lu (1990) in China reported that silver color mulch significantly reduced onion thrips density in the field.

In Ethiopia, Dejene (2006) assessed the effect of mulching on thrips infestation and found that mulching onion plots with a white plastic sheet significantly suppressed thrips population and consequently improved fruit yield compared to mulching with a black plastic sheet, 'tef' straw and sawdust.

2.2.7.2 Biological Control

There are certain beneficial organisms prey to harm onion thrips including ladybird beetles, minute pirate bugs, ground beetles, lacewings, hover flies, predatory mites, and spiders (Hoffmann, 1996). Predators of onion thrips are usually not in abundance until late summer when the majority of thrips feeding injury has already occurred. Some of the predators of onion thrips include *Aelothrips* spp., green lacewing (*Chrysoperla* spp.) larvae, minute pirate bug (*Orius* spp.), coccinellids (*Coleomegilla maculata*), and big-eyed bug (*Geocoris* spp.) (Fok *et al*., 2014). In India, the major natural enemies of onion thrips in onion and garlic were parasitoids (>80%) rather than predators (16%). The parasitoid population was solely composed of *Ceranisus menes* (Eulophidae: Hymenoptera) (Jayanthi Mala and Nighot, 2013). Another study in India showed that *C. menes* parasitized onion thrips, but the range of parasitism varied from 2 to 18% during the season (Saxena, 1981).

It was reported that different species of entomopathogenic nematodes (*Steinernema carpocapsae*, *S. feltiae*, *Heterorhabditis bacteriophora*) were evaluated for control of onion thrips in a laboratory study and one with onion and green bean plants grown in a controlled environment. While onion thrips prepupal and pupal mortality was high (>90%) in the high nematode concentration treatments in the laboratory, there was no effect of nematodes on onion thrips mortality on plants grown in the controlled environment (Kashkouli *et al*., 2014).

Entomopathogenic fungi (*Beauveria bassiana*) in India were shown to be successful in reducing onion thrips populations and increasing onion yield (Singh *et al*., 2011; Ganga and Krishnamoorthy, 2012). In China, the SZ-26 strain of *B. bassiana* significantly lowered the population of larval and adult stages of onion thrips under greenhouse conditions (Wu *et al*., 2013). A study in western Kenya documented that the entomogenous fungus, *Metarhizium anisopliae*, has the potential to control onion thrips in onion (Maniania *et al*., 2003). In Jordan, integration of entomopathogenic fungi and sublethal doses of neem tree extracts (botanicals) effectively controlled onion thrips (Almazra *et al*., 2009). Combinations of entomopathogenic fungus *Paecilomyces lilacinus* with nonconventional agents such as *Azadirachta indica* and diatomaceous earth formulations may be effective for controlling onion thrips (Wakil *et al*., 2012).

In Ethiopia, a study concluded that entomopathogenic fungi (*B. bassiana*) and some botanicals (*Nicotiana* spp., *Phytolacca dodecandra*, *Securidaca longepedunculata*, *Nicotiana tabacum*) applied at recommended rates were significantly effective against onion thrips in the onion field. Entomophathogenic fungi, *Beauveria* and *Metarhizium* caused 46.18 and

26.09% mortality of onion thrips, respectively at the 3rd day of application. *Beauveria bassiana* was most effective when used early at economic threshold level, before large thrips populations have built up (Tadele *et al*., 2013). Another study conducted with entomopathogenic fungi, *Metarhizium anisopliae*, *Beauveria bassiana*, and *Paecilomyces fumosoroseus* in the greenhouse in 2004 revealed that the three entomopathogens significantly reduced onion thrips population and percentage of leaf area damaged compared to the untreated check (Mendesil *et al*., 2006).

2.2.7.3 Use of Botanicals

Uses of botanical insecticides is ideal for organic farming, safe for both the environment and human health and is affordable where the materials are locally available (Ibrahim *et al*., 2015). Botanicals may offer protection against onion thrips, especially when combined with other management tactics. Efficacy of some botanical products have been shown to tend to be lower than efficacy of synthetic products (Nault and Hessney, 2010, 2011), so their use may be more practical in situations where onion thrips infestations are low to moderate. Khaliq *et al*. (2014) evaluated the effectiveness of three botanical insecticides (neem, datura and bitter apple) against onion thrips and gave more than 60% control of onion thrips. Klein *et al*. (1993) also found that neem (*Azadirachata indica*) seed extract retarded the growth of onion thrips and used to control the pest. On the other hand, even the botanical insecticides disappointed the users when neem products were reported toxic to beneficial insects, like lady beetles (Julie and Strak, 1998). Gami *et al*. (1994) obtained 96% onion thrips mortality by *Humicola* sp. In a field experiment in India, efficacy of neem seed powder extract, neem soap, essential oils from basil or tulsi (*Ocimum tenuiflorum* syn. *O. sanctum*), and scented Geranium (*Pelargonium graveolens*) was compared with the efficacy of commonly used synthetic insecticides such as dimethoate, acephate, and fipronil for onion thrips control. The lowest mean onion thrips population and the highest marketable yield were achieved by applying fipronil, while neem-based formulations were less effective relative to untreated control (Krishna *et al*., 2013; Pandey *et al*., 2013). Hazara (1999) used a neem extract against onion thrips successfully.

In Ethiopia, it was reported that ethanol extracts of neem seeds and pepper tree (*Schinus molle*), and leaves of bersema (*Bersema abyssinica*) were evaluated during the 1995-1996 seasons at Melkassa for their efficacy against onion thrips. Results indicated that all of the treatments gave significantly lower insect population than the untreated check. It was suggested that the botanicals are more effective when applied at low onion thrips population levels than at the threshold established using synthetic insecticides (Gashawbeza, 2005). A report of a similar study conducted at the Debre Berhan Agricultural Research Center (DBARC) in 2003 and 2004 indicated that extracts of neem leaf, garlic, ginger, mixtures of ginger, garlic, and chilli as well as ginger, garlic, chilli and cow urine mixtures controlled onion thrips infestation and gave better yields than the synthetic pyrethroid, λ-cyhalothrin (karate) and the untreated check (DBARC, 2005). According to Gashawbeza (2005), ethanol extracts of neem seed powder evaluated against onion thrips, reduced thrips (onion thrips) population under field condition. Ibrahim *et al*., (2015) evaluated botanical extracts obtained from neem (*Azadirachta indica*), Mexican marigold (*Tagetus minuta*), tree tobacco (*Nicotian glauca*) and jimson weed (*Datura stramonium*) for their managing effect on onion thrips and tree tobacco had the best performance.

2.2.7.4 Host Plant Resistance

There are no onion cultivars that are highly resistant to onion thrips, but some onion cultivars can tolerate feeding damage by onion thrips. These cultivars require fewer insecticide applications, which not only lower the control costs, but they might delay the development of insecticide resistance and may enhance biological control by protecting biocontrol agents (Panda and Khush, 1995; Diaz-Montano *et al*., 2011). Onion cultivars with yellow-green, glossy to semi-glossy leaf surfaces and an open neck were less attractive to onion thrips compared with cultivars with blue-green, waxy leaves, and tight necks (Diaz-Montano *et al*., 2012b). Onion cultivars with glossy (shiny and smooth) and semi-glossy leaves have lower levels of epicuticular waxes, especially the wax ketone hentriacontanone-16, compared with standard nonglossy cultivars (Damon *et al*., 2014). Thus, it is indicated that glossy to semi-glossy onion cultivars with low levels of epicuticular waxes should be integrated into onion thrips management strategies (Harsimran, *et al*., 2015).

2.2.7.5 Chemical Control

Insecticides are the most common practices for onion thrips management on onion in the world including Ethiopia. Owing to the irruptive outbreaks of onion thrips in onion fields, insecticides have been the primary mode to manage this pest (Morse and Hoddle, 2006; Nault and Shelton, 2010). Insecticides vary in their toxicity to different life stages of thrips. Larvae are often more likely to be killed by insecticides compared with other stages. Adults can fly quickly when disturbed and also have a thicker cuticle (external covering) than larvae, which makes them more difficult to kill. Prepupae and pupae seek protection in the soil or at the base of onion plants, escaping contact by most insecticides (Harsimran, *et al*., 2015). Onion thrips is difficult to manage because the mobile stages of this insect are found mainly in the narrow spaces between the inner leaves where spray coverage is difficult to accomplish (Mau and Kessing, 1991).

Despite their availability and ease of use, insecticide resistance has been a historical problem (Gill and Garg, 2014). Development of resistance by onion thrips to most commonly used insecticides has been observed in different areas and reported by many authors. The inability to control onion thrips infestations in onion using organophosphate such as azinphosmethyl, diazinon, and methyl parathion, and synthetic pyrethroid including cypermethrin, and permethrin insecticides has been observed across the United States (Cranshaw, 1989; Davis *et al*., 1995; Shelton *et al*., 2003, 2006). In Ontario, Canada, insecticide resistance in onion thrips populations from onion fields was reported for k-cyhalothrin, deltamethrin, and diazinon (MacIntyre-Allen *et a*l., 2005b). In Auckland (New Zealand), onion thrips tested resistant to diazinon, deltamethrin, and dichlorvos (Martin *et al*., 2003). In Australia, onion thrips from onion fields were resistant to a-cypermethrin (164-fold), k-cyhalothrin (606-fold), diazinon (27-fold), dimethoate (5.2-fold), although no resistance was reported to omethoate, malathion, and methidathion (Herron *et al*., 2008). Nazemi *et al*., (2015) concluded that most of *Thrips tabaci* populations in onion fields developed resistance to the conventional organophosphate and pyrethroid insecticides. Due to the polyphagous nature of onion thrips species and their need to detoxify allelochemicals, metabolic detoxification plays an important role in insecticide resistance development (Bielza *et al*., 2007; Gao *et al*., 2012).

In Ethiopia, earlier studies conducted in the 1980s at Melkassa showed that cypermethrin was effective against onion thrips (Tsedeke, 1983). Three to four sprays of cypermethrin when the threshold of 5 thrips/plant is exceeded was recommended (Tsedeke and Gashawbeza, 1994). However, it was reported that the efficacy of cypermethrin to control onion thrips was declining. The efficacy of cyhalothrin and phenom were evaluated together with cypermethrin and some botanicals in 1995 and 1996 at Melkassa, and it was found that cyhalothrin was better than all of the other treatments both in reducing onion thrips infestation and onion yield losses (Gashawbeza, 2005). However, a decline in the efficacy of cyhalothrin against onion thrips is being observed in many onion fields. DBARC (2005) reported that the performance of cyhalothrin was lower than that of the insecticide selecron and botanical treatments in an experiment carried out in 2003 and 2004 (DBARC, 2005). Nimbecidine 0.03% was reported to be as effective as the insecticides currently in use in 2003 and 2004 trials at Melkassa (MARC, 2004).

2.3 Adverse Effects of Pesticide Use in Agriculture

FAO (2002) defined a pesticide as any substance or mixture of substances intended for preventing, destroying or controlling any pest, including vectors of human or animal disease, unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or substances which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies. The term includes substances intended for use as a plant growth regulator, defoliant, desiccant or agent for thinning fruit or preventing the premature fall of fruit, and substances applied to crops either before or after harvest to protect the commodity from deterioration during storage and transport.

2.3.1 Categories of Pesticides

Pesticides are agrochemicals widely used in agriculture to control and protect crop plants from several pests including insect pests, plant diseases and weeds and increase productivity and improve quality of products since these pests bring about substantial quantitative and qualitative yield losses in crops. Globally, the use of synthetic pesticides has increased rapidly in the last fifty years due to intensification of farming in order to obtain higher yields to feed the ever increasing human population of the world. However, apart from their pest control use, residues of pesticides applied could remain in the crop and in the environment, and can contaminate agricultural food commodities including fruits and vegetables and can pollute the environment such as water and soil. Pesticides can broadly be classified according to the *intended target pests they control* and also by their *chemical structure and properties*. Based on intended target pests they control, pesticides can be categorized as insecticides which kill insects, fungicides which control fungi, herbicides that kill weeds, acaricides which control mites, rodenticides which kill rodents, fumigants that control particularly storage pests and avicides which kill avians. According to their chemical structure and properties, pesticides can also be classified as organochlorine pesticides (OCPs), organophosphate (organophosphorus) pesticides (OPs), carbamates (CMs), synthetic pyrethroids and neonicotinoids (Cantox Health Sciences International, 2004; Wangila & Mavura, 2004; Ashenafi, 2009; Seblework *et al*., 2017; Tamane, 2018). Particularly insecticides play a vital role in controlling insect pests of agricultural crops. However, compared to other pesticides, insecticides are the most acutely toxic to target and non-target species including humans. All of the insecticides used today are neuron-toxicants which are acted by poisoning the nervous system of the target organisms (Daba, 2011). Target sites of toxicity for insecticides to insects are also found in mammals including humans. Because of this, insecticides are not species selective towards toxicity. Neurotoxicity is an adverse health effect on the central or peripheral nervous system caused by chemical, biological or physical agents (Mekonnen & Agonafir, 2002; Lucio *et al*., 2008).

The contamination of food items by hazardous substances such as residues of persistent pesticides especially by residues of persistent organochlorine insecticides is a worldwide public health concern. Some pesticides are hazardous and toxic to human health; exposure to residues of such toxic substances can pose danger to humans and may cause certain diseases (Lucio *et al*., 2008; Seblework *et al*., 2017). Most pesticides are generally toxic to non-target species including humans. Pesticides affect human health in a number of ways. Some have mild irritant effects in the skin, others affect liver or lung functions and some are carcinogenic. Several pesticides, particularly insecticides, are neurotoxic to insects and humans as well (Lucio *et al*., 2008). Exposure to pesticides can occur in a number of ways; residues in food, mixing and loading of pesticides and application of the pesticides, harvesting of pesticide sprayed crops are common ways of exposure to pesticides that could lead to higher risk. Mostly the high exposure by these means occurs in developing countries (Seblework *et al*., 2017; Tamene, 2018).

2.3.1.1 Organochlorine Pesticides

Organochlorine pesticides (OCPs) are chlorinated hydrocarbons used for agriculture and public health purposes predominantly as insecticides since 1950, though the uses of some have since then been severely restricted or banned altogether because of their high environmental persistence and recognized toxicity to non-target species, including humans (Greenpeace, 2015). These pesticides are typically very persistent in the environment, and are known for accumulating in sediments, plants and animals. Most of them break down slowly and can remain in the environment long after application and in organisms long after exposure. Although the acute toxicity of organochlorine insecticides is somehow moderate (some way less than that of organophosphate insecticides), but chronic exposure causes adverse health effects mainly in the liver (Willet *et al*., 1998; Lucio, 2008; Somayyeh & Mohammad, 2010; Crentsil *et al*., 2012; Francisco *et al*., 2012; Greenpeace, 2015). In humans these substances and their metabolites alter the electrophysiological properties and enzymatic neuronal membranes, causing alterations in the kinetics of the flow of Na^+ and K^+ through the membrane of the nerve cell, resulting in the spread of multiple action potentials for each stimulus, causing symptoms such as seizures and acute poisoning death from respiratory arrest (Somayyeh & Mohammad, 2010; Francisco *et al*., 2012). These organic compounds have high lipid solubility (lipophilicity), low polarity, low aqueous solubility, chemically stable and persistent in the environment with enduring half-lives (Somayyeh & Mohammad, 2010; Daba, 2011).

Especially some organochlorine pesticides particularly organochlorine insecticides are very stable compounds and, therefore, extremely persistent in the environment because of their resistance to natural breakdown processes. For this reason several of the chemicals listed as

Persistent Organic Pollutants (POPs) under the 2001 Stockholm Convention are OCPs. There are twelve POPs known as the dirty dozen that have been selected under Stockholm Convention in 2001. Eight of them are pesticides, including Aldrin, Chlordane, DDT, Dieldrin, Endrin, Heptachlor, Hexachlorobenzene (HCB) and Toxaphene; the other chemicals include Polychlorinated biphenyls (PCBs), Mirex as well as certain byproducts such as Polychlorinated dibenzo-*p*-dioxins and Polychlorinated dibenzo-*p*-furans (Stockholm Convention, 2001; Siti, 2007; Ashenafi, 2009). POPs are characterized by their long lifetimes (persistence) in the water, soil, sediments or air, and the Stockholm Convention establishes that a contaminant is persistent if its half-life in water is greater than two months, or that its half-life in soil is greater than six months, or that its half-life in sediment is greater than six months, or its half-life in air is greater than two days (Stockholm Convention, 2001). Half-life is the time it takes for a pesticide to be reduced its amount by half which may be through break down or dissipation. It is also known that especially organochlorine insecticides are very stable chemicals (chemical compounds) which biodegrade slowly and their metabolites and residues move through the water from the application site to the surrounding area (Rahman *et al*., 1995; Adjrah *et al*., 2013). Although environmental levels of some organochlorines have fallen over time, many can still be found as contaminants in a wide range of ecosystem compartments, including soils, river sediments, coastal marine sediments reaching as far as the deep oceans and the poles (Willet *et al*., 1998; Greenpeace, 2015). Hence, continuous monitoring of OCPs, the majority of them being organochlorine insecticides, residues in food is needed because of their environmental persistent and high tendency to accumulate in living organisms and the food chain (Crentsil *et al*., 2012).

Organochlorine pesticides vary in their chemical structures.The OCPs and their metabolites are mainly classified into three categories: (i) *Diphenyl aliphatics* which includes DDT and its metabolites, *p,p'*-DDT, *p,p'*-DDE, *p,p'*-DDD and methoxychlor. DDT successfully controlled spreading of malaria, a disease still plaguing large parts of the human population in Africa. (ii) *Cyclodienes* are compounds that are collective group of synthetic cyclic hydrocarbons, which includes aldrin, dieldrin, endrin, endrin aldehyde, endrin ketone, heptachlor, heptachlor epoxide, α-endosulfan, ß-endosulfan, and endosulfan sulfate. They are particularly effective where contact action and long persistence is required; for example, endosulfan acts as a contact poison on sucking, chewing and boring insects of field crops. (iii) *Hexachlorocyclohexanes* are manufactured chemicals which exist in several structural isomers such as α-HCH, ß-HCH, γ-HCH, and δ-HCH. Only one of these forms, γ-HCH (commonly called lindane) has insecticidal activity and used as an insecticide on fruits, vegetables, in forestry and animal husbandry. Lindane is also used as active ingredient in lotion, cream, or shampoo to treat head and body lice, and scabies (Nur Banu & Semra, 2004; Ahmed, 2007; Ashenafi, 2009).

Organochlorine pesticides involve (comprise of) organic molecules that contain several halogenated atoms. They are chemically stable and do not degrade in environmental conditions. OCPs are fat soluble. Organochlorine (OC) contaminants generally have chemical characteristics such as nonpolarity, lipophilicity, and low volatility due to their multi-chlorinated structure (Leo, 2000).

2.3.1.2. Organophosphate Pesticides

The pesticidal particularly insecticidal properties of certain organophosphate compounds were discovered during military nerve gas research and, since World War II, a number of organophosphate insecticides have been commercialized for agricultural use, and they are the most commonly used insecticides in agriculture. They include a diverse range of chemical structures. They have high acute toxicity, and their mode of toxicity makes them effective as insecticides as the chemicals inhibit a critical enzyme (acetylcholinesterase) in the central and peripheral nervous system, a property which also accounts for some of their observed toxicity to non-target species including humans (De Silva, 2006; Greenpeace, 2015).

The target site of organophosphate insecticides for toxicity is acetylcholinesterase enzyme (AChE), whose role is hydrolyzing acetylcholine (ACh), a neurotransmitter in the central and peripheral nervous system. The organophosphate insecticides bind with the cholinesterase enzyme (ChE) at the neuromuscular junction and deactivate or inhibit the activity of the enzyme (AChE/ChE) by irreversible phosphorylation. Inhibition of AChE by organophosphate insecticides causes accumulation of acetylcholine at cholinergic synapses, with overstimulation of cholinergic receptors of the muscarinic and nicotinic type (Kaushik

& Chandrabhan, 2003; Lucio *et al*., 2008). As these receptors are localized in most organs of the body, a cholinergic syndrome ensures, which includes increased sweating and salivation, profound bronchial secretion, bronchoconstriction, miosis (miosis is contraction of pupil of eye), increased gastrointestinal motility, diarrhea, tremors, muscular twitching (muscular twitching is hurting of muscles with sharp or sudden pain), and various central nervous system harmful effects. Human acute exposure to high doses of the insecticides (organophosphate insecticides) may result in long-lasting adverse health effects in the central nervous system (CNS) (Lucio *et al*., 2008).

In addition to the acute cholinergic syndrome, organophosphate insecticides may also cause an intermediate syndrome (Kaushik & Chandrabhan, 2003) called organophosphate-induced delayed polyneuropathy (OPIDP) whose signs and symptoms include tingling of the hands and feet, followed by sensory loss, progressive muscle weakness and flaccidity of the distal skeletal muscles of the lower and upper extremities, and then ataxia (ataxia is lack of or inability to control and/or coordinate movements of muscles), which may occur 2-3 weeks after a single exposure (Kaushik & Chandrabhan, 2003; Lucio *et al*., 2008).

Generally, poisoning of organophophate insecticides can be faced both intentionally and unintentionally, resulting in worldwide health problems, and exposure to organophosphate insecticides at low to moderately high doses develop a pesticide-related illness. These mild to moderate symptoms of organophosphate toxicity include nausea, headache, dizziness, blurred vision, abdominal pain, vomiting, and chest tightness, with ChE depression (Kaushik & Chandrabhan, 2003; De Silva, 2006; Tamene, 2018).

It was shown that cholinesterase-inhibitor pesticides, such as organophosphates (OP), and also carbamates (CM) represent an important risk for human health and are considered the main chemical pesticides responsible for pesticide poisoning in low-and-middle-income countries (LMIC) (Muñoz-Quezada *et al*., 2017; UN, 2017?; Buralli *et al*., 2020). Carbamates are another group (class) of chemical pesticides which generally are neurotoxic and are also acetylcholinesterase inhibitors, and some have been associated with adverse (health) effects on human development, affecting both babies and children (Morais *et al*., 2012). Organophosphate/carbamate (OP/CM) pesticides are mainly used as insecticides

(Ramírez-Santana *et al*., 2020), and their mechanism of action is through inhibition of acetylcholinesterase (AChE) in insects, but they also affect the human enzyme in a similar way (Fukuto, 1990; Nigg & Knaak, 2000; Ramírez-Santana *et al*., 2020). Acute exposure to high concentrations of OP/CM produces an accumulation of acetylcholine (ACh) at central and peripheral synapses triggering cholinergic symptomatology (Marrs, 1993; Casida, 2009; Ramírez-Santana *et al*., 2020). Acetylcholinesterase (AChE) and butyrylcholinesterase (BChE) inhibition, respectively, are biomarkers of chronic and acute exposure to OP and CM pesticides) (Buralli *et al*., 2020), and the AChE and BChE biomarkers are useful for an initial screening of pesticide poisoning, although they have low specificity and sensitivity, and they are not effective to assess other chemical classes of pesticides (Bendetti *et al*., 2014; Buralli *et al*., 2020). Cholinesterase enzymes are useful for screening of OP and CM poisoning or continuous monitoring, despite their high variability, and low sensitivity and specificity (Bendetti *et al*., 2014; Buralli *et al*., 2020). Measurements of urinary biomarkers are more suitable exposure assessment (Muñoz-Quezada *et al*., 2016; Buralli *et al*., 2020), though expensive and seldom available in LMIC. Erythrocyte acetylcholinesterase level is an indicative of exposure to cholinesterase inhibiting OP and CM insecticides (Mwabulambo *et al*., 2018). In order to determine acute exposure, biomonitoring strategies in human populations exposed to OP/CM measure erythrocyte AChE, which is equivalent to the enzyme found in cholinergic synapses (Chen *et al*., 1999; Ramírez-Santana *et al*., 2020), and butyrylcholinesterase (BChE), a plasma enzyme synthesized in the liver with similar catalytic properties (Kapka-Skrzypczak *et al*., 2011; Strelitz *et al*., 2014; Ramírez-Santana *et al*., 2020). Acylpeptide hydrolase (APEH), another enzyme that has been identified as a highly sensitive target for some Ops such as dichlorvos, chlorpyrifosmethyl oxon, and diisopropylfluorophosphate (DFP) (Richards *et al*., 2000; Ramírez-Santana *et al*., 2020) has been also studied as a putative biomarker, with some promising results (Quistad *et al*., 2005; Ramírez-Santana *et al*., 2018, 2020). Contrary to acute exposure, symptoms in populations chronically exposed to low levels of OP/CM are more difficult to identify, partly due to the absence of clear cholinergic symptoms, although, for instance, in some studies, study participants could report non-specific symptomatology, including headache, fatigue, insomnia, confusion, and difficulty with concentration (Kamel & Hoppin, 2004; Ramírez-

Santana *et al*., 2020). In adults, neurobehavioral impairment due to relatively low concentrations of OPs has been reported particularly in people exposed for more than ten years (Kamel *et al*., 2003; Roldán-Tapia *et al*., 2005; Ramírez-Santana *et al*., 2020). In general, there is agreement that chronic occupational OP exposure causes neurobehavioral impairment (Ismail *et al*., 2012; Ramírez-Santana *et al*., 2020); however, this condition often remains undetected in part due to (the) lack of predictive or diagnostic capacity of cholinesterase biomarkers (Rohlman *et al*., 2011; Ramírez-Santana *et al*., 2020). For instance, the Chilean surveillance system of outbreaks of acute pesticide intoxications conducted by the Ministry of Health has reported cases of pesticide poisoning during the spring, which overlaps with the spraying season for insect control in agricultural areas (Vallebuona, 2015; Ramírez-Santana *et al*., 2020), and it is stated that pesticide exposure may affect both agricultural workers and individuals from the general population, including children and pregnant women (Muñoz-Quezada *et al*., 2014, 2017; Ramírez-Santana *et al*., 2020). Also, previous studies conducted in Chilean agricultural communities showed that populations are both occupationally and environmentally exposed to high levels of OP and CM, among other types of pesticides, indicating a need for more effective regulation (Muñoz-Quezada *et al*., 2017, 2019; Ramírez-Santana *et al*., 2018, 2020).

The study conducted by Mwabulambo *et al*. (2018) for investigating health symptoms associated with pesticides exposure among flower and onion pesticide applicators in Arusha, Tanzania, reported a significantly high proportion of neurological health symptoms in pesticide applicators in (on) onion farms compared to pesticide applicators in (on) flower farms, with a greater risk of pesticide exposure. This was due to lack of personal protective equipment (PPE) for pesticide applicators in onion farms compared to those of pesticide applicators in flower farms, which poses a greater risk of cholinesterase inhibition and neurological health symptoms to pesticide applicators in onion farms, and a large group of pesticide applicators from onion farms (onion farmers) with high level of exposure to pesticides was found to have higher prevalence of body weakness (91.1%), headache (58.9%), dizziness (53.6%), irritation (46.4%), and feeling cold or hot (23.2%), while pesticide applicators from flower farms (flower farmers) showed lower prevalence of body weakness (34.5%), headache (27.4%), irritation (13.1%), feeling cold or hot (7.1%), and dizziness (7.1%). Generally, (the) majority of pesticide applicators (75%) in their study suffered from one or more forms of pesticide-related health symptoms. The predominance of OPs in their study showed the importance of monitoring cholinesterase activity as the main test of poisoning with pesticides, and the statistically significant depletion (inhibition) in AChE activity among pesticide applicators clearly exhibits their (pesticide applicators') exposure to OP and CM pesticides. They showed that about 39% of onion farmers (pesticide applicators in onion farms) and 19% of flower farmers (pesticide applicators in flower farms) had acetylcholinesterase levels below the normal range, whereas 60.7% from onion farms and 81% from flower farms had cholinesterase level above the limit (normal) level, and the mean cholinesterase level among onion and flower farmers was 27.882 ± 3.829 U/g Hgb and 25.146 ±3.9607 U/g Hgb, respectively, and the mean average of AChE level among pesticide applicators in onion farms was greater by 2.736 U/g Hgb as compared to those of pesticide applicators in flower farms. The mean average value of the AChE levels in flower and onion farm workers was 26.788 ± 4.0952 U/g Hgb (which, they stated, was not a statistically significant difference between the two groups as seen with a paired T test of 1.301 and $p < 0.195$). The relationship between AChE level and irritation was significant in onion farms, for instance, among the pesticide applicators in onion farms who reported irritation, 58.8% had AChE levels within the normal range, while 27.3% had AChE levels below the normal range ($p<0.05$), and among pesticide applicators in flower farms who reported feeling abnormally tired, 83.3% had AChE levels below the normal range and 28.6% were within the normal range. Other neurological health symptoms among the flower farm pesticide applicators with AChE levels below the normal range that occur in high proportion include excessive sweating (45.6%), body weakness (36.8%) and headache (26.5%). However, it was stated in their study that for all reported symptoms, those with AChE levels below the normal range did not differ significantly from those with AChE levels within the normal range, and there was no indication of blood AchE level depression, which explains the relationship between symptoms and AChE, even if the proportion of the participants with depressed numbers was observed to be higher than those who were above the limit. Studies have shown that the blood AChE level must be depressed to less than 20% of its normal value before symptoms of systemic poisoning appear (Jensen *et al*., 2011; Mwabulambo *et al*., 2018).

Another study done in Tanzania on acute health effects of organophosphorus pesticides on Tanzanian small-scale coffee growers showed that the mean AChE level among study subjects was 32.0 U/g Hgb (Ngowi *et al*., 2001), and according to the Brazilian law, all farmers must be periodically subjected to medical exams and cholinesterase tests, albeit this is not provided to millions of smallholder family farmers distributed in 4.4 million properties (Buralli *et al*., 2020).

2.3.2 Environmental Fate of Pesticides after Application

Fate refers to the pattern of distribution of an agent, its derivatives or metabolites in an organism, system, compartment or subpopulation (population) of concern as a result of transport, partitioning, transformation or degradation (OECD, 2003; Keikotlhaile & Spanoghe, 2011). Pesticides are distributed into four major compartments after applied in the field (of/on crops): water, air, soil, and biota (living organisms) (Osman & Cemile, 2010). The amount of fraction of pesticides moved into each compartment depends on the physicochemical properties of the pesticide. Physical processes such as sedimentation, adsorption, and volatilization play a vital role in the distribution of pesticides in the environment (Racke *et al*., 1997; Osman & Cemile, 2010). Following this, they can be degraded by chemical and biological processes. The physicochemical characteristics of the pesticide (water solubility, its absorptivity to the soil, volatility) and soil characteristics (clay, pH, sand and organic matter) determine the fate of pesticides in the environment. The dissipation of pesticides from the application site creates three major problems: economic loss to farmers, inefficient control of pests, and possible environmental contamination (Osman & Cemile, 2010). Generally, solubility, hydrolysis, volatility, photodegradation, microbial degradation, leaching, oxidation/reduction, are all factors that determine the fate of pesticides in the environment (Racke *et al*., 1997; Holger *et al*., 2006; Osman & Cemile, 2010; Zorawar *et al*., 2016; Tamene, 2018).

Particularly fate of organochlorine pesticides in the environment is of major concern because organochlorines are noted for their persistence, bioaccumulation and toxicity characteristics in the environment. Due to their widespread use, these compounds are detected by determination of their residues in various environmental matrices such as water, air, sediments, soil, vegetation and biota. An organochlorine pesticide (OCPs) residue reaches the aquatic environment through direct run-off, leaching, equipment washing and careless disposal of empty pesticide containers (Imo *et al*., 2007). For instance, DDT and its metabolites are persistent in the environment and resistant to complete degradation by microorganism, although photochemical degradation does occur (Ashenafi, 2009).

2.3.3 Pesticide Poisoning, Contamination and Food Safety Issues

Pesticide use has increased at least over the past 20 years, the highest identified in low-income countries starting from a low base such as Cameroon, Ethiopia, and Burkina Faso with an 8- to 50-fold increase (Pretty & Bharucha, 2015; Tambe *et al*., 2019). In middle income countries like China, Argentina, Brazil, and Thailand, pesticide use increased from three- to eightfold, while it has been stable, or even decreasing, in high income countries such as in the USA, Germany, Japan, and Denmark (Pretty & Bharucha, 2015; Tambe *et al*., 2019). Even though there has been a rise in pesticide use in developing countries, very limited information exists about the health and safety of the farmers (Tambe *et al*., 2019).

Chemical pesticides especially synthetic chemical insecticides have been extensively and excessively used for the control and/or management of pests of crops in agriculture in general and on horticultural crops (vegetables, fruits, flowers, spices) in particular in small-scale and large-scale (commercial) farming systems globally (Wilkowska & Biziuk, 2011; Li *et al*., 2014). And, the most common management tactic for onion thrips infestations on onions in the world including Ethiopia is the use of chemical pesticides (synthetic insecticides) (Casida and Quistad, 1998; Tsedeke and Gashawbeza, 1994; Harsimran *et al*., 2015). Pesticides, by their nature, are potentially toxic to humans and many other living organisms other than their target audience; therefore, they must be used safely, and their waste should be disposed of appropriately (Cevik *et al*., 2020), and according to the World Health Organization (WHO) standards (WHO, 1986), only pesticides that are (relatively) safe to farmers and farm-workers should be used (Tambe *et al*., 2019). However, it has been reported in earlier studies that particularly small-scale farmers use chemical pesticides (mostly synthetic insecticides) excessively, indiscriminately and improperly with disregard to recommended safety measures and without recognizing harmful consequences (unsafe use of pesticides) especially in the third world (developing) countries (Wesseling *et al*., 1997; Ecobichon, 2001; Mohanty *et al*., 2013; Abbas *et al*., 2014; Bakhtawer & Afsheen, 2021). Excessive and unsafe use of pesticides represents a serious risk to human health, the environment, and quality of food (food safety) (Buralli *et al*., 2020). Work-related (occupational) pesticide poisoning has increased globally, especially in less-developed countries (Litchfield, 2005; Tambe *et al*., 2019). And, pesticide poisoning is a major public health concern, particularly in developing countries where the most persistent and hazardous pesticides are used by untrained farmers (WHO, 1985; U.S. General Accounting Office, 1989; Ncube *et al*., 2011). Moreover, pesticides that are banned, unregistered or suspended in developed countries due to their toxicity and harmful environmental and human health effects are often exported to developing nations (Weir & Schapiro, 1981; U.S. General Accounting Office, 1989; Ncube *et al*., 2011). Many of these highly toxic pesticides are applied by people with minimum or no training in safe application or storage of pesticides, and without suitable protective gear (WHO, 1985; U.S. General Accounting Office, 1989; Ncube *et al*., 2011). Many developing countries do not have effective monitoring systems in place to assess the extent of pesticide poisonings and the majority of cases are unreported (Ecobichon, 2001; Ncube *et al*., 2011). It is estimated that annually about 25-41 million people globally experience unintentional pesticide poisoning (Jeyaratnam, 1990; PAN International 2007; Alavanja, 2009; Adesuyi *et al*., 2018; Tambe *et al*., 2019; Buralli *et al*., 2020), resulting in an estimated deaths of about 200,000-300,000 annually, mainly (99%) affecting low- and middle- income countries (LMIC) (Jeyaratnam, 1985; WHO, 2009; UN, 2017; Adesuyi *et al*., 2018; Alice *et al*., 2019; Buralli *et al*., 2020). And, the extensive use of pesticides have led to an accumulation of a huge amount of pesticide residues in the environment, thereby causing a substantial environmental health hazard (risk) due to uptake and accumulation of these toxic compounds in the food chain and drinking water (Adesuyi *et al*., 2015; Adesuyi *et al*., 2016; Njoku *et al*., 2017; Adesuyi *et al*., 2018). In LMIC, the occupational human exposure to pesticides has been associated with gastrointestinal, musculoskeletal, respiratory, allergic, and nervous system adverse effects (Manyilizu *et al*.,2017; Muñoz-Quezada *et al*., 2017; Hutter *et al*., 2018; Negatu *et al*., 2018), and common mental disorders (CMD) such as depression, anxiety, and suicide (Poletto & Gontijo, 2012; Faria *et al.*, 2014; Campos *et al.*, 2016).

However, these adverse health effects are not only restricted to LMIC, occupational human exposure to pesticides was also associated with adverse health impacts in high-income countries such as the USA, England, South Korea, and Spain (Muñoz-Quezada *et al*.,2016; Khan *et al*.,2019; Buralli *et al*.**,** 2020). Mental illness is a major public health concern in terms of lost health and burden of disease, and its symptoms are often overlooked by health services (Carmo *et al*., 2018; Buralli *et al*., 2020); for example, depression and anxiety affect, respectively, 5.8% and 9.3% of population of Brazil, and more than 4.4% and 3.6% affected worldwide (WHO, 2017; Buralli *et al*., 2020). According to Fuglie (1998), an estimated of about 20,000 unintentional deaths and 3 million poisonings caused by pesticides misuse occur each year in the third world (developing) countries due to lack of training, lack of money, illiteracy, farmers applying inappropriate pesticides to crops without protective clothing and families consume treated seeds during lean periods. And, it is also estimated that approximately 1-5 million cases of pesticide poisoning occur per year among farmers and agricultural workers, mostly in developing countries (Abdou & Hend, 2018; Taghdisi *et al*., 2019; Cevik *et al*., 2020), and nearly 20,000 deaths occur among these groups of people (farmers and agricultural workers) per year, caused by chemical pesticides (Taghdisi *et al*., 2019); and it is stated that the poisoning caused by pesticides is regarded as the most prevalent hazard particularly to farmers (Zyoud *et al*., 2010; Taghdisi *et al*., 2019). Apparently, there are no groups in the human population that are completely unexposed to pesticides (Meyer-Baron *et al*., 2015). Also, an estimated 99% cases of human pesticide poisoning fatalities occur only in developing countries, although these (developing) countries account only for 20% to 30% of the total global pesticide consumption (from pesticides manufactured and supplied in the world market) (WHO, 1990; Dinham, 1993; Wesseling *et al*., 1996; Ncube *et al*., 2011; Mohanty *et al*., 2013; De Jong *et al*., 2014; Mwabulambo *et al*., 2018; Cevik *et al*., 2020). Africa consumes about 4% of the total pesticides produced in the world (Abdelbagi *et al*., 2006; Mwabulambo *et al*., 2018).

Although a tremendous number of toxic pesticides under the World Health Organisation (WHO) classes Ia (extremely hazardous) and Ib (highly hazardous), and some pesticides belonging to class II (moderately hazardous) and class O (obsolete pesticide) (WHO, 2019) have been restricted for use in several countries, they are still extensively used in middle- and low-income countries (Tambe *et al*., 2019). The use of these restricted pesticides is due to its broad spectrum application, costs, and ease of use (Carvalho, 2006; Tambe *et al*., 2019). The main obstacle to control and prevent work-related (occupational) pesticide poisoning is that the scope and magnitude of this issue often remains uncharacterised, especially in an underserved population such as farmers (London & Bailie, 2001; Tambe *et al*., 2019). Many of the adverse effects of pesticides on the environment depend on the interactions between the physicochemical properties (vapour pressure, stability, solubility, pK_a) of the pesticide, soil adsorption and soil persistence, the soil factors (pH, organic components, inorganic surfaces, soil moisture, soil microflora, soil fauna), the plant species, and the climatic variation (Damalas and Eleftherohorinos, 2011; Adesuyi *et al*., 2018).

Farmers from low-and-middle-income countries (LMIC), mostly located in tropical areas with easy pest proliferation, tend to be more exposed to pesticides and pesticide exposure risks due to lack of safety regulation, surveillance and training, increased use of highly toxic chemicals, low risk awareness, misuse or no use of personal protective equipment (PPE), and careless handling and pulverization (Muñoz-Quezada *et al*., 2017; UN, 2017; Hutter *et al*., 2018; Buralli *et al*., 2020). Still, farmers and agricultural workers in these developing countries (LMIC) are particularly susceptible to the adverse health effects of pesticide exposure because of factors such as insufficient regulations, lack of surveillance systems, lack of training, poor work conditions, poorly maintained or nonexistent personal protective equipment and unsafe storage and application (London & Bailie, 2001; Cevik *et al*., 2020). Pesticide applicators, who are mostly young men and usually work as casual laborers, sometimes with no knowledge or training about the adverse environmental and human health effects of pesticides and are thus ill-equipped to deal with exposures and their effects, face great risks of exposure to toxic pesticides that were banned or restricted due to incorrect application techniques, poorly maintained or totally inappropriate spraying equipment, inadequate storage practices, and often reuse of old pesticide containers for food and water storage (Perry, 2008; Mwabulambo *et al*., 2018). Uses of protective measures during pesticide application depend on availability, affordability, comfortability and regulations, and thus are limited in small-scale farming areas (Mwabulambo *et al*., 2018). In addition, without proper protection, pesticide exposure risk and the occurrence of adverse health effects increase (Mwabulambo *et al*., 2018). Several adverse health effects, such as temporary acute effects like irritation of eyes and excessive salivation may result from exposure to pesticides. Adverse effects on the central nervous system (CNS) like restlessness, loss of memory, convulsions and coma are also common. Negative effects on the parasympathetic and sympathetic nervous system, such as respiratory paralysis, have been widely reported (Mhauka *et al*., 2014; Mwabulambo *et al*., 2018). In a study conducted by Mourad (2005), 62.5% of the participants experienced burning sensations in the eyes or face and 37.5% experienced itching or irritated skin after spraying organophosphate insecticides (Mourad, 2005; Ncube *et al*., 2011). In another study done in Zimbabwe at Kwekwe district on adverse health effects of agrochemicals on farm workers, headache (66.7%), cold/flu (62.2%), weakness (45.9%), dizziness (41.1%) and skin irritation (39.0%) were reported among farm workers in commercial farms (Magauzi *et al*., 2011; Mwabulambo *et al*., 2018).

Particularly farmers, agricultural workers, pesticide applicators and the agrarian communities at large (the public at large (the society)), especially in developing countries, encounter occupational and environmental acute pesticide poisoning (APP), and chronic health problems (adverse health effects) due to (from) short-term (direct and immediate pesticide contact and exposure) (direct and immediate contact and exposure to pesticides) (acute exposure to pesticides), and long-term (prolonged) pesticide exposure (chronic exposure to pesticides) respectively. Occupational acute pesticide poisoning (APP) emerges as a serious public health problem due to unsafe pesticide application (Cevik *et al*., 2020; WHO, 2020), and acute pesticide exposure can lead to death or serious illness (Ncube *et al*., 2011). Chronic exposure can increase the risk of developmental and reproductive disorders, immune system disruption, endocrine disruption, impaired nervous system function and development of certain cancers (WHO, 1990; Ncube *et al*., 2011). There is a high risk of exposure to toxic pesticides through lack of protective gear, leaky spray equipment, from mixing and applying pesticides with bare hands and storage of pesticides near food (WHO, 1985; U.S. General Accounting Office, 1989; WHO, 1990; Ncube *et al*., 2011). Pesticide uses in agriculture activities expose pesticide users (agricultural workers, pesticide applicators and farmers) to risk factors for neurological health symptoms; neurological health symptoms include excessive sweating, body weakness, and headache (Mwabulambo *et al*., 2018). Pesticide users handling (mixing (preparing) and applying) pesticides without using personal protective equipment (PPE) were more likely to develop neurological symptoms compared to those who used PPE, and therefore, the use of PPE is unavoidable and should always be encouraged during application of pesticides (Mwabulambo *et al*., 2018). High-income countries have overcome the acute pesticide poisonings and are more concerned about chronic effects and long-term exposure (Buralli *et al*., 2020), but acute and chronic poisonings still persist and are growing problems for LMIC (Negatu *et al*., 2018; Buralli *et al*., 2020). In the study done by Buralli *et al*. (2020) in Brazil in family farmers, smallholder family farmers were occupationally and environmentally exposed to pesticides from an early age, lived near crops, worked without safety training, technical support and full recommended PPE, and had a considerable number of acute and mental health symptoms, and their findings emphasize the role of protection equipment and technical support in chemical pesticide poisoning prevention (Buralli *et al*., 2020). Cumulative pesticide exposure was operationalized as the number of years working in an agricultural setting requiring pesticide use for occupational exposure (OE), or number of years living within that agricultural setting for environmental exposure (EE) as stated (defined) in the study conducted by Ramírez-Santana *et al*. (2020) in Chile. In developed countries, the annual APP incidence rate in full-time agricultural workers is 18.2 per 100,000 (Thundiyil *et al*., 2008; Cevik *et al*., 2020). A UN report estimated that the potential cost of pesticide-related illness in sub-Saharan Africa alone between 2005 and 2020 could reach $90bn (£56bn) (The Guardian, 2012; Alice *et al*., 2019).

Acute pesticide poisoning (APP) is defined (stated) in somehow different ways: (1) A case of previous acute pesticide poisoning (APP) was defined as any self-reported short-term illness or adverse health effects associated with the farmer in the preceding pesticide exposure (Lekei *et al*., 2014), and this approach has been used in other (similar) studies in developing countries (Sivayoganathan *et al*., 1995; Atkin & Leisinger, 2000; Yassin *et al*., 2002; Lekei *et al*., 2014). (2) According to the WHO (World Health Organisation), an APP must present clear signs of exposure, temporal cause-effect relationship, and at least three symptoms compatible with the exposure (Thundiyil *et al*., 2008; Buralli *et al*., 2020). (3) Based on the WHO standard case definition, an APP case is defined as two or more symptoms that occur within 48 hours of spraying in the past year (Thundiyil *et al*., 2008; Cevik *et al*., 2020), and the symptoms can affect (can be felt in) the respiratory system, the nervous system, the gastrointestinal system, the urinary system, the cardiovascular system, and involve dermal, ocular and general symptoms (Cevik *et al*., 2020). (4) According to the WHO standard case definition (of APP), an APP is defined as any illness or health effect resulting from suspected or confirmed exposure to a pesticide within 48 hours, which is used to facilitate the identification and diagnosis of APP, especially at the field level, in rural clinics and primary health-care systems. This APP case definition is inclusive of all circumstances of poisoning including (APP resulting from) suicide, homicide, non-intentional (unintentional) (accidental exposure) and occupational (intentional) exposures. Health effects may be local (dermal and ocular) and/or systemic. This includes respiratory, neurotoxic, cardiovascular, endocrine, gastrointestinal, nephrotoxic and allergic reactions (Thundiyil *et al*., 2008). The definition of a case can be classified as: probable, possible or unlikely/unknown (Keifer *et al*., 1996; Meulenbelt & de Vries, 1997; Henao & Arbalaez, 2001; Henao & Arbelaez, 2002; Reeves & Schafer, 2003; Thundiyil *et al*., 2008). These categories were chosen to provide simple delineations, ease of initial identification of cases and to provide a meaningful tool for quantifying the magnitude of problems in specific situations (Thundiyil *et al*., 2008). The WHO has developed a practical case identification matrix that standardizes the definition of APP cases and can be used in rural clinics and primary care settings to improve the estimates of APP cases (Thundiyil *et al*., 2008; Cevik *et al*., 2020). In the study by Buralli *et al*. (2020) in Brazil, prevalence of probable common mental disorders (CMD) such as depression, anxiety, and suicide associated with acute (short-term) and chronic (long-term) pesticide exposure poisoning (pesticide exposure and poisoning) (exposure to pesticides) was assessed by the Self-Reporting Questionnaire (SRQ-20), proposed by WHO as a low-cost and easy tool for psychiatric screening, and it is recommended for community studies and basic care.

Studies in developing countries of farmer’s knowledge and practices have reported low to moderate levels of knowledge about pesticides (Ibitayo, 2006; Nalwanga & Ssempebwa, 2011), non-usage of personal protective equipment (PPE) (Sivayoganathan *et al*., 1995; Ajayi & Akinnifesi, 2007), unsafe pesticide storage at homes (Ngowi, 2002; Ajayi & Akinnifesi, 2007), poor disposal of empty pesticide containers (Ibitayo, 2006), misuse of pesticides and relatively low knowledge about pesticide safety labels (Ajayi & Akinnifesi, 2007; Lekei *et al*., 2014). A study on farmers' safety practices in Ethiopia reported nonusage or use of worn-out PPE (Mekonnen & Agonafir, 2002).

Poor farmers' education, inadequate training and awareness about pesticide use and disposal (disposal of pesticide wastes), insufficient information on hazards, and inadequate regulation and regulatory enforcement, particularly in developing countries, are major factors responsible for poor management, handling and application of pesticides which could thus cause increased risk of direct pesticide exposure and poisoning (acute pesticide exposure poisoning) of humans and chronic human health problems, the entry and accumulation of pesticide residues into agricultural food commodities (produce) including onion and contamination of the food commodities (produce) by the pesticide residues, and environmental pollution (contamination) (Sharafi *et al*., 2018; Alice *et al*., 2019). Recena and Caldas (2008) have also opined that low educational levels of farmers contribute to higher exposure to pesticides.

Pesticide wastes have been defined as any kind of useless material containing pesticide, such as surplus spray solutions, pesticide solution leftover in the spray equipment, pesticide-contaminated water and materials produced after cleaning up spray equipment (rinsate), empty pesticide containers, old pesticide products (stocks), and obsolete pesticides (Nesheim and Whitney, 1989; Shimelis, 2014). Disposal of pesticide wastes (liquid or solid) into nearby water bodies, burning or dumping of empty pesticide containers around the farm (Ntow *et al*., 2006; Oluwole and Cheke, 2009; Jones, 2014) are common poor practices reported among farmers in the developing countries (Alice *et al*., 2019). Worse still, some farmers re-use the empty pesticide containers for storing food and drinking water (Coppola *et al*., 2007; Mengistie *et al*., 2016; Huici *et al*., 2017). After they have been used and emptied, if not rinsed properly, pesticide containers are considered hazardous due to residual pesticides retained in them (Elfvendahl *et al.*, 2004; Buczynska & Szadkowska-Stanczyk, 2005; Ntow *et al*., 2006; Huici *et al*., 2017; Alice *et al*., 2019), and can cause damage to human health and the environment (Alice *et al*., 2019).

According to Pesticide Registration and Control Proclamation of Ethiopia (Proclamation No. 674/2010) “obsolete pesticide” means a pesticide: the use of which has been banned or severely restricted for environmental or human health reasons by applicable provisions of the Basel Convention (1989), Rotterdam Convention (1998) or the Stockholm Convention (2001); that has deteriorated as a result of improper or prolonged storage and can neither be used in accordance with its label specifications nor easily reformulated for use; or that cannot be used for its intended purpose,

According to Food and Agriculture Organization of the United Nations (FAO) (1999), obsolete pesticides have been defined as those pesticides (stocked pesticides) that can no longer be used for their original (intended) purpose or any other purpose and therefore require disposal (must be disposed of). Such pesticides can no longer be used because their use has been banned, because they have deteriorated, or because they are not suitable for the use purpose originally intended and cannot be used for another purpose, nor can they easily be modified to become usable, i.e., these include, among others, banned, outdated, and deteriorated pesticides.

Particularly farmers and pesticide applicators, especially greenhouse workers, are highly exposed or vulnerable population groups which are exposed to high levels of chemical pesticides in their work. This has been clearly shown in pesticide levels found in the blood and hair of these workers. And, also unborn and young children are more exposed to pesticides in that when women are exposed to pesticides during pregnancy, some of these chemicals pass directly to the developing child in the womb. During development, the fetus is particularly vulnerable to the toxic impacts of pesticides. Young children, in general, are more susceptible than adults due to their increased exposure rates, in that toddlers and crawling babies are more likely to touch surfaces in the home and put their hands in their mouths. Children also have much smaller body sizes than adults and are less able to metabolize toxic substances within their systems (Greenpeace, 2015). Negative health impacts that have been reported for children exposed to elevated levels of pesticides in the womb include delayed cognitive development, behavioural effects and birth defects. There is also a strong correlation between pesticide exposure and incidences of childhood leukemia (Greenpeace, 2015).

Studies have also related higher pesticide exposures to increased incidence of several types of cancer including prostate and lung cancers, and neurodegenerative diseases such as Parkinson's and Alzheimer's disease. There is also evidence that suggests some pesticides can disrupt normal endocrine function and immune systems in the body. Whilst the mechanisms of such impacts are poorly understood, it is clear that, in some cases, enzyme function and important signaling (signalling) mechanisms at cellular levels can be disrupted. Studies using DNA-based methods also indicate that certain chemicals disrupt gene expression and this may follow on to generations that are not exposed to pesticides through epigenetic inheritance (epigenetic is of gene control unassociated with DNA). This means that the adverse effects of pesticide usage to the health of the environment and humans (to the health of humans and the environment) can be extremely long term, even after the substance has been outlawed (Greenpeace, 2015). According to WHO (1999), no individuals or groups are completely protected against pesticide exposures and the potentially serious health effects, which usually and mostly affect people of the developing countries.

Over time, many of the chemical pesticides used in agriculture have become extremely pervasive in our environment as a result of their widespread and repeated use and, in some cases, their environmental persistence. Some pesticides take an extremely long time to degrade, even those banned decades ago, including DDT and its secondary products, are routinely found in the environment today (Wilkowska & Biziuk, 2011; Li *et al*., 2014).

As a consequence of this persistence, and potential hazards to forms of life and the environment, effect-related research on the impact of pesticides has increased exponentially over the past 30 years (Köhler and Triebskorn, 2013), and it is now becoming clear that these effects vary with wide dimensions. Over the same period, scientific understanding of the effects of pesticides on human health and their mechanisms of action has also expanded rapidly, with studies revealing statistical associations between pesticide exposure and enhanced risks of developmental impairments, neurological and immune disorders and some cancers (Greenpeace, 2015).

2.3.3.1 Peticide Residues in Agricultural Food Commodities

Pesticide residue means any specified substances in food, agricultural commodities, or animal feed resulting from the use of a pesticide. The term includes any derivatives of a pesticide such as conversion products, metabolites, reaction products, and impurities considered to be of toxicological significance. The term pesticide residue includes residues from unknown or unavoidable sources such as environmental, as well as known uses of the chemicals (Codex, 1997; FAO, 2002; Ashenafi, 2009).

Pesticide residues are commonly present in agricultural food commodities that are grown through intensive industrial and small-scale farming systems particularly that use extensive, excessive, indiscriminate and inappropriate application of pesticides to control crop pests, and crops treated with pesticides invariably contain small amount of these chemicals and the hazard depends on the amount of pesticide residues that remain on the crop and their toxicity level and nature. The amount of the residue that may remain on the crop or other agricultural food (commercial) commodity depends on the nature of the pesticide, crop, cultural practices and various other environmental conditions under which the crop is grown or a treated commodity is stored. Residues of the pesticides applied often accumulate on the outer peel or skin, the cuticle, or can persist within the tissues or on the surface of crops when the crops reach for consumption as food. Studies show that food often contains multiple residues and therefore pesticides are presented to us as mixtures or cocktails (Taube, 2002; Ashenafi, 2009; Fenik *et al*., 2011; Wilkowska and Biziuk, 2011; Li *et al*., 2014; Tri Thanh *et al*., 2020). The toxic effect of these mixtures is particularly poorly understood, though it is recognized that some substances can interact synergistically in that their combined effect is greater than that of the individual components (Reffstrup *et al*., 2010). Assessing the toxicity of mixtures of pesticide residues is highly complex given the number of potential combinations and interactions which could occur (Greenpeace, 2015).

Sutton *et al*., (2011) states that, as a result of pesticide residues in food produce, typical food consumption patterns in the US can result in potentially high cumulative exposure in the general population. This is likely true for other countries and may be of concern considering repeated consumption of pesticides, particularly those that are lipophilic (bind with fats) and bioaccumulate in the body over time.

Children are particularly susceptible to exposure to pesticides, and they are more endangered by short-term and chronic exposure to pesticides (Lozowicka, 2015; Jallow *et al*., 2017; Mohamed *et al*., 2020). According to DeWaal and Nadine (2005), contaminated food contributes to 1.5 billion cases of diarrhoea in children each year, resulting in more than three million premature deaths, and the World health Organization (WHO) (1999) pointed out that both developed and developing nations share those deaths and illnesses. Masud and Hassan (1992) also reported that pesticide residues were found in fruits sold in markets which indicate the indiscriminate, wrongful and careless use of pesticides by farmers.

Consumers' exposure to pesticides due to the small quantities that are left on harvested crops raises challenges related to health issues. The quantities of pesticides left on food crops after harvest are known as pesticide residues. Maximum Residue Limits (Levels) (MRLs) are maximum amount of pesticide residue permissible in the animal or food crop commodity following an application of pesticides in accordance with Good Agricultural Practice (GAP). MRLs are specific limits for pesticide residues in food commodities, established by national, regional or international authorities or organization (EPA, 2006; EC, 2008). Pesticide Maximum Residue Limit (MRL) means the maximum concentration of a pesticide residue that is legally permitted or recognized as acceptable in or on a food or agricultural commodity or animal feedstuff. MRL is the maximum concentration of a pesticide residue (expressed as mg/kg), permitted in or on food commodities (agricultural food commodities) and animal feeds. MRLs are primarily a check that Good Agricultural Practice (GAP) is being followed and to assist international trade in produce treated with pesticides (FAO, 2002; Ellis, 2005; Ashenafi, 2009). MRLs are based on Good Agricultural Practice (GAP) data and must meet requirements for pesticide registration (Tereza *et al*., 2020). MRLs for pesticide/commodity combinations have also been established by the European Union in the Regulation of European Commission as the highest level of pesticide residues that are legally tolerated in food or feed (EC (European Commission) Regulation (EC) No. 396/2005, 2005). It was indicated that to meet the legal limits for pesticide residues in various food crops at a given harvest time, a pre-harvest interval (PHI) is officially established for particular pesticides defined as the time between the last pesticide application and the harvest of the treated crop (Tereza *et al*., 2020); this value is based on FAO (Food and Agriculture Organization of the United Nations) recommendation (FAO, 2009), and is usually fixed at a country level (Itoiz *et al*., 2012; Tereza *et al*., 2020). Also, it was noted that adopting MRLs and PHIs helps to keep residue-related health risks below an "acceptable risk level", and the aim of "zero-residue" vegetable production ("pesticide residue free production") is achieving pesticide residues in respective crops as low as 0.01 mg/kg (or even lower) (Tereza *et al*., 2020).

Maximum residue levels (MRLs) are the highest levels of residues expected to be in the food when the pesticide is used according to authorised agricultural practices (EFSA, 2010; Keikotlhaile & Spanoghe, 2011). The MRLs are always set far below levels considered to be safe for humans (Keikotlhaile & Spanoghe, 2011). It should be understood that MRLs are not safety limits, a food residue can have (a pesticide residue in or on a food can have) higher level than MRL but can still be safe for consumption; safety limits are assessed in comparison with acceptable daily intake (ADI) for long-term exposure, and/or acute reference dose (ARfD) for short-term exposure (Keikotlhaile & Spanoghe, 2011). The ADI is the estimate of the amount of a substance in food (mg/kg body weight/day) that can be ingested daily over a lifetime without appreciable health risk to the consumer (WHO, 1997; Keikotlhaile & Spanoghe, 2011). ADI is calculated by dividing the no-observed-adverse-effect-level (NOAEL) for animal studies with an uncertainty factor of 100 to convert to a safe level for humans. A factor 100 (10 x 10) mostly used to account for species differences and individual variability in sensitivity to the chemicals (Renwick 2002; Keikotlhaile & Spanoghe, 2011). The highest dose of the pesticide that does not cause detectable toxic effects on the test organisms is called the no-observed-adverse-effect-level (NOAEL) and is expressed in milligrams per kilogram of body weight per day (WHO, 1997). ARfD is the estimate of the amount of a substance in food that can be ingested over a short period of time, usually during one meal or one day, without appreciable health risk to the consumer (WHO, 1997; Keikotlhaile & Spanoghe, 2011). Pesticide short-term intake ought not to exceed the acute reference doses (ARfDs), and pesticide long-term intake should be below the acceptable daily intake (ADI) limits recommended by the Joint FAO/WHO Meetings on Pesticide Residues (JMPR) to avoid negative health effects (JMPR, 2011; ECPA, 2014; Codex, 2016; Marlene *et al*., 2017). MRLs are subject to legal requirements in most of the countries (Keikotlhaile & Spanoghe, 2011). In developed regions like Europe, the responsibility of the legislation is lead by the European Commission (EC) with input from the member states, EFSA and the standing committee on the Food Chain and Animal Health; in the US, the leading agency is Environmental Protection Agency (EPA) with input from the United States Department of Agriculture (USDA) and the Scientific Advisory Panel, while in New Zealand the leading agency is the New Zealand Food Safety Authority (NZFSA) with input from the Environmental Risk Management Authority (Keikotlhaile & Spanoghe, 2011).

MRL setting can be the responsibility of one or more authorities in a country and normally involves the health, agriculture and environmental agencies (Keikotlhaile & Spanoghe, 2011). MRL enforcement can be a responsibility of one or more agencies and may also depend on different food types (Keikotlhaile & Spanoghe, 2011). MRL setting is based on the national registered good agriculture practice (GAP) data combined with the estimated likely residue from the supervised trials mean residue (level) (STMR), acceptable daily intake (ADI), and acute reference dose (ARfD); the information is then evaluated by the risk assessment agency like European Food Safety Authority (EFSA) in European Union (EU) or Joint Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO) Meeting on Pesticide Residues (JMPR) for CODEX Alimentarius (Commission) (Keikotlhaile & Spanoghe, 2011). MRLs may be exceeded because of pesticide misuse, false positives due to naturally occurring substances, differences in national MRLs, lack of registered pesticides and incorrect pesticide application (EFSA, 2010; Keikotlhaile & Spanoghe, 2011). Where national or regional MRLs are not available, internationally recognised bodies such as the United Nations Codex Alimentarius Commission MRLs can be used as guidance (Keikotlhaile & Spanoghe, 2011).

The emerging trend is to harmonize MRL in each region or globally and is highly supported by international organisations such as FAO, WHO, Codex Committee on Pesticide Residues (CCPR) and Organization for Economic Cooperation and Development (OECD)

(Keikotlhaile & Spanoghe, 2011). In the EU the MRLs are already harmonised as from the beginning of September 2008 under the new regulation EC No. 396/2005 (OECD 2010; Keikotlhaile & Spanoghe, 2011). In developing regions like Africa, efforts were initiated under the Global MRL Harmonization Initiative – Africa Project that was supported by United States (US) Department of Agriculture – Foreign Service, IR-4 Project and United States Environmental Protection Agency (USEPA). A summary of the questionnaire from the same project indicated that most of the African countries have adopted the CODEX MRLs with South Africa establishing some of its own in addition (Anonymous 2009; Keikotlhaile & Spanoghe, 2011).

Good agricultural practices in the use of pesticides (GAP) are the nationally authorized safe uses of pesticides under actual conditions necessary for effective and reliable pest control. It encompasses a range of levels of pesticide applications up to the highest authorised use, applied in a manner which leaves a residue which is the smallest amount practicable. Authorized safe uses are determined at the national level and include nationally registered or recommended uses, which take into account public and occupational health and environmental safety considerations. Actual conditions include any stage in the production, storage, transport, distribution and processing of food commodities and animal feed (Codex, 2011).

Over many years, scientists have developed a variety of techniques to quantify levels of pesticides (pesticide residues) in food, and results have suggested that continuous monitoring is necessary to ensure as much as possible that limit values set for pesticide residues are not exceeded in produce reaching the market place (consumers) (Wilkowska and Biziuk 2011; Li *et al*., 2014). Most countries, either on a national or regional basis, maintain a threshold Maximum Residue Level (Limit) (MRL) for each substance, above which the foodstuff is thought unacceptable for human consumption **(**Greenpeace, 2015).

The view to regulate pesticide residues to safer levels was originally initiated by the Joint Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO) expert committee on food safety and they defined food safety as "all conditions necessary during production, processing, distribution, storage and during the preparation of food to ensure it is safe, wholesome, sound and fit for human consumption'' (Codex, 1995). To facilitate the implementation of this work, *Codex Alimentarius Commission* (Codex), comprising 120 member states, was established by the Joint FAO/WHO Food Standards Programme in 1963. Codex is an international intergovernmental food standards-setting body with mandates of protecting customers' health, ensure fair trade practices and hence facilitate international trade, coordinate work on food standards with other international organizations including international non-governmental organizations (INGOs) and international intergovernmental organizations (IGOs), and develop and maintain the *Codex Alimentarius (Codex Alimentarius Commission's* mandates (objectives)), for instance, amend (update) and maintain Codex database for MRLs for pesticides (pesticide residues). The Codex international food standards, guidelines and codes of practice are voluntary for countries to reference or employ as part of their national regulations. Codex is the single most important international reference point in developing food associated standards. The *Codex Alimentarius* serves as the basis for many national food standards and related regulations. Most countries at least use Codex MRLs as a reference point, and so the Codex standard and process for setting new MRLs remains very relevant. Codex establishes various committees or task forces including *Codex Committee on Pesticide Residues* (CCPP). CCPP is a subsidiary body on the Codex charged to develop standards on pesticides in food and feed, and advises on all issues relating to pesticide residues. The main objective of Codex (CCPP) was to come out with Maximum Residue Limits (MRLs) to protect consumers and foster international trade (Codex, 2008, 2011; Michael, 2012; Codex, 2016; Joint FAO/WHO Food Standards Programme, 2016).

Various literature published between 2007 and 2014 suggests that legumes, leafy greens and fruits such as apples and grapes frequently contain the highest levels of pesticide residues (Bempah *et al*., 2012; Jardim *et al*., 2012; Fan *et al*., 2013; Yuan *et al*., 2014). There is consistent evidence that these substances are regularly present as mixtures of multiple residues and, in many cases, at levels above MRL limits in certain countries (Latifah *et al*., 2011; Jardim *et al*., 2012). Among many other pesticides, cypermethrin, chlorpyrifos, iprodione, boscalid, dithiocarbamates and acephate are regularly detected in our food (Claeys *et al*., 2011; Lozowicka *et al*., 2012; Yuan *et al*., 2014). It is also suggested that among the many active ingredients that are potentially dangerous to health are the currently approved organophosphates, chlorpyrifos and malathion. Chlorpyrifos is routinely found in food, and in human breast milk, and public health studies indicate strong evidence that it is linked to numerous cancers, impaired development in children, impaired neurological function, Parkinson’s disease and hypersensitivity (Greenpeace, 2015). Whilst extensive research suggests that washing and cooking vegetables does reduce some of these residues of pesticides that are on the surface of the plant, in some cases food preparation can actually concentrate levels (Keikotlhaile *et al*., 2010).

The list of twelve fruits and vegetables with the highest amounts of pesticide residues, named “dirty dozen”, is annually published by the Environmental Working Group (EWG). In 2019, the “dirty dozen” ranking was composed, in order of importance by: strawberry, spinach, kale, nectarine, apple, grape, peach, cherry, pear, tomato, celery, and potato. These products were found to have higher levels of pesticides than all other ones over the year (EWG, 2019).

From the data obtained by the United States Department of Agriculture (USDA) for their Pesticide Data Program in recent years, strawberry may contain as many as 45 different types of pesticide residues. Other fruits and vegetables also present (contain) a high number of pesticide residues, such as grapes (56), sweet bell peppers (53), apples (47), cherries (42), tomatoes (35) and potatoes (35). Among them (among the pesticide residues detected (found)), tetrahydrophthalimide (THPI), a metabolite from the non-systemic fungicide-captan, was found in 55% of strawberry samples, while permethrin, an insecticide of the pyrethroid family, dominated in 52% of spinach samples; formetanate hydrochloride, a carbamate pesticide that inhibit cholinesterase, in 53% of nectarines; diphenylamine (DPA), an aromatic amine used as a scald inhibitor for apples, was found in 83% of samples; imidacloprid, a systemic insecticide, in 48% of grapes; fludioxonil, a non-systemic fungicide, in 48% of peaches; boscalid, a non-systemic fungicide, in 65% of cherries; pyrimethanil, an anilinopyrimidine class of fungicides, in 40% of pears; endosulfan, an organochlorine insecticide and acaricide, in 17% of tomatoes; and chlorpropham, a carbamate herbicide, in 80% of potato samples (Pesticide Action Network (PAN), 2019; Tri Thanh, 2020).

In Ethiopia, nationwide and crop-belt based studies and database on pesticide poisoning of pesticide users (end users) and pesticide residue analysis including established MRL values in agricultural food commodities such as vegetables including onion are scanty except some work done by such as Negatu *et al*. (2018) and Kumelachew *et al*. (2020).

2.3.4 Methods of Pesticide Residue Analysis in Vegetables

Vegetables and fruits are prone to being contaminated with higher pesticide (pesticide residue) levels when compared to other food groups (Chen *et al*., 2011; Mohamed *et al*., 2020). Pesticide residues in vegetables and fruits including onion contain not only their main compounds, but also their metabolites and/or degradation products, which have different physicochemical characteristics (vapor pressure, polarity, solubility). This multi-compound presence results in difficult and complex methods to isolate pesticide residues in micro-quantities from fruit and vegetable matrices (Tri Thanh *et al*., 2020).

There are several techniques that can be used for pesticide residue analysis in vegetable and fruit crops including onion (Richter *et al.*, 2001). The first step is sampling, where the sample is obtained from the object to be analyzed and the sample collected should represent the original object (Winefordner, 2003). A number of different sampling procedures can be utilized including *simple random sampling, systematic random sampling, stratified random sampling* and *convenient sampling*, and their choice depends on the nature of the bulk material, the system investigated, and the purpose of analysis. The next step is sample preservation. Sample preservation ensures that the sample retains its physical and chemical characteristics so that the analysis truly represents the object under study (Winefordner, 2003). In instrumental analysis, pesticide residues in fruits and vegetables are analyzed through two steps: (a) sample preparation, that is, extraction and clean-up of the target analytes from the matrix, and (b) determination of the target analytes (Prodhan *et al*., 2017; Tri Thanh, 2020).

2.3.4.1 Sample Preparation for Pesticide Residue Analysis

Sample preparation is important for the reason that most samples are not ready for direct introduction into instruments for analysis (Winefordner, 2003). Especially determination of trace contaminants in complex matrices, such as food, often requires extensive sample extraction and preparation regimes prior to instrumental analysis operation. Food samples cover a wide range of physical types from dry powders to biological matrices, such as meat, fats and liquids or solutions, thus before the residues were determined, samples required extraction and purification (David, 2000; Montury & Urruty, 2002; Cho *et al*., 2007; Ashenafi, 2009).

Sample preparation is the first step in any instrumental analysis, which involves the isolation or extraction of the desired analytes from the sample matrix since they are present at trace concentration (usually μg/kg or less). It helps in the elimination of any interferences and also reduces the volume of extracts, thereby concentrating the analytes (Małgorzata *et al*., 2014). The type, nature, composition of sample and concentration of analytes to be isolated or extracted determines the choice of separation and detection method to be used. This also dictates the type of sample preparation to be employed since the efficiency of any analysis is determined by the sample preparation step (Guan & Lukman, 2012; Tamene, 2018).

On the other hand, in accordance with current trends, the analytical procedures should aim at the miniaturization and simplification of the sample preparation step, while maintaining the high throughput performance, low-cost operation, and improvement of the sample preparation, such as extraction, concentration, isolation of analytes, and clean-up. This effort focuses on sample preparation; where there is a shift from laborious traditional method to new fast and simple approaches, such as the quick, easy, cheap, effective, rugged, and safe (QuEChERS) multi-residue method (Guan & Lukman, 2012; Kapil, 2012; Małgorzata, *et al*., 2014; Ashish *et al*., 2015; Tamene, 2018).

Various techniques have been used for sample preparation, such as accelerated solvent extraction (ASE), matrix solid phase dispersion (MSPD), liquid partition extraction (LPE), Liquid-liquid extraction (LLE), solid phase extraction (SPE), liquid–gas extraction (LGE), liquid-solid extraction (LSE), solid phase micro extraction (SPME), and QuEChERS (quick, easy, cheap, effective, rugged, and safe) sample extraction and cleanup technique (Ashenafi, 2009; Tri Thanh, 2020).

I. Quick, Easy, Cheap, Effective, Rugged, and Safe (QuEChERS) Method

There have been substantial efforts in the past two decades to adapt the existing sample preparation methods and develop new approaches to save time, labor and materials (Lambropoulou and Albanis, 2007). It has been estimated that the sample preparation step in most determinations consumes approximately 60 – 70 % of the total time required for the analysis (Kapil, 2012; Tamene, 2018).

The QuEChERS (quick, easy, cheap, effective, rugged, and safe**)** method was first introduced for pesticides residues analysis from fruits and vegetables with high water content, and becoming a popular means of sample preparation procedure internationally (WHO, 1990; Dasika *et al*., 2012; Ligani & Hussen, 2014; Narenderan & Meyyanathan, 2018). However, more recently it is gaining popularity for the analysis of pesticides and other compounds in a huge variety of food products and other different matrices (Paula *et al*., 2007; Sadowska-rociek, *et al*., 2011). QuEChERS method and its modifications are now rapidly developing beyond its original scope of application for multi-residue analysis in various matrices. Both polar and non-polar compounds are extracted simultaneously where initial extraction involves the use of an organic solvent followed by partitioning with the addition of salt mixtures and final clean up (Tamene, 2018).

The QuEChERS sample preparation is a simple, fast, and inexpensive method, originally described by Anastassiades *et al*. (2003), for the determination of pesticide residues in fruits and vegetables. QuEChERS was developed using an extraction method for pesticides in fruits and vegetables, coupled with a cleanup method that removes sugars, lipids, organic acids, sterols, proteins, pigments, and excess water. This technique offers a user-friendly alternative to traditional liquid-liquid and solid phase extractions. The QuEChERS technique involves two steps: a liquid-liquid extraction (LLE) and dispersive solid-phase extraction (d-SPE) clean-up. First, the homogenized samples are extracted and partitioned using an organic solvent and salt solution. Then, the supernatant is further extracted and cleaned using a dispersive solid phase extraction (d-SPE) technique (Restek, 2012; Tri Thanh, 2020). The samples pre-treated using QuEChERS are clean enough to be analyzed using gas or liquid chromatography (Iqbal *et al*., 2020). Due to the numerous advantages of this method, it was used by many researchers (Tri Thanh, 2020).

Nowadays, dispersive solid-phase extraction (d-SPE) is the most widely used method for the clean-up. The d-SPE method is similar to the SPE principle but solid phase such as octadecyl (C_{18}), primary secondary amine (PSA) or graphitized carbon black (GCB) is added directly and makes the clean-up process easy. This clean-up process is widely used after the enactment of the QuEChERS extraction method in the multi-residue analysis (Narenderan & Meyyanathan, 2018). The usage of absorbent PSA is standardized along with the addition of magnesium sulfate to remove unwanted substances (sugar, fatty acids, and water) from organic solvents in the gas chromatography (GC) application. The use of salts such as magnesium sulfate to induce an exothermic mass partition of pesticides from the aqueous to the organic phase is crucial in the procedure (Cervera *et al*., 2010; Seblework *et al*., 2014; Rejczak *et al*., 2015; Tamene, 2018).

Using QuEChERS sample preparation method, a batch of 10−20 samples could be extracted in 30−40 minutes by a single analyst, hence it is very rapid; the need of using only basic laboratory devices makes this sample preparation technique relatively inexpensive in comparison to most traditional extraction methods, and low solvent and glassware usage (no chlorinated solvents usage). In contrast to this, since it uses 1gram sample per milliliter of final extract, the concentration of the extract is lower than for the concentrated extracts obtained by use of most traditional procedures (Paula *et al*., 2007; Chai *et al*., 2012; Rejczak *et al*., 2015; Pérez-Ortega *et al*., 2017; Tamene, 2018).

In a recent study, QuEChERS process provided satisfactory results with high recovery (acceptable ranges) of 72 pesticides in carrot, corn, melon, rice, soy, silage, tobacco, cassava, lettuce and wheat (Viera *et al*., 2017), and 11 fungicides and three insecticides in strawberry by-products (Sojka *et al*., 2015). In another research on optimization of the clean-up step of QuEChERS method in coffee leaf extracts (Trevisan *et al*., 2017), it was possible to analyze 52 pesticides by liquid chromatography tandem mass spectrometry (LC-MS/MS). For this, the clean-up procedure of QuEChERS method was modified with different combinations of adsorbents, resulting in high recovery (>70%). Recently, the combination of modified

QuEChERS method by adding of acetonitrile with 0.1% formic acid, followed by ultra-high performance liquid chromatography tandem mass spectrometry (UHPLC-MS/MS) determination, was applied by Lee *et al*. (2018) for a multiresidue analysis of 310 pesticides in brown rice, orange, and spinach, which resulted in 87–89% of the pesticides at spiking level of 10 ng/g met the acceptability criteria (recovery 70–120%, and RSD ≤ 20%) (Tri Thanh, 2020).

2.3.4.2 Analytical Determination of Pesticide Residues

Various analytical methods (analytical instruments) have been developed and reported for the determination of pesticide residues in various foods and food commodities including fruits and vegetables, that is, for the second step in pesticide analytical determination, which is the detection or analysis of target analytes (pesticide residues) in agricultural food commodities like fruits and vegetables including onion, numerous conventional analytical methods have been used such as thin layer chromatography (TLC), gas chromatography (GC), high performance liquid chromatography (HPLC), or more delicate ones including gas chromatography associated with mass spectrometry (GC-MS), liquid chromatography associated with mass spectrometry (LC-MS), and ultra-high performance liquid chromatography tandem mass spectrometry (UHPLC-MS/MS) (Araoud *et al*., 2007; Ashenafi, 2009; Tri Thanh, 2020).

These days, the most important and commonly used analytical methods for pesticide residue determination are gas chromatography (GC) and liquid chromatography (LC) (Sharma *et al.*, 2010). Liquid chromatography (LC) coupled with tandem mass spectrometry (MS/MS) is one of the most powerful techniques for pesticide residue analysis in fruits and vegetables. But, this technique is used for highly polar, thermally labile (unstable) and non-volatile compounds (Narenderan & Meyyanathan, 2018). Unlike LC, GC is an analytical technique for separating compounds based primarily on their volatilities (Sharma *et al.*, 2010). Since its introduction in the late 1960s, GC has an inherent remarkable feature to perform multi-residue analysis (Lambropoulou & Albanis, 2007; Tamene, 2018).

I. Gas Chromatography (GC)

The gas chromatography (GC) has been the major analytical method used in the determination of pesticide residue in crop produce due to its high separation ability and the presence of GC-amenable pesticides in several samples. Most analytical methods for the determination of pesticide residues in various fruits and vegetables used gas chromatography (GC), either with electron-capture detection, nitrogen-phosphorus detection or flame photometric detection. Other methods used GC coupled to mass spectrometry (GC-MS) to have a highly selective detection. Mass spectrometry is a very sensitive and selective technique for both multi-residue determination and trace-level identification of a wide range of pesticides. It can quantify and confirm the results by its full scan or selected ion monitoring (SIM) spectra (Fillion *et al*., 1995; Araoud *et al*., 2007; Ashenafi, 2009; Michael, 2012).

A number of GC based studies have been reported for pesticide residue analysis by coupling with various detectors such as electron capture detector (ECD) (Maria *et al.*, 1999; Ngan *et al*., 2013; Seblework *et al*., 2014), mass detector (mass spectrometry (MS) or tandem mass spectrometry (MS/MS)) (Paula *et al*., 2007; Cervera *et al*., 2010; Daba *et al*., 2011; Ashenafi *et al*., 2018), nitrogen phosphorus detector (NPD) and flame photometry detector (FPD). Particularly, ECD is a popular detector due to its sensitivity and specificity for electronegative chlorine atoms (Maria *et al*., 1999; Tamene, 2018).

For volatile pesticides, which can be easily vaporized, GC is a popular separation method applied in several studies. It is usually coupled with specific detectors, including flame ionization detector (FID), as for the analysis of organophosphorus pesticides in onion, grape and apple juices (Farajzadeh *et al*., 2016), or pyrethroid pesticides in vegetable oils (Farajzadeh *et al*., 2014). Electron capture detector (ECD) has been used as well in the determination of chlorpyrifos-methyl, fenitrothion, procymidone and vinclozolin on peach (Balinova *et al*., 2006), and the flame photometric detector (FPD), to determine 11 organophosphorus pesticide residues on cabbage, kale and mustard samples (Sapahin *et al*., 2015). Mass spectrometer detectors (MS and tandem MS) are also popular choices for pesticide determination, as MacLoughlin *et al*. (2018) analyzed 35 commonly used pesticides by GC-MS, and 381 different types of pesticides in grapes were monitored by gas chromatography tandem mass spectrometry (GC/MS-MS) (Stoytcheva, 2011; Tri Thanh, 2020).

II. High Performance Liquid Chromatography (HPLC)

For high polarity and non-volatile extracted analytes, HPLC analytical techniques are preferably used as an effective separation method. It can be coupled with detectors such as ultraviolet (UV) in the case of analysis of pyrethroid residues in fruit and vegetable samples (Bagheri *et al*., 2016) or MS and tandem MS in the determination of malathion, diazinon, imidacloprid and triadimefon in fruit juices of apple, cherry, raspberry, orange and pineapple (Timofeeva *et al*., 2017; Tri Thanh, 2020). Fungicides, carbamates and herbicides in fruits were determined by high- performance liquid chromatography with UV detection. Samples were extracted in 10% methanol in methylene chloride and cleaned up the sample content using Extrelut® (Merck, Germany) column (Extrelut® sorbent column is liquid-liquid extraction column which simplifies liquid-liquid extraction by replacing separation funnels, i.e., by replacing classical liquid-liquid extraction) (Ohlin, 1986; Michael, 2012).

III. Ultra-High Performance Liquid Chromatography (UHPLC)

In recent years, UHPLC started the use of smaller stationary-phase particle size (≤2 µm) than those used in classical LC (3–5 µm), for the detection of 21 pesticide residues in tomato and sweet pepper samples, coupled with tandem mass spectrometry (UHPLC-MS/MS) (Martins *et al*., 2017). In another study, time-of-flight mass spectrometry (TOF-MS) was combined with UHPLC to detect 60 pesticides in 286 vegetable and fruit samples (Sivaperumal *et al*., 2015; Tri Thanh, 2020).

3 MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted in Kewet district, North Shewa, central Ethiopia, located 230 km north east of Addis Ababa with latitude and longitude of 10°00′N and 39°54′E, respectively.

Its climate includes mid-lowland and mid-highland agroecological zones with elevation of about 1150-2850 m above sea level. The main rainy season of the area is in the summer (locally known as *kiremt*) season of the northern hemisphere (June to September) (monomodal) with mean annual rainfall of about 600 mm. Its average annual temperature ranges from 19^{O}C to 32^{O}C. Most of the soil is classified as vertisol dominated by clay soil type. The major cultivated cereal crops include sorghum (*Sorghum bicolor* (L.) Moench) and *tef (Eragrostis tef),* and among vegetabe crops, onion is extensively produced by small-scale (smallholder) onion cultivating farmers under irrigation conditions.

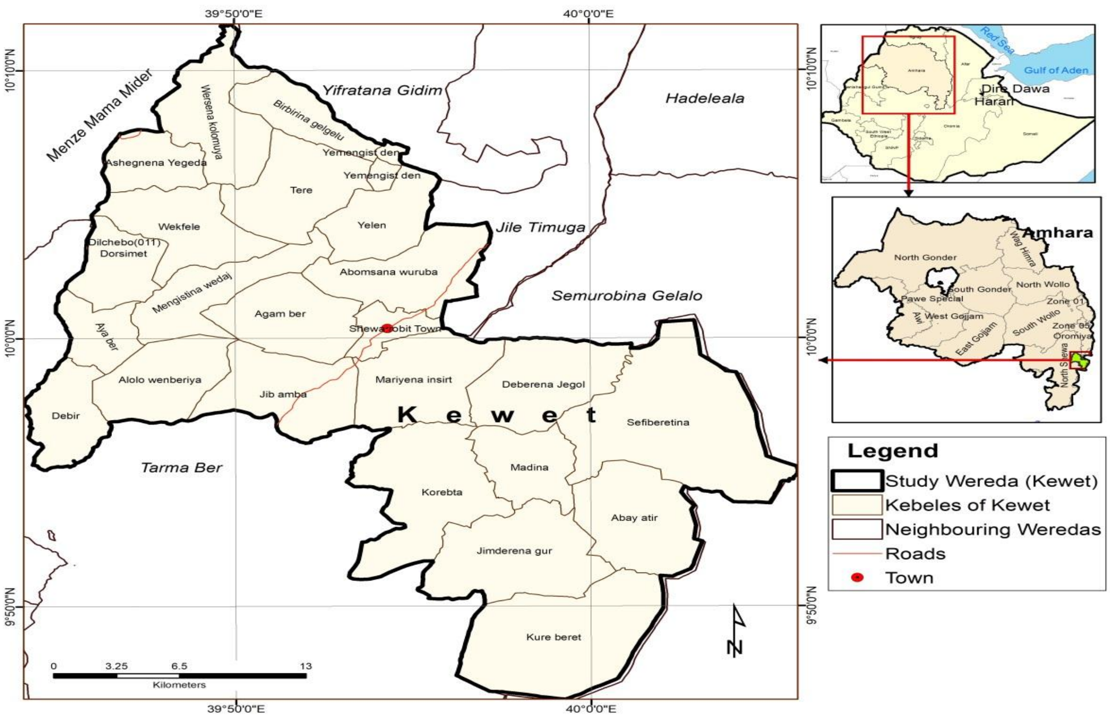

Figure 3: Map of Kewet district, the study area

3.2 Field Survey Study

3.2.1 Sampling Methods and Sample Size Determination

Purposive samplings followed by systematic random sampling techniques were employed to select sampling units. At the beginning, a consultation was held with Kewet District Agricultural Office. Accordingly, three onion producing 'kebeles' ('kebele' (an Amharic word) is the lowest administrative structure) were selected purposively from the district for their extensive onion production, more frequent onion thrips infestation on onion and their accessibility. The sampling frame of onion growing farmers from these three kebeles was carefully prepared checking for its comprehensiveness since agricultural extension agents often hold and keep lists of onion growing householder farmers updated so that the farmers use limited irrigation water source properly according to their turn. Then, the sampling units were selected through systematic random sampling technique based on the sample size determined.

The sample size was determined based on proportion using a 95% confidence interval, 5% desired level of precision (margin of error), and because there were no prior studies conducted on insecticide use knowledge and practices in the study area, estimated proportion of an attribute of interest being measured that is present in the population (p) is unknown, and it is assumed to be 0.5 (maximum variability/maximum heterogeneity). Thus, the sample size was determined using the following infinite population formula (Cochran, 1963).

$$\mathrm{n} = \frac{(1.96)^2 pq}{d^2}, \qquad \mathrm{n} = \frac{z^2 pq}{d^2}, \qquad \mathrm{n} = \frac{4pq}{d^2}$$

Where n= required sample size, p= proportion of the population having the characteristic, q=1- p, d= degree of precision. And hence, based on the formula above, the required total sample size was expected to be 385 (+ 5% replacement participants assumed to compensate for non-response cases (as a substitute for non-response cases)).

3.2.2 Data Collection Instrument and Procedures

Data collection instrument used was carefully prepared structured questionnaire (the questionnaire was designed based on the study objectives and standard procedures reviewed, which was first prepared in English and then meticulously transcribed verbatim into the local language). Data were collected from 385 householder farmers administered through in-depth face-to-face interview often conducted in the farmers' fields during 2020. The questionnaire consisted of two parts: the first part focused on demographic and socioeconomic characteristics of the study subjects while the second part of the questionnaire emphasized on chemical pesticide particularly synthetic chemical insecticide use knowledge and practices of small-scale (smallholder) onion growing (onion producing) farmers in controlling onion thrips on onion in Kewet district, central Ethiopia, which included information such as source and type of chemical insecticides (chemical pesticides) used by onion growing farmers, onion farmers' conditions of use of safety measures (safety precautions) like use of personal protective equipment (PPE)) during pesticide (insecticide) use (when using and handling (purchasing, storing, preparation (mixing), application (spraying)) (of) pesticides (insecticides) and disposal mechanisms of pesticide (insecticide) wastes including empty pesticide (insecticide) containers). Moreover, focus group discussion (FGD) with three key informant community leaders and key government actors included being four 'kebele' agricultural extension agents, four district and three zone agricultural development office leaders and irrigation agronomy professionals was held to triangulate the data collected from individual respondent farmers.

3.3 Analytical Experiment

3.3.1 Materials

3.3.1.1 Onion Sample Collection

Considering that Shewa Robit town could be representative of Kewet district because it is the main town and the major market place in the district of Kewet, and after observing the market situation at the town, Shewa Robit town was selected for taking onion samples for pesticide residue analysis in the district. Consequently, three onion primary samples of each 1kg were purchased from three randomly selected retailers at Shewa Robit town open market in the month of June, 2021 in accordance with sampling procedures of Codex and European

Commission (EC) for pesticide residue analysis in food commodities (Codex, 1999; European Commission (EC) Directive 2002/63/EC), and the samples were enclosed tightly in clean polythene bags to protect them (the samples) from cross contamination or external contamination. Then, the primary samples were combined and well-mixed to produce a bulk (aggregate) sample. From the bulk sample, a representative laboratory sample of 1kg onion was prepared, properly labeled, enclosed tightly in a clean polythene bag and soon delivered to Bless Agri Food Laboratory Services Privately Limited Company (PLC) for analysis of pesticide residues in onion. The recipient laboratory is a pioneering PLC laboratory in Ethiopia, and it is accredited by the Ethiopian National Accreditation Office (ENAO) with Facility Accreditation No: T0030 in accordance with the requirements of ISO/IEC 17025: 2017, general requirements for the competence of testing and calibration laboratories.

3.3.1.2 Chemicals and Reagents

All chemicals and reagents used for onion samples extraction, clean-up and pesticide residue determination in this analysis were of analytical quality grade, and obtained from different suppliers and importers found in Ethiopia and from outside. Anhydrous magnesium sulfate ($MgSO_4$), acetonitrile (MeCN), acetic acid (HOAc) (glacial) and anhydrous sodium acetate (NaOAc) were obtained from Sigma-Aldrich (Germany), and primary secondary amine (PSA) sorbent and graphitized carbon black (GCB) sorbent were supplied by Supelco (USA), all of which were with quality of sufficient purity that were free of interfering compounds (species). The gas used was helium (with 99.9% purity). Analytical standard grade and high purity reference pesticide standards of the pesticide target analytes (α-HCH, β-HCH, heptachlor, aldrin, heptachlor epoxide, endosulfan I (α-endosulfan), chlordane, DDE, endosulfan II (β-endosulfan), DDD, DDT, methoxychlor, hexachlorobenzene, fenthion and fenitrothion) were obtained from Sigma-Aldrich (Germany). Pesticide standards solution was prepared by mixing each reference pesticide standards in quantities ranging from 50 mg to 250 mg in 100 mL acetonitrile through appropriate measurement and stored in $-4^{0}C$ deep freezer.

3.3.1.3 Instruments and Equipment

Instruments and equipment used during conducting this analysis were gas chromatography (GC: model 7890B, manufactured by Agilent Technologies, USA) coupled with mass selective detector (MSD) (mass spectrometry (MS)) (MSD: model 5977B, product of Agilent Technologies, USA); blender: model RRH-500A (high speed multifunction comminutor) (homogenizer) (China); Ohaus balance (capable of measuring accurately from 0.00-200g): model 028.02.09-ODOF (Canada); vortex Genius 3 shaker (mixer): model VG-3S000 (Germany); centrifuge (capable of holding 50mL centrifuge tube) Universal 320 SN-0007342-10 (Hettich, Germany); centrifuge (capable of holding 15 mL d-SPE centrifuge tube): Corning LSE SN-7414000 (Germany); Freezer-Hisense (No Frost) (refrigerator) (China). Other equipment such as centrifuge tube (Corning Centristar 50 mL) and pipettes of different sizes were also used.

3.3.2 Methods

3.3.2.1 Sample Preparation

Onion sample preparation was performed using QuEChERS (Quick, Easy, Cheap, Effective, Rugged and Safe) sample preparation technique (procedure), a new sample preparation method published recently as *AOAC (Association of Official Analytical Chemists) Official Method 2007.01* (AOAC Official Method 2007.01, 2007; David *et al*., 2008), which involves homogenized samples extraction and partitioning using organic solvent and salt solution, and then dispersive solid phase extraction (d-SPE) cleanup of sample extract with a combination of primary secondary amine (PSA) sorbent, $MgSO_4$ and graphitized carbon black (GCB) sorbent procedures. The extraction and clean-up procedures were outlined as follows: (1) 1kg onion sample was finely chopped and comminuted with stainless steel knife on clean cutting board, and then 200 g subsample was homogenized with high speed multifunction blender; (2) 15 g subsample was transferred to 50 mL centrifuge tube, and 15 mL 1% HOAc in MeCN (v/v) +1.5 g anhydrous NaOAc + 6 g anhydrous $MgSO_4$ were added; (3) the mixture was immediately shaken with vortex for 1 minute, and then centrifuged at >1500 rcf (relative centrifugal force) for 1 minute to facilitate and enhance extraction and partitioning; (4) 5ml of the supernatant was transferred to 15 mL d-SPE centrifuge tube with 150 mg anhydrous $MgSO_4$ + 50 mg PSA sorbent + 50 mg GCB sorbent per mL extract, and shaken with vortex for 30 seconds and centrifuged at >1500 rcf for 1 minute for cleanup; (5) 0.6 mL clean onion sample extract was transferred to GC autosampler (AS) vial, and then, one microliter (1µL) of the clean onion sample extract was injected into GC for the analysis of pesticide residues in onion samples.

3.3.2.2 Gas Chromatographic Analysis (Operating Conditions)

All pesticide residue analysis of onion samples were performed using gas chromatography (GC) (model: GC-7890B, manufactured by Agilent Technologies, USA) coupled with mass selective detector (MSD) (mass spectrometry (MS)) (model: MSD-5977B (MS-5977B), manufactured by Agilent Technologies, USA) having with gas chromatographic (GC) capillary column of model HP-5 of size 30 m length x 0.25 mm internal diameter (ID), 0.25 µm film thickness (product of Agilent Technologies, USA) under the following conditions: The GC column oven temperature was programmed as follows: Initial temperature was 60 ^{O}c which was held for 1 min (minute) and run for 1 min followed by a ramp of 40 ^{O}c/min to 120 ^{O}c and was held for 0 (zero) min and run for 2.5 min, then it was ramped by 5 ^{O}c/min to 310 ^{O}c and was held for 0 min and run for 40.5 min. The total GC run time was 44 min. Auxiliary temperature was 250 ^{O}c. Source temperatures and MS temperature were 300^{O}c and 150 ^{O}c respectively. The carrier gas used was pure helium (99.9% purity) with a constant column head pressure of 50 kPa and at a flow rate of 1.2 mL/min. Pesticide standards solution, reagent blank and sample extract, each 1µL, were injected into GC in splitless mode with inlet temperature of 180 ^{O}c during all the analysis in the same batch. Standard sample injection was performed each time starting with the lowest calibration concentration.

Chromatographic separation of target pesticide analytes (pesticide residues) in onion samples was accomplished inside the column that was driven by the intermolecular interactions between the stationary phase (due to its chemical nature) and target pesticide analytes, i.e., the degree of target pesticide analyte chemical affinity to the stationary phase and the target pesticide analyte vapor pressure (differences in stationary phase affinity and the relative vapor pressures (and boiling points) of the target pesticide analytes) which was governed by the column temperature. Identification and quantitation of target pesticide analytes were achieved using the mass selective detector (MSD). Peak area or peak height was used for quantitation.

3.4 Data Analysis

The field survey data collected were analyzed using Statistical Package for the Social Sciences (SPSS) version 20. Results are presented in frequency tables and percentages for specific (categorical) variables, and mean and standard deviation for continuous variable in descriptive statistics. Pesticide residues data were analyzed using MassHunter version B.07 software (mass spectrometry (MS) application software) (manufactured by Agilent Technologies, USA), set up and programmed with the GC/MSD instrument apparatus.

4 RESULTS

4.1 Field Survey Study

4.1.1 Demographic and Socioeconomic Characteristics of Respondent Farmers

In the present study, the demographic and socioeconomic characteristics of respondent small-scale (smallholder) onion cultivating farmers in the study area are shown in Table 1. Of the total 385 study subjects, 369 (95.8%) were males while 16 (4.2%) were females as onion farming (onion cultivation) activities and synthetic chemical pesticide use operations especially application (spraying) of pesticides are primarily and exclusively performed by men in the study area. Among the participants, 137 (35.6%) were aged between 20-39 years, 214 (55.6%) were aged 40-60 years and 34 (8.8%) were above 60 years of age. The mean age of the respondents was 45±9.4 (SD) years with minimum and maximum values of 20 and 65 years, respectively. From the total of 385 participants, 206 (53.5%) were found unable to read and write, while 179 (46.5%) could read and write who learned through formal (primary) and informal (adult) education.

With regard to participants' cultivated land size of onion, most of the study subjects (317 (82.3%)) owned 0.25-0.75 hectare (ha), while 68 (17.7%) possessed >0.75-1.25 ha, and concerning their land tenure status, 289 (75.1%)) study participants were landowners and the rest (96 (24.9%)) were rented landholders. Regarding frequency of onion production per year, the majority (307 (79.7%)) of respondents reported that they produced two times per year, while 43 (11.2%) and 35 (9.1%) produced one time and three times per year respectively. All (100%) participant farmers have been producing onion using irrigation with traditional and small-scale irrigation schemes. Also, 79 (20.5%) study particiapants had <15 years of onion farming experience, and 211 (54.8%) had 15-25 years of experience of onion cultivation, while 95 (24.7%) had >25 years of onion farming experience, with average onion production experience of 21 years (Table 1).

Table 1: Demographic and socioeconomic characteristics of respondent farmers in the study area (n=385)

Variable	Frequency (n)	Percentage (%)
Gender		
Male	369	95.8
Female	16	4.2
Age		
20-39	137	35.6
40-60	214	55.6
>60	34	8.8
Educational level		
Illiterate (unable to read and write)	206	53.5
Can read and write (formal (primary) and informal		

(adult) education)	179	46.5
Land tenure status Landowner Rented landholder	 289 96	 75.1 24.9
Cultivated land size of onion (hectare (ha)) 0.25- 0.75 ha >0.75 -1.25 ha	 317 68	 82.3 17.7
Onion production condition (production season) Irrigation Rain fed	 385 0	 100 0
Frequency of onion production per year One time Two times Three times	 43 307 35	 11.2 79.7 9.1
Farmers' onion cultivation experience (years) <15 years 15-25 years >25 years	 79 211 95	 20.5 54.8 24.7

4.1.2 Farmers' Responses to the Economic Impact of Onion Thrips on Onion and Its Control Method

Participant smallholder onion producing farmers' responses to the negative economic impact of onion thrips on onion and its control method in the study area of the present study are presented in Table 2. All (100%) study subjects reported that onion thrips is the major and serious insect pest of onion attacking in every growing season (year). And, all (100%) study participants responded that they have been controlling onion thrips on onion by using synthetic chemical pesticides (synthetic chemical insecticides) only, purchasing the chemicals from local pesticide suppliers (pesticide retailers (pesticide vendors)), and spraying with manual backpack (knapsack) spraying equipment (pesticide sprayer) (Table 2). From the assessment made, commonly used synthetic chemical pesticides (synthetic chemical insecticides) by the farmers for the control of onion thrips on onion in the study area by their trade names with active ingredients (a.i.) or active substances (a.s.) or common names in parentheses were: Selecron 720% EC (profenofos ‘’Q’’ g/l); Helerat 5% EC (lambda-cyhalothrin (λ-cyhalothrin) (lambda cyhalothrin)); Karate 5% EC (lambda-cyhalothrin), Megaban Plus (chlorpyriphos-ethyl 48% w/v); Profit 72% EC (profenofos); Thionex 35% EC (endosulfan); Confidence 350 SC (imidacloprid), and Diazinon 60% EC (diazinon) (Table 3). However, none of these chemical pesticides (chemical insecticides) are specifically registered (specifically approved) for the control of onion thrips on onion in Ethiopia. Some of the registered chemical insecticides for the control of onion thrips on onion in Ethiopia by their trade names with common names or a.i. or a.s. in parentheses include: Ajanta 72% EC (w/v) (profenofos); Bestfield 360 SC (chlorfenapyr); Cutter 112 EC (acetamiprid + emamectin benzoate); Danefos 72% EC (profenofos); Fighter (imidacloprid); Girgit-Plus (profenofos 72% EC); Golbe 72% EC (profenofos); Imidacel (imidacloprid); Lamog 5% EC (lambda-cyhalothrin); Locslay 5% EC (lambda-cyhalothrin); Prior 72% EC (profenofos); Radiant 120 SC (spinetoram); Triger 5 EC (lambda-cyhalothrin), and Rectro 25 SC (imidacloprid + lambda-cyhalothrin) (Table 4).

Regarding frequency of spray per season by study participants, 216 (56.1%) responded that they sprayed insecticides 8-12 times per season on onion to control onion thrips, and 144 (37.4%) reported they sprayed 3-7 times per season, while 25 (6.5%) replied they sprayed insecticides weekly. Even some respondents stated that they sprayed on weekly basis especially after watering of onion not only to control onion thrips but also for the ‘good appearance’ or ‘good looking’ (‘quality’) of onion for the market. With regard to yield loss (%) of onion by onion thrips per one production season (year), 294 (76.4%) respondents estimated (guessed) about 20-30% yield loss, and 74 (19.2%) claimed about 31-50% loss of yield, while 17 (4.4%) estimated >50% yield loss per production season (year) if untreated.

Table 2: Responses of farmers on onion thrips economic impact on onion and its control method in the study area (n=385)

Variable	Frequency (n)	Percentage (%)
Major pests of onion*		
Onion thrips	385	100
Others	3	0.8

Do onion thrips attack onion in every growing season (year)? Yes No	 385 0	 100 0
How much yield loss (%) of onion by onion thrips do you estimate (guess) per one production season (year) if untreated? 20-30% 31-50% >50%	 294 74 17	 76.4 19.2 4.4
Control methods of onion thrips on onion Chemical control (using chemical pesticides) Others	 385 0	 100 0
Where do you buy chemical pesticides (chemical insecticides) and pesticide sprayers? Pesticide vendours (pesticide retailers) Others	 358 0	 100 0
Types of pesticide sprayers used 15 L backpack (knapsack) sprayer 20 L backpack (knapsack) sprayer	 251 134	 65.2 34.8
Pesticide (insecticide) spray frequency per season 8-12 times 3-7 times On weekly basis (weekly)	 216 144 25	 56.1 37.4 6.5

*Multiple responses were possible

Table 3: Assessment of synthetic chemical pesticides (synthetic chemical insecticides) commonly used by the farmers for the control of onion thrips on onion in the study area

Trade name	Common name (active ingredient)	Chemical group (class)	WHO* class	Approved use
Selecron 720% EC	Profenofos "Q" 720 g/l	Organophosphate	II	For the control of thrips and lepidopteran caterpillars
Helerat 5% EC	Lambda-cyhalothirin	Pyrethroid	II	For the control of bollworm on cotton
Karate 5% EC	Lambda-cyhalothirin	Pyrethroid	II	For the control of cotton pests on large scale farms

Megaban Plus	Chlorpyriphos-ethyl 48% w/v	Organophosphate	II	For the control of termites on pepper
Profit 72% EC	Profenofos	Organophosphate	II	For the control of pea aphid (*Acyrtosiphon pisum*) on field pea
Thionex 35% EC	Endosulfan	Organochlorine	II	For the control of African bollworm on cotton, maize, sorghum and tobacco
Confidence 350 SC	Imidacloprid	Neonicotinoid	II	For the control of aphids on cotton
Diazinon 60% EC	Diazinon	Organophosphate	II	For the control of armyworm on cereals

Source: My own assessment, 2020

**WHO (World Health Organization) pesticide hazard (toxicity) classification: Ia= Extremely hazardous; Ib=Highly hazardous; II=Moderately hazardous; III=Slightly hazardous; U/IV= Unlikely to present acute hazard in normal use; O=Obsolete pesticide*

Source: Tambe et al., 2019; WHO, 2019

Table 4: Some synthetic chemical insecticides registered in Ethiopia for the control of onion thrips on onion

Trade name	Common name (active substance)	Chemical group (class)	WHO class
Ajanta 72% EC (w/v)	Profenofos	Organophosphate	II
Bestfield 360 SC	Chlorfenapyr	Organophosphate	II
Cutter 112 EC	Acetamiprid +emamectin benzoate	Neonicotinoid + Avermectin	II
Danefos 72% EC	Profenofos	Organophosphate	II
Fighter	Imidacloprid	Neonicotinoid	II
Girgit-Plus	Profenofos 72% EC	Organophosphate	II

Golbe 72% EC	Profenofos	Organophosphate	II
Imidacel	Imidacloprid	Neonicotinoid	II
Lamog 5% EC	Lambda-cyhalothirin	Pyrethroid	II
Locslay 5% EC	Lambda-cyhalothirin	Pyrethroid	II
Prior 72 EC	Profenofos	Organophosphate	II
Radiant 120 SC	Spinetoram	Spinosyn	II
Triger 5 EC	Lambda-cyhalothirin	Pyrethroid	II
Rectro 25 SC	Imidacloprid+ lambda-cyhalothirin	Neonicotinoid + Pyrethroid	II

Source: Ministry of Agriculture (MOA), 2018

4.1.3 Pesticide Use Knowledge of Farmers in Controlling Onion Thrips on Onion

Synthetic chemical pesticide (synthetic chemical insecticide) use knowledge, awareness and understanding of participant smallholder onion cultivating farmers in controlling onion thrips on onion investigated in the present study including farmers' knowledge of the names of pesticides (insecticides) they have been purchasing and using, their knowledge and perception of adverse (harmful) effects of exposure to chemical pesticides (chemical insecticides) on human health and the environment, farmers' knowledge and understanding of the pesticide laws of Ethiopia, their knowledge, awareness and understanding of the importance and use of wearing personal protective equipment (PPE) during pesticide use, i.e., when handling (purchasing, storing, preparation (mixing), application (spraying)) of pesticides and handling and 'disposal' of pesticide wastes including handling and 'disposal' of empty pesticide containers, and the farmers' common self-reported health symptoms (frequent self-reported symptoms of health problems) encountered during and immediately after pesticide (insecticide) use and application are illustrated in Table 5. All (100%) study participants responded that they do not have knowledge of the names of synthetic chemical pesticides (synthetic chemical insecticides) they have been purchasing and using for the control of onion thrips on onion, i.e., they stated that they cannot identify pesticides they have been purchasing and using for the control of onion thrips on onion by their (the pesticides') name. Among the respondents, 134 (34.8%) reported that they perceived exposure to pesticides can cause (or can pose) some harmful effects to (on) human health, whereas 212 (55.1%) of them responded that they thought exposure to pesticides do not have adverse effects on (to) the health of humans, while the rest (39 (10.1%)) replied that they do not have knowledge on the deleterious effects of pesticides to (on) human health. And, from the total study subjects, 112 (29.1%) responded that they perceived exposure to pesticides can have some adverse effects to (on) the health of the environment, whereas 216 (56.1%) of them reported that they thought exposure to pesticides do not affect the environment, while 57 (14.8%) replied that they are ignorant of (they do not have knowledge of) this issue.

Participant farmers in the present study reported that the main informal information sources mainly for mixing (dosage) of chemical pesticides (chemical insecticides) are pesticide vendors (pesticide retailers) (188 (48.8%)), followed by agricultural extension workers (179 (46.5%)) and past personal experiences (18 (4.7%)), but none of them used pesticide labels. Also, all (100%) of the study subjects responded that synthetic chemical pesticides (synthetic chemical insecticides) currently are indispensable for onion production; however, none of the participant farmers reported that they have ever received any formal training (any formal educational training) and technical support on the appropriate and safe use (on appropriate and safe use, handling and application) of chemical pesticides and pesticide use safety measures (safety precautions and safety practices of pesticide use), and adverse (harmful) effects (negative impacts) of inappropriate and unsafe pesticide use (inappropriate and unsafe pesticide use, handling and application) to human health and the environment, and that all the study participants do not have knowledge and understanding of (they lack knowledge of) the national pesticide legislation of Ethiopia. Regarding participant farmers' knowledge, awareness and understanding of the importance and use of wearing personal protective equipment (PPE) during pesticide use, i.e., when handling (purchasing, storing, preparation (mixing), application (spraying)) of pesticides, and handling and disposal of pesticide wastes including handling and disposal of empty pesticide containers, most (361 (93.8%)) study subjects responded that they do not have knowledge, awareness and understanding (they have no knowledge) of the importance and use of wearing PPE during pesticide use, i.e., when handling (purchasing, storing, preparation (mixing), application (spraying)) of pesticides and handling and 'disposal'of pesticide wastes including handling and 'disposal'of empty pesticide containers, while 24 (6.2%) replied that they have some informal information (they stated that they informally heard some information) about the importance and use of wearing PPE during pesticide use. Besides, all the respondents stated and also it was assessed that there has not ever been any availability or supply (provision) of PPE in the study area. With regard to common self-reported health symptoms (frequent self-reported symptoms of health problems) encountered by participant farmers during or immediately after pesticide handling and application, 149 (38.7%) respondents reported they felt dermal irritation, 81 (21%) stated they felt headache, 66 (17.1%) reported they faced problem of eyesight (blurred vision), 46 (12%) stated they felt internal burning sensation (stomach and heart), while 43 (11.2%) of them reported they felt nausea; nevertheless, none of the study participants reported they have ever visited (they have ever been presented to) any health facility or they have ever been admitted to any health institution due to these health symptoms (Table 5).

Table 5: Pesticide use knowledge of participant farmers in controlling onion thrips on onion in the study area (n=385)

Variable	Frequency (n)	Percentage (%)
Do you know synthetic chemical pesticides (synthetic chemical insecticides) you purchase and use by name?		
Yes	0	0
No	385	100
Do you think that exposure to pesticides can cause (can pose) harmful effects to (on) human health?		
Yes	134	34.8
No	212	55.1
Do not know	39	10.1

Do you think that exposure to pesticides can affect the environment?		
Yes	112	29.1
No	216	56.1
Do not know	57	14.8
Informal information sources for the farmers mainly for pesticide mixing (pesticide dosage)		
Pesticide vendors (pesticide retailers)	188	48.8
Agricultural extension workers	179	46.5
Past personal experience	18	4.7
Pesticide labels	0	0
Do you think synthetic chemical pesticides (synthetic chemical insecticides) currently are indispensable for onion production?		
Yes	385	100
No	0	0
Do you have knowledge, awareness and understanding of the importance and use of wearing personal protective equipment (PPE) during pesticide use, i.e, when handling (purchasing, storing, preparation (mixing), application (spraying)) and handling and 'disposal' of pesticide wastes including handling and 'disposal'of empty pesticide containers?		
Yes	24	6.2
No	361	93.8
No availability or supply (provision) of PPE	385	100
Have you ever received any formal training (any formal educational training) and technical support on the appropriate and safe use (on appropriate and safe use, handling and application) of pesticides and pesticide use safety measures?		
Yes	0	0
No	385	100
Common self-reported health symptoms (frequent self-reported symptoms of health problems) encountered by the farmers during or immediately after pesticide handling and application?*		
Dermal irritation	149	38.7
Headache	81	21
Problem of eyesight (blurred vision)	66	17.1
Internal burning sensation (stomach and heart)	46	12
Nausea	43	11.2

Have you ever visited (have you ever been presented to) any health facility or have you ever been admitted to any health institution due to health symptoms you faced during or immediately after pesticide use and application?		
Yes	0	0
No	385	100
Do you have knowledge and awareness of the pesticide legislation of Ethiopia particularly one of its provisions which states that no person shall dispose of any pesticide or pesticide waste in a way that may harm human or animal health or the environment?		
Yes	0	0
No	385	100

*Multiple responses were possible (allowed)

4.1.4 Pesticide Use Practices of Farmers in Controlling Onion Thrips on Onion

Synthetic chemical pesticide (synthetic chemical insecticide) use practices of respondent small-scale onion producing farmers in controlling onion thrips on onion explored in the present quantitative field survey research including their situation of use of pesticide use safety measures (pesticide use safety precautions) like use of PPE during pesticide use and application, the farmers' pesticide storage conditions, and their disposal ways of pesticide wastes including particularly of empty pesticide containers are analysed in Table 6. All (100%) study subjects responded that they do not wear any personal protective equipment (PPE) during pesticide handling and application (purchasing, storing, preparation (mixing), application (spraying) of pesticides, and handling and 'disposal' of pesticide wastes including handling and 'disposal' of empty pesticide containers) except only wearing their ordinary (casual, regular or normal) clothings. Regarding storing of pesticides, the majority of respondent farmers (328, 85.2%) reported that they did (do) not store pesticides because they stated that they bought needed quantity (quantities) of pesticides (insecticides) for current uses and applied it soon after purchase, whereas 39 (10.1%) responded that they stored pesticides in their living houses, and a few of them (18 (4.7%)) replied that they transferred (gave or lent) the remained (leftover) pesticides to friends for current use.

With regard to pesticide (insecticide) mixing, most study subjects (366 (95.1%)) reported that they mixed the amount of pesticides needed for current applications and finished what they mixed, while a handful of them (19 (4.9%)) applied the mixed (diluted) leftover pesticide solutions on the same treated crop. And, the majority of participant farmers (311 (80.8%)) responded that they mixed pesticides on-farm (in the field), while 74 (19.2%) of them mixed pesticides near irrigation water sources (rivers). Also, the most study subjects (373 (96.9%) reported that they discarded empty pesticide containers on-farm and around in the open field, while a dozen of them (12 (3.1%)) replied that they collected the empty pesticide vessels (boxes, cans) in some containers such as plastic receptacles and burnt on-farm, and none of them reported they are currently using empty pesticide containers for other purposes including domestic uses. All the interviewed small-scale onion growing farmers in the present study responded not eating or drinking during preparation (mixing) or application (spraying) of pesticides. And, most (368 (95.6.%)) study participants reported that they sprayed pesticides (insecticides) considering wind direction (wind situation) at about dawn or at around dusk (twilight) with the intention that, as they claimed, there is no or less wind and dazzling rays of the sun at these times of the day and the weather is often calm at those duirinal times, and also, according to their claim, to prevent and avoid burning of onion crop by pesticides which happened when pesticides had been sprayed at the hot sunny times of the day, while a few of them (17 (4.4%)) replied that they applied pesticides (insecticides) at any time of the day without considering wind direction (wind situation). On the other hand, most participants (348 (90.4%)) responded that they did not clean pesticide spraying equipment after completing pesticide spray because, as they stated, they repeatedly use the pesticide sprayers, while only 37 (9.6%) of the respondent farmers reported that they cleaned sprayers after finishing application of pesticides. Regarding keeping their hygiene after pesticide spraying, the majority (344, 89.3%) of the study subjects responded that they took bath and washed their clothes in the irrigation water sources (rivers) with soap after completing pesticide spraying, but 41 (10.7%) of them replied they did not bathe themselves and wash their clothes after finishing pesticide application. Regarding storing of pesticide sprayes, 213 (55.3%) participants responded that they stored pesticide sprsying equipment in kitchens, 93

(24.2%) stored sprayers in grain (or grain and fertilizer) stores, and 79 (20.5%) stored sprayers in their living houses.

Table 6: Pesticide use practices of respondent farmers in controlling onion thrips on onion in the sudy area (n=385)

Variable	Frequency (n)	Percentage (%)
What do you wear during pesticide handling and application?		
Ordinary clothings	385	100
Personal protective equipment (PPE)	0	0
Where do you store pesticides (insecticides)?		
Do not store pesticides-buy needed quantity of pesticides for current uses and applied soon after purchase	328	85.2
In living house	39	10.1
Transfer (give or lend) remained (leftover) pesticides to a friend for current uses	18	4.7
Where do you mix pesticides?		
On-farm (in the field)	311	80.8
Near irrigation water sources (rivers)	74	19.2
Do you consider wind direction (wind situation) and time of spray when spraying of pesticides?		
Spray pesticides considering wind direction at around dawn or at about dusk	368	95.6
Do not consider wind direction and time of spray when applying pesticides	17	4.4
What do you do with mixed (diluted) leftover pesticide solutions?		
No leftover of diluted pesticide mixtures-mix needed amount of pesticides for current applications	366	95.1
Finish on the same treated crop	19	4.9

What do you do with empty pesticide containers? Discard on-farm Burn on-farm Use for other purposes	 373 12 0	 96.9 3.1 0
Do you eat or drink while using pesticides (during handling (preparation (mixing), application (spraying)) of pesticides)? Yes No	 385 0	 100 0
Do you clean pesticide sprayer immediately after finishing spraying of pesticides? Yes No	 37 348	 9.6 90.4
Do you take bath and wash your clothes (keep your hygiene) immediately after completing pesticide applications? Yes No	 344 41	 89.3 10.7
Where do you store pesticide spray equipment? In kitchen In grain (or grain and fertilizer) store In the living house	 213 93 79	 55.3 24.2 20.5

In addition, from the focus group discussion (FGD) held with Kewet district key informant community leaders and key government actors from agricultural development organization on chemical pesticide (chemical insecticide) use knowledge and practices of small-scale onion cultivating farmers in controlling onion thrips on onion using discussion points (Appendix 1, Part II), similar and confirmatory responses and reflections to that of the responses of individual respondent farmers of the present study were obtained from the FGD participants including: onion thrips is a major and serious insect pest of onion in Kewet district and all smallholder onion producing farmers in the district control onion thrips only by using synthetic chemical pesticides (synthetic chemical insecticides) purchasing the chemical pesticides from local pesticide suppliers (pesticide retailers (pesticide vendors)); none of small-scale onion growing farmers in Kewet district have ever received any formal training and technical support on the appropriate and safe use and application of chemical pesticides, and they do not use any pesticide use safety measures (onion cultivating farmers do not use any safety precautions of pesticide use) like use of personal protective equipment (PPE) during pesticide use, i.e., when handling (preparation (mixing), application (spraying), 'disposal') of pesticides and pesticide wastes, and there has not ever been any availability and supply (provision) of PPE in Kewet district; also, most of the farmers discarded ('disposed of') empty pesticide containers on-farm and around in the open field.

4.2 Analytical Experiment

The second part of the main objective of the present research, as described in the introduction section, was analysis (analytical determination and evaluation) of the level and degree of concentration and contamination (pollution) of onion with organochlorine and organophosphate pesticide residues. Thirteen organochlorine pesticides (OCPs), namely, α-HCH, β-HCH, heptachlor, aldrin, heptachlor epoxide, endosulfan I (α-endosulfan), chlordane, DDE, DDD, DDT, endosulfan II (β-endosulfan), methoxychlor and hexachlorobenzene, and two organophosphate pesticides (OPPs), viz., fenthion and fenitrothion were analysed for their residues in onion samples.

4.2.1 Calibration Curve for the Analytical Determination of Target Pesticide Analytes (Pesticide Residues)

Standard analytical calibration curves have been produced for quantification of target pesticide analytes which were obtained by injecting different concentration ranges of the standard analytical calibration solutions, i.e., that were generated by running of different point concentration ranges (levels) of external standard calibration solutions of the pesticide standards of the target pesticide analytes in a concentration range of 2 ng/mL to 100 ng/mL, that is, 2 ng/mL to 50 ng/mL for hexachlorobenzene and fenitrothion; 10 ng/mL to 100 ng/mL for α-HCH, β-HCH, heptachlor, aldrin, heptachlor epoxide, endosulfan I (α-endosulfan), chlordane, DDE, DDD and DDT; 15 ng/mL to 50 ng/mL for fenthion; 30 ng/mL to 100 ng/mL for endosulfan II (β-endosulfan), and 10 ng/mL to 80 ng/mL for methoxychlor (Table 7). These ranges (levels) of concentrations were selected in function of the sensitivity of the gas chromatography towards each pesticide and its MRL in onion (David *et al.*, 2008).

Table 7: Analytical calibration performance parameters and characteristics of the test method (method of analysis) implemented for the study

Pesticide Standard	Concentration Range (ng/mL)	Regression Equation	r^2
α-HCH	10-100	Y=35.675x – 0.099	0.999
β-HCH	10-100	Y=23.161x + 5.093	0.999
Heptachlor	10-100	Y=11.381x + 28.651	0.998
Aldrin	10-100	Y=8.835x + 39.130	0.995
Heptachlor epoxide	10-100	Y=14.052x + 47.645	0.999
Endosulfan I	10-100	Y=9.947x + 38.773	0.999
Chlordane	10-100	Y=43.181x + 128.174	0.998
DDE	10-100	Y=18.492x + 236.783	0.996
Endosulfan II	30-100	Y=1.610x + 16.025	0.996
DDD	10-100	Y=35.160x + 304.236	0.995
DDT	10-100	Y=81.045x + 690.387	0.996
Methoxychlor	10-80	Y=89.331x + 299.526	0.997

Hexachlorobenzene	2-50	Y=34.860x – 32.083	0.997
Fenitrothion	2-50	Y=2.927x + 23.534	0.998
Fenthion	15-50	Y=1.488x – 1.391	0.999

α-HCH=Hexachlorocyclohexane (α isomer); β-HCH=Hexachlorocyclohexane (β isomer); DDD= Dichlorodiphenyldichloroethane; DDE=Dichlorodiphenyldichloroethylene; DDT=Dichlorodiphenyltrichloroethane

r^2 =squared correlation coefficient

Linearity in the analytical calibration curves has been observed all along the area of concentration studied depending on the target pesticide chemicals (Figure 6, Appendix 2 (Part IV)). The quality of a bioanalytical method is highly dependent on the linearity of the calibration curve and a linear calibration curve is a positive indication of assay performance (Seyed & Sussan, 2018). Acceptability of linearity is often assessed by examining squared correlation coefficient (r^2) of the linear regression equation line for the analytical response (target analyte peak areas or peak heights) versus target analyte concentration plot. A squared correlation coefficient (r^2) of ≥0.995 is generally considered acceptable (AOAC Official Method 2007.01, 2007; Ashenafi, 2009). Calibration curves of all the studied target analytes show satisfactory linearity over selected concentration ranges with regression correlation coefficients (r^2) ranging from 0.999 for α-HCH, β-HCH, heptachlor epoxide, endosulfan I and fenthion; 0.998 for heptachlor, chlordane and fenitrothion; 0.997 for methoxychlor and hexachlorobenzene; 0.996 for endosulfan II, DDT and DDE to 0.995 for DDD and aldrin (Table 7). Also, analysis (extraction) of reagent blank showed no interfering species in the reagents.

Analytical peak responses (peak areas or peak heights) were identified by comparison of the retention times with those in the corresponding standards (Figures 4(a-c) and 5(a-c), Appendix 2 (Part III)). Concentrations of pesticide residues in onion samples were quantified from the analytical peaks (peak areas or peak heights) using the standard analytical calibration curves produced by the analytical instrument (Appendix 2 (Part IV)). Calibration curve is a regression model used to predict the unknown concentrations of analytes of interest based on the response of the instrument to the known standards, and it is a linear relationship between concentration (independent variable) and response (dependent variable) using a least squares method (Seyed & Sussan, 2018).

Heptachlor

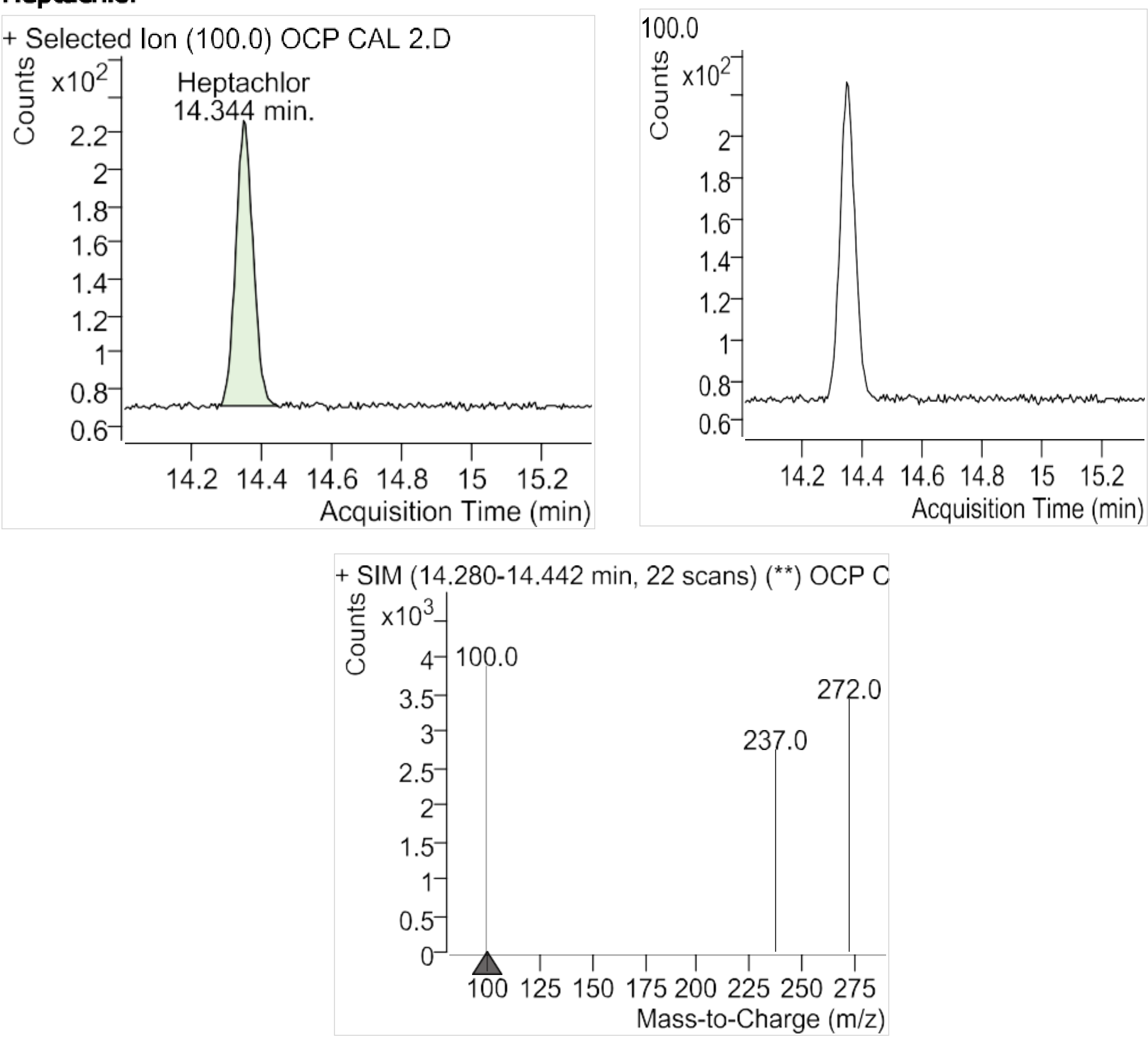

Figure 4 (a): Sample chromatogram for heptachlor

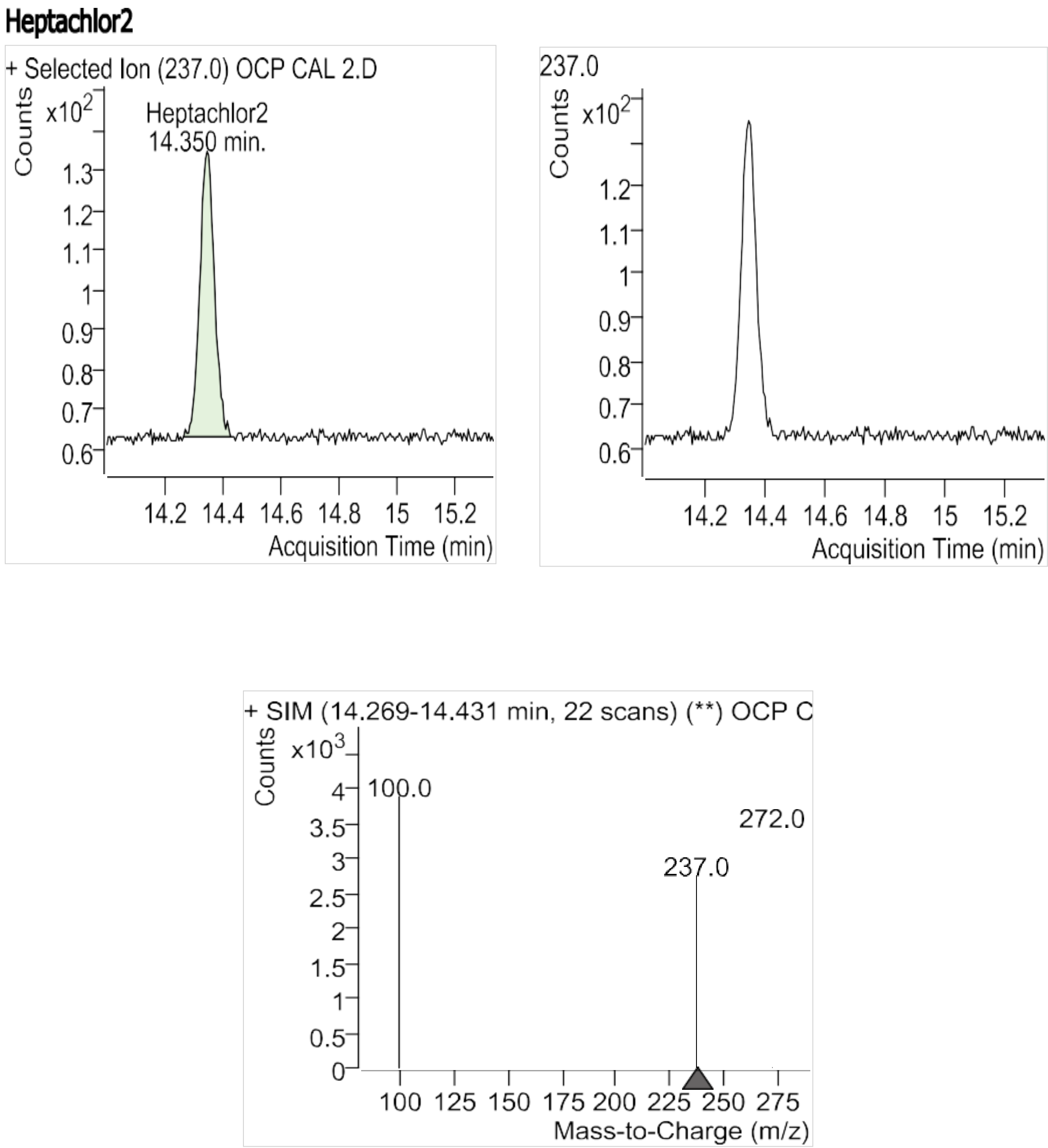

Figure 4 (b): Sample chromatogram for heptachlor

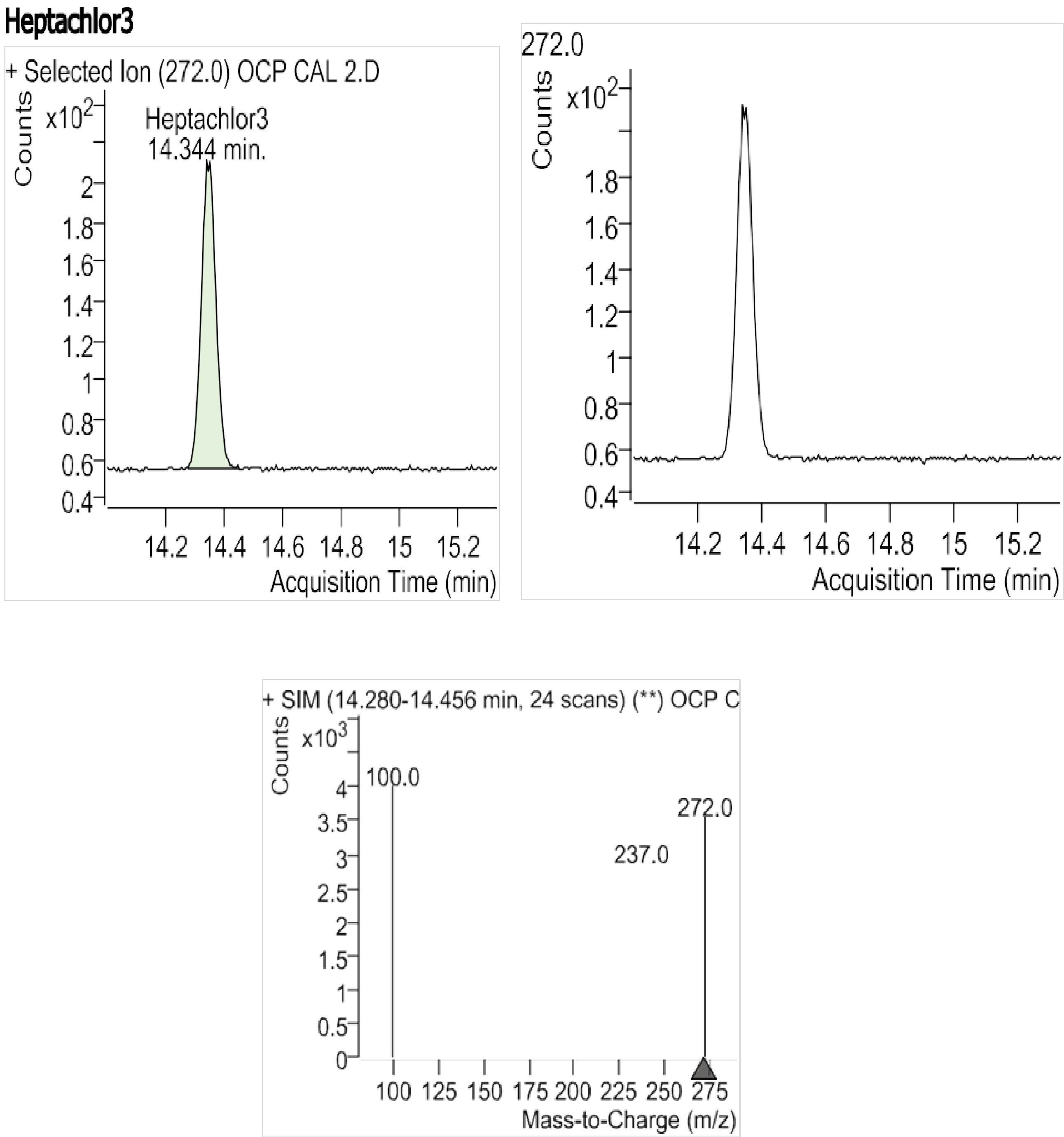

Figure 4 (c): Sample chromatogram for heptachlor

DDE (Dichlorodiphenyldichloroethylene)

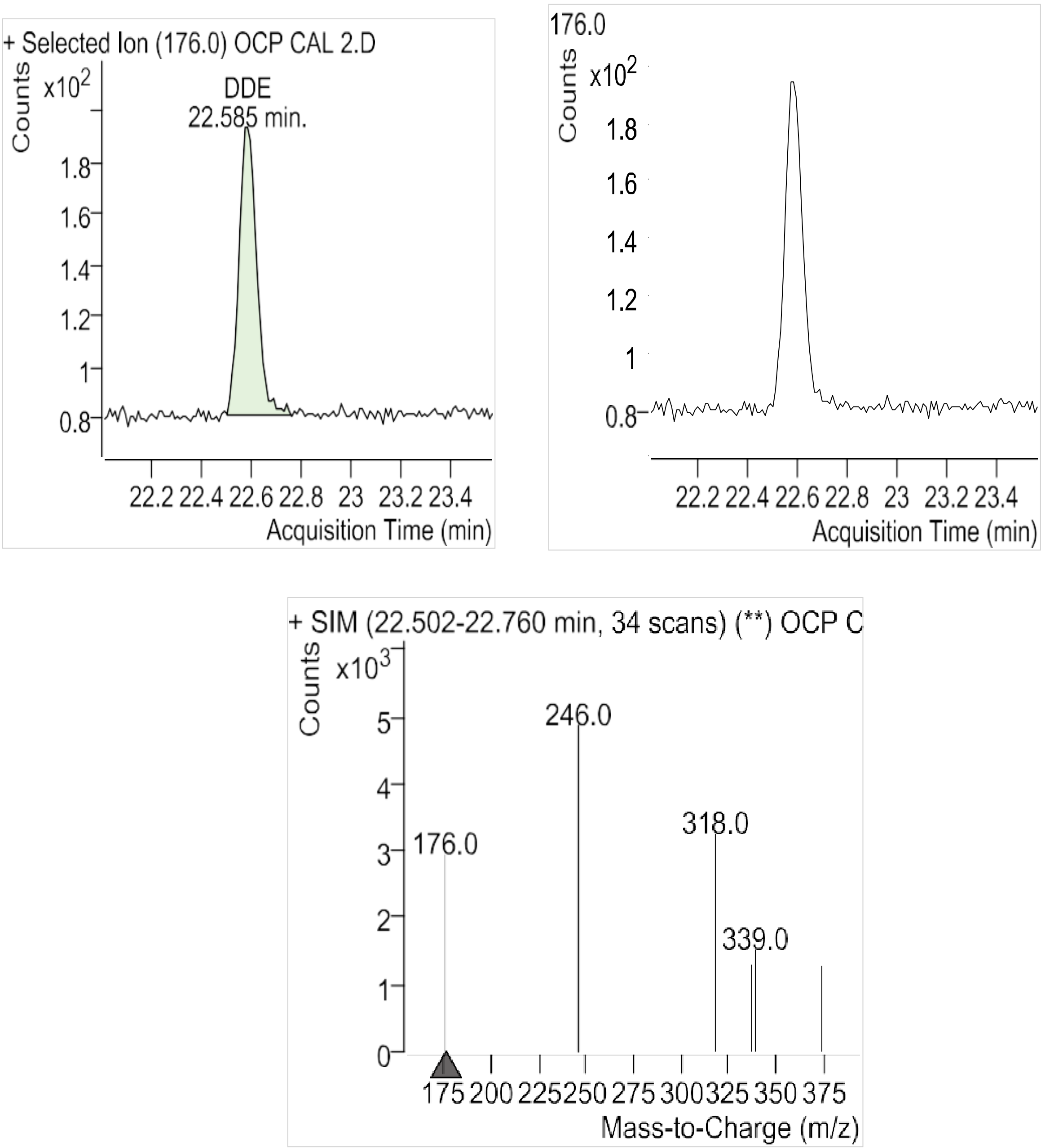

Figure 5 (a): Sample chromatogram for DDE

DDE2

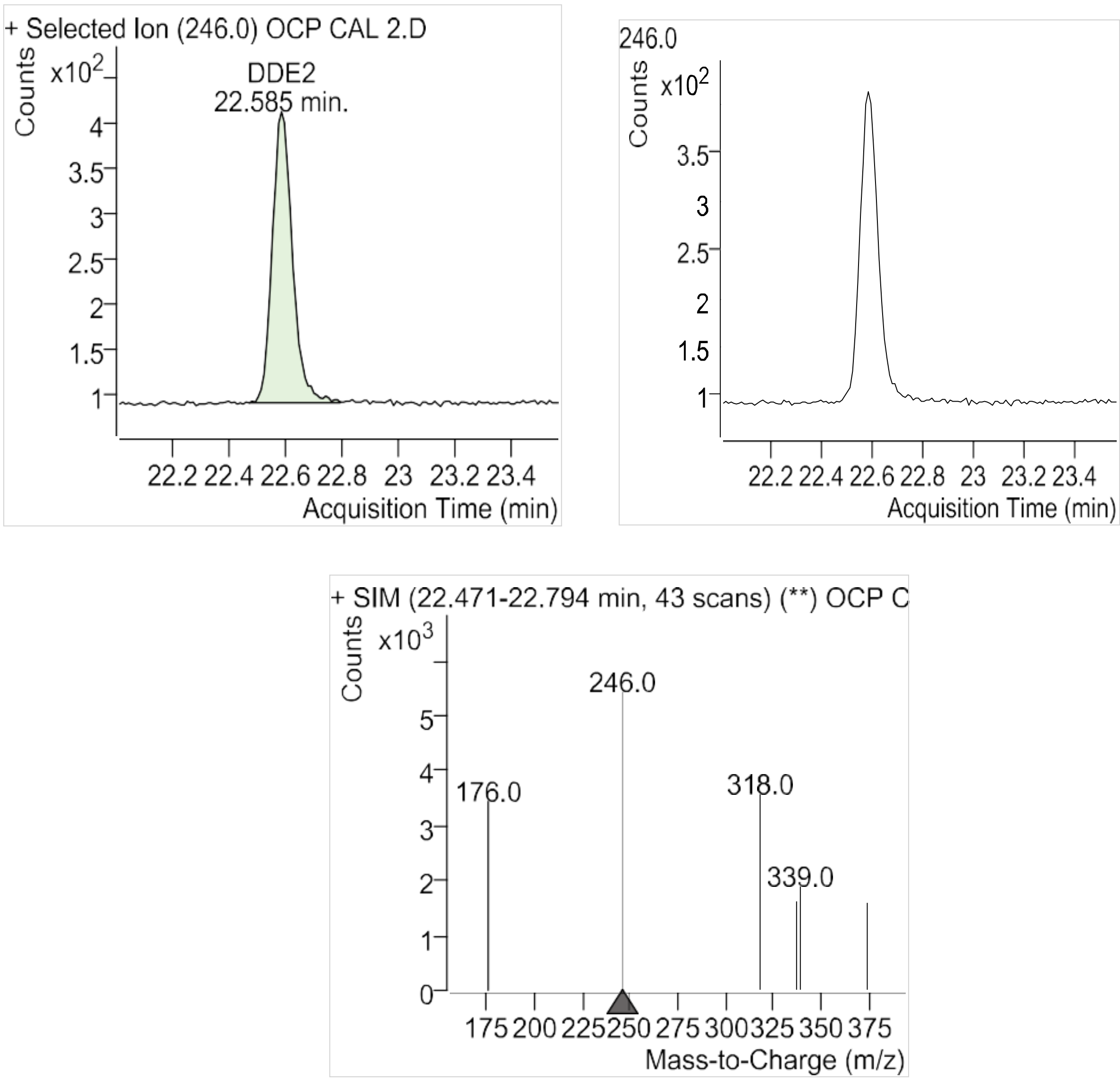

Figure 5 (b): Sample chromatogram for DDE

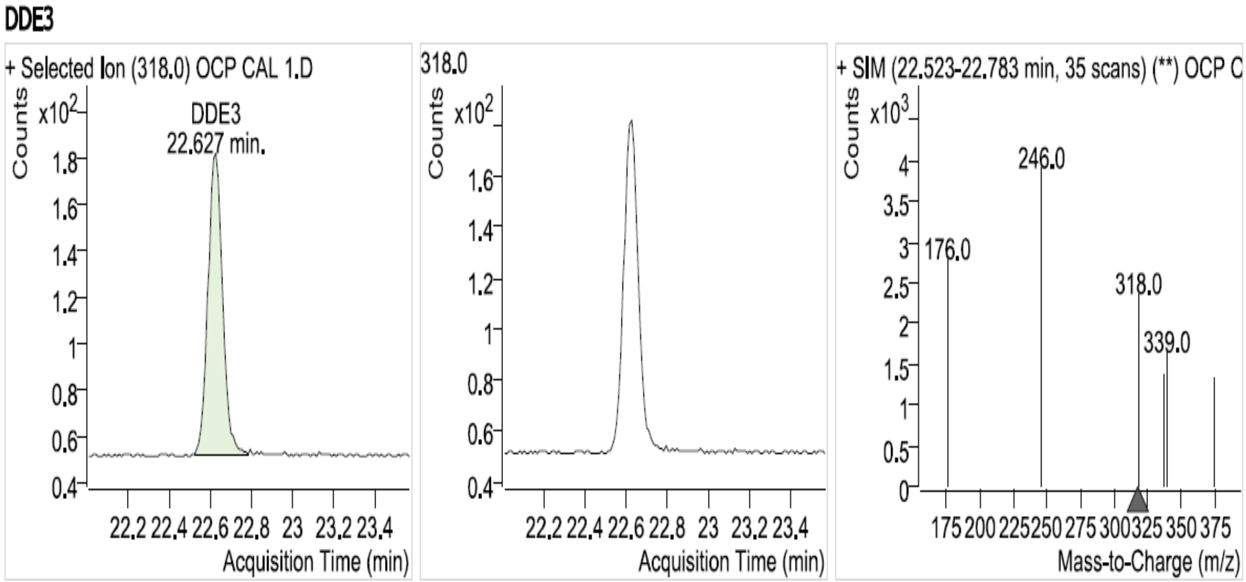

Figure 5(c): Sample chromatogram for DDE

DDD (Dichlorodiphenyldichloroethane)

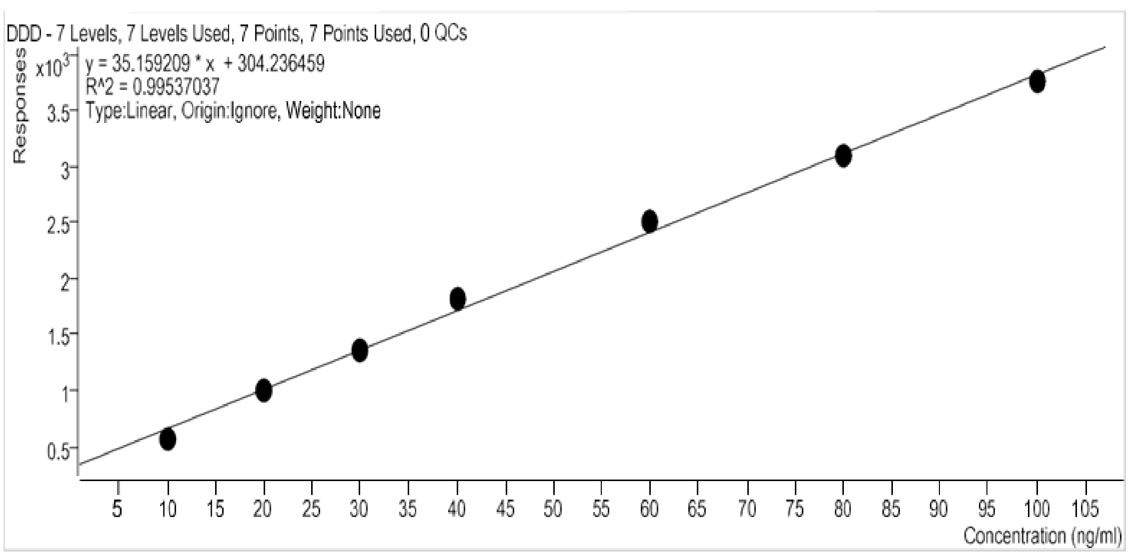

Figure 6: Sample calibration curve for DDD

4.2.2 Analysis of Pesticide Residues in Onion

Analysis (analytical determination and evaluation) of thirteen organochlorine and two organophosphate pesticide residues (analysis of the pesticides for their residues) in onion samples in the present study were performed in triplicate and concentrations of the pesticides residues were determined using the reference standards. Out of the organochlorine and organophosphate pesticide residues analysed, only four pesticide residues were detected. These were α-HCH which was detected in the first and second analyses with average pesticide residue of 0.004 mg/kg, β-HCH and heptachlor epoxide that were detected only in the first analysis with residue values of 0.001 mg/kg and 0.007 mg/kg respectively, and DDE which was detected in the second analysis with 0.008 mg/kg residue. However, heptachlor, aldrin, endosulfan I, Chlordane, endosulfan II, DDD, DDT, methoxychlor, fenitrothion, fenthion and hexachlorobenzene were not detected in the onion samples in all the analyses (Table 8).

Table 8: Average concentrations of OCPs and OPPs residues analyzed in onion in the study

Test Method (Method of Analysis) Used	Pesticide	Average pesticide residue concentration (mg/kg) in onion
AOAC Official Method 2007.01	α–HCH	0.004
	β-HCH	0.001
	Heptachlor	ND
	Aldrin	ND
	Heptachlor epoxide	0.007
	Endosulfan I	ND
	Chlordane	ND
	DDE	0.008
	Endosulfan II	ND
	DDD	ND
	DDT	ND
	Methoxychlor	ND
	Hexachlorobenzene	ND
	Fenitrothion	ND
	Fenthion	ND

ND=Not detected
OCPs=Organochlorine pesticides
OPPs=Organophosphate pesticides

4.2.3 Comparison of Pesticide Residues Results in Onion in the Study with MRL Values in Onion from Different Sources

Comparison was made between pesticide residues detected in onion samples in the present study and MRLs in onion established by Japan, EU, Codex (FAO/WHO) and USA. All the detected pesticide residues in onion in the present study were below the MRL values set by the different sources mentioned here (i.e., of Japan, EU, Codex (FAO/WHO) and USA) (Table 9).

Table 9: Concentrations of target pesticide analytes (pesticide residues) detected in onion in the study (Ethiopia) compared with Japan, EU, Codex (FAO/WHO) and USA MRLs of the OCPs and OPPs in onion

Pesticide	Concentration of target pesticide analytes in onion (mg/kg) (Ethiopia)	Japan MRLs in onion (mg/kg)	EU MRLs in onion (mg/kg)	Codex (FAO/WHO) MRLs in onion (mg/kg)	USA MRLs in onion (mg/kg)
α -HCH	0.004	0.01	NF	NF	NF
β -HCH	0.001	0.01	NF	NF	NF
Heptachlor	ND	0.03	0.01	NF	NF
Aldrin	ND	0.02	NF	NF	NF
Heptachlor epoxide	0.007	NF	NF	NF	0.03
Endosulfan I	ND	0.2	0.05	NF	NF
Chlordane	ND	0.02	NF	NF	NF
DDE	0.008	0.5	NF	3.5	0.5
Endosulfan II	ND	0.2	0.05	NF	NF
DDD	ND	0.5	NF	3.5	0.5
DDT	ND	0.5	NF	3.5	0.5
Methoxychlor	ND	0.01	0.01	NF	NF
Hexachlorobenzene	ND	NF	0.01	0.01	NF
Fenitrothion	ND	NF	0.01	0.01	NF
Fenthion	ND	NF	0.01	0.01	NF

ND=Not detected; EU=European Union; FAO/WHO=Joint Food and Agriculture Organization of the United Nations and World Health Organization; Codex=Codex Alimentarius Commission of FAO/WHO; USA=United States of America; OCPs=Organochlorine pesticides; MRLs=Maximum residue limits; OPPs=Organophosphate pesticides; NF=Not found

Sourcces: David et al., 2008; Ashenafi, 2009; Kumelachew et al., 2020; Tereza et al. 2020

5 DISCUSSION

5.1 Field Survey Study

The objective of the present quantitative field survey study (which is the first part of the main objective of the present research) was to investigate and evaluate levels of synthetic chemical pesticide particularly synthetic chemical insecticide use knowledge and practices of small-scale (smallholder) onion cultivating farmers in controlling onion thrips on onion in Kewet district, central Ethiopia. Understanding farmers' levels of knowledge and practices of pesticide and pesticide use (identifying pesticide and pesticide use knowledge, awareness, understanding and practices gaps in farmers) is vital for urgently developing, formulating and implementation of sound pesticide and pesticide use policies, policy recommendations and strategies, promptly reviewing (updating) and developing pesticide regulatory framework, particularly urgently reviewing, amending (making inclusive and reinforcing) and developing pesticide legislations (pesticide laws and regulations), and instantly and stringently enforcing pesticide legislations at all levels starting at the retail (retailer) level and at the farm (farmer) level, and immediately formulating and implementation of pesticide and pesticide use intervention strategies and intervention measures including designing comprehensive (holistic) and appropriate pesticide and pesticide use education (extension education) and training (educational training) programs and immediately addressing and presenting to the farmers to elevate their (the farmers') levels of knowledge, awareness and understanding of pesticide and pesticide use that aimed at preventing, reducing (minimizing and limiting) and avoiding (eliminating) environmental health and human health hazards and risks (overall ecosystems health problems) caused by and associated with pesticide and pesticide use, especially in developing countries like Ethiopia and particularly in small-scale (smallholder) onion and other vegetables producing farmers where inappropriate (irrational), injudicious, excessive, extensive, abuse (abused) and unsafe use and misuse of pesticides is immense and adverse (deleterious) effects of inappropriate and unsafe use (negative (harmful) impacts of inappropriate and unsafe use, handling and application) of pesticides to the health of humans and to the health of the environment (to the health of aquatic and terrestrial ecosystems in general) are alarming and threatening because of farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (on the appropriate and safe use, handling and application) of pesticides, due to the prevalence of numerous pests (especially insect pests) of these vegetable crop plants, lack (absence) of promotion of the available alternative pest control and management approaches (methods) and practices such as integrated pest management (IPM) approaches (methods) and good agricultural practices (GAP), and pesticide-independent (pesticide non-dependent) farming approaches and practices such as organic (ecological or eco-friendly) farming (ecological (eco-friendly) agriculture) approaches (systems) and practices, and unavailability of other newly innovated alternative pest control and management approaches and methods, and where these environmental health and human health hazards and risks (overall ecosystems health problems) caused by and associated with pesticide and pesticide use have been generally ignored (or left neglected), or otherwise less explored in the developing countries including Ethiopia.

In the present study, most (95.8%) of the participant smallholder (small-scale) onion cultivating farmers were males, the majority of them (91.2%) being in their active ages (within young and middle age ranges (20-60 years of age)) with the respondents' mean age of 45 ± 9.4 (SD) years, and 8.8% of the study participants were above 60 years of age. This implies that the workforce in the small-scale onion farming in Kewet district is mostly male-dominated, and this could be attributed to the labour-intensive nature of onion cultivation which requires hard and labourious physical (mechanical and/or manual) work and energy, which might naturally limit the involvement of females and elderly people, and hence it may be less attractive to most females and the elderly. Also, the active age ranges indicated (20-60 years of age) could be the likely subject groups for accepting and adopting agricultural and other development technologies and interventions including pesticides (insecticides) (could be early adopters of agricultural technologies and interventions including pesticides (insecticides)). These findings of the present study are similar to the study conducted by Adesuyi *et al*. (2018) for investigating pesticide related knowledge, attitude and safety practices among small-scale vegetable farmers in Nigeria that 94.8% study subjects (94.8% of study subjects) were males while 5.2% were females in vegetable farming. Likewise, in a study conducted by Mwabulambo *et al*. (2018) for evaluating health symptoms associated with pesticides exposure among flower and onion pesticide applicators in Arusha, Tanzania, it was reported that all the study participants were males whose mean ages were 30.63 ± 6.048 years, and 28.02 ± 7.557 years for flower and onion farms (pesticide applicators), respectively, and a majority of pesticide applicators in onion farms (62.5%) were below 29 years of age (in which 5.4% were ≤18 years and 57.1% were aged 19-28 years), 26.8% were 29-38 years of age, and 10.7% were 39 and above years, while, 52.4% of pesticide applicators in flower farms were aged between 29 and 38 years, 36.9% were 19-28 years of age, and 10.7% were aged 39 and above years. Also, Dilek *et al*. (2018) in their study for investigating knowledge level, attitude, and behaviors of farmers regarding the use of pesticides in Çukurova, Turkey showed that all (100%) study subjects were males with their mean age of 40.2 ± 10.6 years, and more than half (51.9%) of the farmers were over 40 years of age, while 24.3% of them were over 50 years, and 6.0% were 60+ years. Similarly, Mergia *et al*. (2021) in their study conducted for exploring small-scale farmer (vegetable farmers) pesticide knowledge and practice and impacts on the environment and human health in the Rift Valley region in Ethiopia (the major vegetable crops in their study area being tomato cabbage and onion) reported that the majority of farming activities (98%) were performed by males. In addition, farmers included in studies in other countries such as in India by Mohanty *et al*. (2013), and Kuwait by Mustapha *et al*. (2017) were all (100%) males, while in studies in Togo by Adjrah *et al*. (2013), most (92%) were males, in which 73% respondent vegetable growers were young or middle-aged men, between 21–50-years-old; Tanzania by Lekei *et al*. (2014), the respondents were mostly (88.4%) males, and age ranged from 18–66 years with an average age of 37.5 years (SD 11.38), and most (88%) farmers had less than 7 years of education; Bangladesh by Ali *et al*. (2020), from 917 study participants, 914 were males, and Brazil by Waichman *et al*. (2007), 97.4% study subjects were males. In contrast, a study conducted by Kafle *et al*. (2021) for investigating factors associated with practice of chemical pesticide use and acute poisoning experienced by farmers in Chitwan, Nepal reported that among 790 participants, 50.8% were females while 49.2% were males. In another study done by Tuna *et al*. (2012) to explore farmers' knowledge, attitudes and behaviors about pesticide storage conditions and safe use in Turkey, the mean age of the farmers was 51.3 ± 8.6 years, while in the study by Mohanty *et al*. (2013) in India, the mean age of the respondents was 54.3 years (SD = 8.2).. In a study conducted by Yassin *et al*. (2002) for evaluating knowledge, attitude, practice, and toxicity symptoms associated with pesticide use among farm workers in the Gaza Strip (Palestine), the average age of the respondent farm workers was 32.4 (0.8) years old, while in the study done by Mergia *et al*. (2021) in Ethiopia, about half of the small-scale vegetable farmers (50.5%) ranged between 31 and 54 years of age, with a mean of 35.2 years, and nearly 8% of the farmers were over 55 years old, and the study by Adesuyi *et al*. (2018) in Nigeria reported that about 50.7% of the farmers had their ages between 35– 44 years with 31.2% within the range of 25 and 34 years, while only 1.2% of the farmers were above 55 years, and the average age of the farmers was 36 years. Likewise, in the study by Kafle *et al*. (2021) in Nepal, it was shown that more than half of the farmers (53.7%) belonged to the age group of 30–50 years, 35.6% had 51 years and above, and 10.8% had 18-29 years of age, with mean age of the farmers being 46.04. Also, Mustapha *et al.* (2017) in their study conducted for exploring pesticide knowledge and safety practices among farm workers in Kuwait reported that majority of the respondent farmers (69.70%) were between 21 and 40 years old, while slightly more than 9% of the farmers were 50 years and over, with average age of the study participants being 29.8 years. On the other hand, in a study conducted by Alice *et al*. (2019) in Burkina Faso, the age range (percent) distribution among participant vegetable farmers grouped was almost similar (18-30 (23.4%); 31- 40 (29.9%); 41-50 (19.6%); 51-58 (26.0%)), and in a study by Cevik *et al* (2020) in Turkey, the farmers' mean age was 47.7±9.9 years, and 72.2% of them were in the age group of 40-59 years. Age, which is one of the socioeconomic factors, is an important element (factor) for farmers' awareness on the prohibited and approved chemicals (Dilek *et al*., 2018). Older farmers may not be aware of the use of new chemicals due to lack of knowledge (Tijani & Nurudeen, 2012; Dilek *et al*., 2018). A study conducted by Taghdisi *et al*. (2019) for investigating knowledge and practices of safe use of pesticides among a group of farmers in northern Iran on the other way found that age had an inverse correlation with pesticide safe use practice stating (noting) that those with higher exposure to pesticides over a longer period of working on field may feel that they are no longer vulnerable to the side effects, and the more experienced farmers, in spite of their satisfactory level of knowledge, were more careless about adhering to safety measures. But, in a study conducted in India, no correlation was found between age of participants and pesticide safe use practice (Kumari & Reddy, 2013; Taghdisi *et al*., 2019). However, higher and prolonged (chronic or long-term) exposures to pesticides especially without appropriate safety measures and inappropriate and unsafe use (inappropriate and unsafe use, handling and application) of pesticides could possibly and likely (could potentially possibly and likely) pose higher (often latent (hidden) but hazardous (dangerous) and serious) health problems (health outcomes) and needs concern of this issue (the issue).

Regarding participant farmers' cultivated land size of onion, the majority of respondents (82.3%) in the present study owned small land size (0.25 ha to 0.75 ha) which might make the participants learn (realize) and have thoughts of using or tending to apply more agricultural technologies including extensive use of pesticides (insecticides) to obtain higher onion produce (yield) from a small plot of land. With regard to land tenure status, about a quarter (24.9%) of the study subjects were rented landholders of small size (0.25 ha to 1.25 ha) who might also think (realize) to use and be enforced to apply more pesticides (insecticides) to compensate their expenses including renting contracts (payments) of/for (the) lands and gain the return they would expect. These findings of the present study are comparable to the study conducted by Alice *et al*. (2019) for evaluating knowledge, attitude and practice of pesticides use and waste disposal among vegetable and cotton farmers in Burkina Faso who showed that majority of the vegetable farmers owned farmlands less than 2 ha, while the cotton farmers owned a maximum of 59 ha, and also, to the study by Mergia *et al*. (2021) in Ethiopia who described that the respondents were typically small-scale farmers with farm sizes ranging from less than one hectare to over ten hectares with an average of 1 ha, and nearly 60% of (the) farmers had land possessions smaller than 1.1 ha and 40% of the farmers possessed land over 1.0 ha, adding that the land used by 61.9% of the small-scale farmers was rented from local farmers for 3 to 5-year contracts. Likewise, in the study by Mustapha *et al*. (2017) in Kuwait, participants' farm sizes varied from less than 5 ha to over 10 ha, with an average of 4.5 ha, and in the study by Adesuyi *et al*. (2018) in Nigeria, majority of the farmers were with less than 5 hectares per respondent. Concerning land tenure, Ojo (2008) in Nigeria noted that the land tenure system in Africa is a major factor, among others, that seriously limits access to land for both small and large scale agricultural production. Majority of the study participants (79.5%) in the present study have 15-25 years and over onion farming experiences with an average onion cultivation experience of 21 years. These experiences they gained (learned from doing) in the course of their onion farming times could enable them possess (acquire) more onion production skills and also could very likely increase their decision capability (ability) on the acceptance and adoption of agricultural technologies including pesticides (insecticides). Dilek *et al*. (2018) reported that the participant farmers in their study had been engaged in farming for a mean duration of 18.5 ± 10.6 years, with 48.1% of them have been engaged in farming for more than 20 years. Also, Cevik *et al*. (2020) described that sixty-five point eight per cent had been farming for 15 years and over, and Adesuyi *et al*. (2018) showed that 46.8% had 6–10 years of farming experience, with 35.0% having more than 10 years of farming experience, with the average number of years of vegetable farming being 9.8 years, while Mustapha *et al*. (2017) reported that most of the respondents (68%) had 5–10 years of farming experience, with 10.4% having more than 10 years of farming experience, and Mergia *et al* (2021) described that 45.7% of farmers had five to ten years of farming experience, and 41.9% had greater than ten years of farming experience, while Adjrah *et al*. (2013) showed that 60% farmers have 5 or over years of experience in vegetable farming processes. Experience in farming is an important factor as it is an important element (factor) in acquiring practical skills in farming (cultivation) activities (in farming (cultivation) operations), and experience can lead to increased production, effective input use, increased output quality and quantity, reduced costs, and could have a positive influence on the management ability of a farmer (Dilek *et al*. (2018).

In the present study, a substantial number of the respondent small-scale (smallholder) onion cultivating farmers (53.5%) were illiterate), while the rest had limited formal (primary) and informal (adult) education, and all (100%) study participants in the present study did not receive any formal educational training (any formal training) and technical support on the appropriate and safe use (usage) (on the appropriate and safe use (usage), handling and application) of pesticides, and pesticide use (usage) (pesticide use (usage), handling and application) preventive, protective, safety and precautionary measures (safety precautions and safety practices of pesticide use (usage)), and adverse (deleterious) effects (negative (harmful) impacts) of inappropriate and unsafe use (inappropriate and unsafe use, handling and application) of pesticides to the health of the environment and to the health of humans. Consequently, illiteracy and low level of education of these farmers in the present study can affect and limit their ability to read and understand pesticide use information especially pesticide labels including particularly of information on preventing, reducing and avoiding human health hazards and risks of pesticide exposure (including particularly of information on preventing, minimizing and eliminating pesticide exposure human health hazards and risks), and also limit and constrain their access to other written information communication on the appropriate and safe pesticide use (on the appropriate and safe pesticide use, handling and application), which could expose farmers to direct pesticide contact and immediate exposure to pesticides and consequent instant acute (short-term) pesticide exposure poisoning (acute pesticide intoxications) (APP) human health hazards and risks and chronic (long-term or prolonged) pesticide exposure human health problems (acute and chronic human health hazards and risks (acute and chronic human health problems)) during and after pesticide use and application, accumulation of pesticide residues (pesticides) on/in onion during the likely excessive pesticide (insecticide) application (spraying) and hence contamination and pollution of the onion produce by these harmful pesticide residues (pesticides) which would pose harm to human health (consumers) (which would pose human health problems), and environmental contamination and pollution which could present negative impacts onto the health of the environment when using and applying pesticides, and during handling and disposal of pesticide wastes including particularly of when handling and disposing of empty pesticide containers due to inappropriate and unsafe use (usage) (inappropriate and unsafe use (usage), handling and application) of pesticides, and inappropriate and unsafe disposal of pesticide wastes including particularly of inappropriate and unsafe disposal of empty pesticide containers without any pesticide use (usage) (without any pesticide use (usage), handling and application) preventive, protective, safety and precautionary measures (without any pesticide use safety precautions and without any pesticide use safety practices), because of the study subjects' poor level of education, and lack of knowledge, awareness and understanding of the appropriate and safe use (usage) (the appropriate and safe use (usage), handling and application) of pesticides in the study area of the present study. Illiteracy and lower level of education of the farmers can particularly affect or limit their ability to perform some critical technical tasks such as calibration of pesticide spray equipment (pesticide spray tanks) and mixing of pesticides that require somewhat better technical education and training (practical educational training) (Adesuyi *et al*., 2018). And, this may affect the farmers' operational behaviours and practices in relation to pesticide use (usage) and application (Okoffo *et al*., 2016; Adesuyi *et al*., 2018). Ashburner and Friedrich (2001), Kemabonta *et al*. (2014) and Adesuyi *et al*. (2018) reported that education has a great influence on the overall behavior and the dispositions of individuals towards adoptions of agricultural related innovation. Educated and enlightened farmers are more knowledgeable about pesticide safety, have better ability to read, understand and follow hazard warnings on pesticide labels, and conceptualized the consequences of poor pesticide use (usage) practices (Karunamoorthi *et al*., 2012; Mustapha *et al*., 2017). Education influences knowledge (Mohanty *et al*., 2013). It was reported that the level of education has an association with the level of knowledge, and there is significant association between good level of knowledge about pesticide and pesticide use such as pesticide waste disposal and education level (Sa'ed *et al*., 2010; Mohanty *et al*., 2013; Mergia *et al.*, 2021). Taghdisi *et al*. (2019) in northern Iran found that there was a correlation between education level and knowledge of the safe use of pesticides, showing that farmers with lower level of education were at higher risk of pesticide poisoning. The high illiteracy rate among the farmers would lead to lack of knowledge of the pesticides' side effects, and of how to manage them (Aghilinejad *et al*., 2006; Taghdisi *et al*., 2019). The level of farmer's education would influence their ability to read and understand pesticide labels, and improper handling and application of pesticides by farmers could be attributed to their no to little educational level (Yİlmaz, 2015; Sharafi *et al*., 2018; Alice *et al.*, 2019). Illiterate farmers and farmers with limited formal education, and who did not receive any formal training (who did not receive any formal educational training) and/or technical support in pesticide safety are hampered in their ability to read and understand pesticide labels regarding the correct and safe use of pesticides (Al-Zadjali *et al*., 2015; Mustapha *et al*., 2017). Farmers' awareness of pesticides is related to their educational status (Dilek *et al*., 2018). Educated farmers can read publications and access information through the Internet, thus reducing the lack of information (Tijani & Nurudeen, 2012; Dilek *et al*., 2018). Being educated increases access to information, training, and communication materials, enables a better awareness of various workplace hazards, and ensures an understanding of safe work procedures and a better propensity to develop a positive attitude towards occupational health and safety (OHS) at work (Tambe *et al*., 2019). Also, educated farmers are able to read and understand the pesticide labels and apply the products correctly, while less educated farmers might be hindered and hampered) in their abilities to follow the prescribed guidelines (Ibitayo, 2006; Recena *et al*., 2006; Michael *et al*, 2016), and a total or an overall lack of education has been associated with poisonings, exposure risks, and high mortality rates in many rural areas of developing countries (Zyoud *et al*., 2010; Zhou *et al*., 2011; Remoundou *et al*., 2014; Michael *et al*, 2016). Uneducated farmers and farmers with low level of education could not read or understand pesticide labels about the proper and safe use of pesticides (Waichman *et al*., 2007; Mergia *et al*., 2021), and hence, the application procedures would be disorganized and haphazard, and this condition of farmers has significant effects on the environment and the health of farmers (Mergia *et al*., 2021). Farmers with high levels of education were well-informed about pesticide safety, and could read, recognize, and obey hazard signs on container labels, and understanding the effects of poor pesticide use (usage) practices (Karunamoorthi *et al*., 2012; Mergia *et al*., 2021). Illiterate and low education level farmers are unable to read and understand the information provided on the containers' labels, especially pesticide labels written with specific foreign language words (Jafari *et al*., 2014; Taghdisi *et al*., 2019). To raise farmers' knowledge, awareness and understanding of appropriate and safe pesticide use (to elevate farmers' knowledge, awareness and understanding of correct and safe use of pesticides), it is compulsory and recommended to educate and train (to deliver (present) educational training to) farmers on pesticide handling and application, pesticides' side effects, and pesticide use preventive, protective, safety and precautionary measures (pesticide use safety precautions and pesticide use safety practices) (Aghilinejad *et al*., 2007; Kumari & Reddy, 2013; Taghdisi *et al*., 2019)

In the present study, none of the participant farmers read (understand) and used (followed) pesticide labels (pesticide label instructions) as their knowledge and information source for appropriate and safe pesticide use (for appropriate and safe pesticide use, handling and application) due to their illiteracy and low level of education, and lack of knowledge, awareness and understanding of the importance of pesticide labels for appropriate and safe use (for appropriate and safe use, handling and application) of pesticides. This is a great cause for concern, and likely an indication of a general ignorance of the importance of pesticide labels in reducing pesticide exposure hazards and risks. The pesticide label is of particular and paramount importance as it is an immediate (frontline) and primary knowledge and information source for appropriate and safe use, (for appropriate and safe use, handling and application) of pesticides, and preventing, reducing (minimizing) and avoiding (eliminating) pesticide exposure environmental health and human health hazards and risks (overall health problems), i.e., for the safe use of pesticides, it is crucial to follow the label instructions on the pesticide packaging (on the pesticide containers or boxes). To serve this critical purpose, pesticide labels must be prepared and written concisely (precisely), clearly and legibly with simple language wording and easily understandable expressions, consisting of the necessary (essential) and relevant information required mainly information on pesticide use safety precautions (pesticide use safety measures) (pesticide use safety information) and pesticide use practical application recommendations in its text content, and its layout must be designed carefully and its text wording (typing) should be written (made) economically but clearly and legibly, and its text contents and language must be stringently and critically evaluated, checked and approved by the authorized regulatory body, taking into account profoundly and incorporating language barriers of pesticide users particularly pesticide end-users (local people)) whilst label approval during/in pesticide registration in Ethiopia (and probably beyond), and the original authorized (approved) label, which is a legal document, must be present (attached) on all original pesticide product packages or pesticide product containers and must be visible on all original pesticide product packs. The pesticide label is one of the most important sources of pesticide information, providing all relevant information for safe application of pesticides and moreover for environmental health and human health hazard and risk reduction (Waichman *et al*., 2007; Adjrah *et al*., 2013). The label on the pesticide container plays an important role in the correct use of the pesticide (Mandel *et al*., 2000). Kafle *et al*. (2021) in Nepal noted that label of pesticides is a critical marker of hazardousness and toxicity of pesticides, and showed in their study that only a quarter of the respondent farmers observed the label and toxicity of pesticide and 16.9% of them observed waiting time of the pesticide during purchase denoting the unawareness of farmers about safety provisions during purchase of pesticides. Adesuyi *et al*. (2018) reported that over 77% of the farmers in their study did not read or follow the instructions on pesticides label, 69.5% of them stating that they cannot read and understand the label instructions, and 31.5% stated that the labels were written in English language, while only 22% of the farmers were able to read, understand, and follow pesticide label instructions correctly. In the study by Mustapha *et al*. (2017), it was shown that the majority of the farmers (72%) did not read or follow pesticide labels due to their illiteracy or had limited formal education, and they did not receive any training or technical support in/on pesticide safety. Similar findings by Khanal and Singh (2016) and Sapkota *et al*. (2020) showed low levels of education and awareness among farmers posed difficulty to farmers to read the instructions in the international language. Mekonnen and Agonafir (2002) in Ethiopia also reported that written information on pesticide packaging was not read by the sprayers. Gesesew *et al*. (2016) in southwest Ethiopia revealed that about two thirds (67.5%) of participants could read and understand labels/instructions from the pesticide container if written in the local language. The negligence of the pesticide users particularly pesticide end-users including onion and other vegetables farmers, family farmers and farm workers (such as pesticide applicators) to exploit pesticide product label information constrained and tended them to use any inappropriate and non-graduated materials, and in this situation, no correct dose could ever be used, and these materials would constitute a source of error for pesticide under-dose or overdose during treatment of onion and other vegetables; under-dose could lead to pest resistance and would increase further application of pesticides by onion (vegetables) cultivating farmers, may be focusing only on good harvest, which could increase potential of pesticide exposure hazards and risks to onion (vegetable) farmers and farm workers; thus, the cumulative effects of such exposure over long periods could constitute a significant risk to farmers and farm workers and likely result in farmers chronic health problems and greater health outcomes (Clarke *et al*., 1997; Adjrah *et al*., 2013). In the study by Adjrah *et al*. (2013) in Togo, it was reported that during the preparation of the different formulae of pesticides, more than 97% of participant vegetable growers (participant vegetable producers) including onion did not use standard pesticide quantification materials;

they used inappropriate materials (tools) to quantify pesticides. On the other hand, Dilek *et al*. (2018) showed that 88.6% of the participant farmers in their study read warnings and precautions on the labels/instructions of pesticides on the container of the pesticides. In a study by Zyoud *et al*. (2010), 71.4% of the farmers read the instructions. Tuna *et al*. (2012) found that 73.0% of the farmers always read the instructions. In a study conducted by Kiraz *et al.* (2012), 89.9% of the farmers read the label on the pesticides. Cevik *et al*. (2020) in Turkey showed that seventy-five point two per cent of participant farmers read the label instructions on the pesticide packaging (boxes), and Lekei *et al*. (2014) in Tanzania reported that 69% of the farmers heavily relied on the labels as their main source of information and, to lesser extent, on extension officers and pesticide retailers, and also, findings in a study by Dung *et al*. (1999) in Vietnam showed that 65% of the farmers relied on pesticide labels as a source of information. In a study by Gaber and Abdel-Latif (2012), 33.0% of the farmers read the instructions for using pesticides. However, the pesticide label as a source of information is of limited quality since many labels are damaged to the extent that they could not be easily read or understood by the users, and the situation was more serious for the products distributed in non-original containers like soft drink containers which bear no relevant information, and also, some pesticides may have the correct labels but the information may not be understandable to the users due to use of complicated terminology or language (Lekei *et al*., 2014). It is particularly worrying, given evidence of poor comprehensibility of labels for working populations in developing countries (Berhanu, 1993; Baloyi, 1997; Banda & Sichilongo, 2006; Rother, 2008; Lekei *et al*., 2014). Therefore/hence, due consideration and extreme care must be taken in the preparation of pesticide labels in its text contents, legibility (readability), understandability and layout, and in order not to tear out (spoil) and detach original pesticide labels from original pesticide containers during transportation (transport) of pesticide products packs (package) (when transporting pesticide products packs (package))

The educational limitations investigated (explored) in the present study are similar to the study conducted by Mergia *et al*. (2021) in Ethiopia who showed that many of the small-scale farmers (41.4%) in their study were illiterate with no formal education, while 51.4% had an elementary school education (grades 1-8), few (5.7%) farmers had completed secondary school, and the remaining had a college/university education, and most of the small-scale farmers (94%) did not receive any training on the proper use and handling of pesticides except only 4.2% of them received training on these issue, adding that many of the farmers had received informal training from untrained farmers. Likewise, the study conducted by Negatu *et al*. (2016) in the Rift Valley region in Ethiopia reported that local government extension workers and farmer cooperatives did not provide needed training to small-scale farmers on the proper use (usage) of pesticides, and there were no other training programs provided by local health extension services or other institutions such as the local labor and social affair or environmental office. The present study also corresponds to the study conducted by Alice *et al*. (2019) in Burkina Faso who showed that most of the vegetable farmers did not have formal education (non-educated (illiterate), 60.3%; primary, 26.6%; secondary, 6%) as opposed to the respondent cotton farmers in which the majority of them had secondary education (non-educated, 32.1%; primary, 29.3%; secondary, 38.6%). In another study by Taghdisi *et al*. (2019) in northern Iran, most of the participants were illiterate or had low level of education. On the other hand, Adesuyi *et al*. (2018) in Nigeria reported that majority of the farmers (68.9%) had formal education, mainly primary education (15.6%), secondary education (46.8%) and tertiary education (6.5%), with 31.1% of the farmers with no formal education, while a considerable number of the respondents had no and limited formal training or technical support in pesticide safety. Likewise, in the study conducted by Mustapha *et al*. (2017) in Kuwait, it was shown that 69.2% had completed either elementary or secondary education, 14% were educated to a tertiary level and most of the farmers educated to the tertiary level were expert agronomists (71.4%), while 16.8% of the respondents were illiterate or had not completed elementary education, and majority of the farmers (64%) had not received any training or technical support on the judicious use and safe handling of pesticides, while 36% of them were trained in which 22.9% had received training in pest management, also over 70% of the farmers in their study did not read or follow instructions on pesticide labels stating that because they were unable to read and understand the meaning of the labels (56%), the labels were written in English (a foreign language to them) (35%), the instructions were too long and complicated (45%), and a little (slightly) more than 15% of the farmers stated that font sizes on the labels were too small to be easily read, while only 28% of the farmers were able to read, understand, and follow pesticide label instructions correctly. Also, Kafle *et al*. (2021) in Nepal reported that more than two-thirds of farmers (68.1%) were able to read and write, and most had attended some level of formal education, while the rest (31.9%) cannot read and write or only writing their names. Likewise, in the analysis of the educational status of the respondent farm workers in the study conducted by Yassin *et al*. (2002) in Gaza Strip, Palestine, a low illiteracy level was recorded among the respondent farm workers, reflecting a well-educated community, where 13.2% had a university degree, 42.9% had finished secondary school, 22.2% had finished preparatory school, 13.2% had passed primary school, while 8.5% were illiterate, and 15.3% participated in seminars and training related to the hazards of pesticides and their effects on human health. Mohanty *et al*. (2013) in south India showed that the educational background of the farmers in their study was 66.7% up to high school level (nearly two third of them had completed high school level education). Similarly, in the study conducted by Dilek *et al*. (2018) in Turkey, it was reported that 1.4% of the participant farmers were illiterate, 1.0% of them were literate, 38.6% were primary school graduates, 53.3% were high school graduates, and 5.7% were university graduates, showing that 59% had high school and above educational level, while none of the participant farmers had received any training on pesticide use (none of them had been trained about pesticides). Kumar *et al*. (2012) also showed that about 90% of the farmers had not received any training on pesticide use. In a study conducted by Kalıpcı *et al*. (2011) to investigate educational status, level of knowledge, and environmental sensitivity of the farmers, it was reported that 55.8% of the farmers were primary school graduates, 26.6% were secondary school graduates, 11.6% were high school graduates, and 5.8% were university graduates. In the study by Mwabulambo *et al*. (2018) in Tanzani, it was reported that 83.9% of the study subjects in onion farms had primary education, 10.7% had secondary education, 5.4% had no formal education, and none of them received any training on pesticide safety or management, while 78.6% of the study participants in flower farms had primary education, 14.3% had secondary education, and 7.1% had no formal education. In the study conducted by Adjrah *et al*. (2013) in Togo, levels of education of the respondent vegetable growers reported in grades were 1-6 (58%), and 7 and over (above primary educational level) (36%), while only 6% were illiterate, and the majority of them (79%) had never received professional training regarding pesticide use, while only a few of them (21%) received training about pesticides applications and did not follow instructions related to those chemicals. In a study conducted by Cevik *et al*. (2020) in Turkey, 9.0% study participants were illiterate; 36.5%, primary school; 35.6% secondary school, and 18.9% had high school and above educational level. In the study by Lekei *et al*. (2014) in Tanzania, most (88%) farmers had less than 7 years of education. In a study conducted by Ncube *et al*. (2011) in northwestern Jamaica, a large proportion of farmers (75%) stated that they had not received training in pesticide handling or safety, while only 25% of them stated they ever received training in pesticide handling or safety. Farmers need regular training to encourage and capable of them of about safe pesticide use (to enable them to use pesticides appropriately and safely), and education to make farmers aware of about the hazards (risks) involved in the wrong and inappropriate use of pesticides (Oluwole & Cheke, 2009; Dilek *et al*., 2018).

In the present study, all (100%) participant small-scale (smallholder) onion cultivating farmers in the study area have been using synthetic chemical pesticides (synthetic chemical insecticides) for the control of onion thrips on onion, and there were no any other alternative pest control methods they used to control (manage) the insect pest, and the farmers stated that chemical pesticides (chemical insecticides) currently are indispensable for onion production in their area. And, the pesticides (insecticides) commonly used by onion producing farmers in the study area of the present study belong to WHO toxicity class II (moderately hazardous) pesticides, most of which are in organophosphate, pyrethroid, organochlorine and neonicotinoid pesticide (insecticide) chemical groups (chemical classes), and no other WHO toxicity class of chemical pesticides being used by the respondent onion farmers were reported. However, all the participant farmers in the present study buy any chemical pesticide available on the market (pesticide retailer’s shop) and use indiscriminately only for it is being a chemical without knowing and recognizing the names of pesticides and their specific (approved) uses, lacking the knowledge, awareness and understanding of choosing and using appropriate pesticides (insecticides) to control onion thrips on onion, i.e., all the study participants do not know proper insecticides by name that have been applied for the control of onion thrips on onion, especially, they do not have knowledge and understanding of insecticides that are registered in Ethiopia for the control of onion thrips on onion, although some commonly used pesticides by the farmers in the study area of the present study and the registered insecticides for the control of onion thrips on onion in Ethiopia have common active ingredients (active substances or common names), for instance, Prior 72 EC and Profit 72% EC, which are registered in Ethiopia for the control of onion thirips on onion, and for the control of pea aphids (*Acyrtosiphon pisum*) on field pea (*Pisum sativum* L.) respectively, the active ingredient of both of these pesticides (insecticides) is profenofos. The use of pesticides that are not specifically registered (or pesticides that are not particularly approved) for the control of onion thrips on onion may likely need excessive use and application of the pesticides to control the insect pest, which could be uneconomical to the farmers, poses greater human health hazards and risks due to increased exposure to the pesticides (poses greater human health problems due to higher pesticide exposure poisoning (higher pesticide exposure and consequent poisoning) risks), increases accumulation of pesticide residues (pesticides) on/in onion, and hence, increases contamination and pollution of onion produce by the pesticide residues (pesticides) and their metabolites and degradation products (food safety (quality of food) issues), contaminate and pollute the environment, and the insect pest (onion thrips) may develop resistance to the pesticides (insecticides). Also, onion growers in the study area of the present study have been commonly using hand-pumped (manual) backpack (knapsack) pesticide tanks, which may result in greater potential additive and synergic deleterious effects to human health due to the proximity of spray droplets (aerosols) to the spray operator (pesticide applicator) during pesticide application (spraying), which is exacerbated by the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides and pesticide use (usage) preventive, protective, precautionary and safety measures (pesticide use safety precautions like use of personal protective equipment (personal protection equipment) (PPE) (personal protective devices (PPD)) (personal protective clothing (PPC)) (personal protective gear (PPG)) and pesticide use safety practices), and unavailability of PPE in the study area of the present study. In the present study, the main informal information sources for the farmers mainly for mixing (dosage) of pesticides (insecticides) are pesticide vendours (pesticide retailers) (48.8%) and agricultural development extension workers (46.5%), in which both of these informal information sources themselves were not educated and trained (did not receive any educational training) on the appropriate and safe use of pesticides and pesticide use safety, and they are in lack of knowledge, awareness and understanding of the appropriate and safe pesticide use and pesticide safety, which demonstrates (indicates) that onion cultivating farmers in the study area of the present study do not have access to appropriate and reliable pesticide use information sources, and the farmers lack overall knowledge, awareness, understanding and information on the appropriate and safe use (on appropriate and safe use, handling and application) of pesticides and detrimental effects of unsafe, inappropriate, irrational (injudicious), indiscriminate, excessive, extensive and abuse (abused) use and misuse of pesticides to the health of the environment and to the health of humans. Therefore, urgently shifting (undergoing paradigm shift) towards other pest control and management alternative methods and approaches (other pest control and management alternatives (options)) such as integrated pest management (IPM) approaches where the use (application) of pesticides is practiced (made) to be minimized (where minimized use of pesticides (minimized pesticide use) is a principle), pesticide-independent (pesticide non-dependent) farming approaches (systems) and practices such as organic (ecological (eco-friendly)) farming (ecological (eco-friendly) agriculture) (natural farming (natural agriculture)) approaches and practices, and promptly exploring, investigating and innovating other new pest control and management alternative approaches and methods are urgently required, while at the moment only selectively providing and using pesticides (crop protection products) that are safe to farmers, family farmers and farmworkers, the farming community, the public at large and the environment when application of pesticides is sought for the current pesticide use indispensable plant (crop) protection practices (for the current pesticide use inevitable control and management of pests of plants (crop plants) including onion and other vegetable crops).

Regarding spray frequency of pesticides (insecticides) per season by participant onion farmers to control onion thrips on onion in the present study, 58.7% of the farmers sprayed pesticides 8-12 times per season on onion to control onion thrips, while 41.3% sprayed 3-7 times per season. These pesticide spray frequencies may probably be beyond the recommendation as seen in an experimental study conducted by Amna *et al*. (2009) for testing the efficacy of different chemical insecticides against onion thrips in Pakistan. However, local conditions-based critical and peak time spray frequency need to be studied and investigated (further research is needed on this issue) because this issue is associated with uneconomical purchase of pesticides by the farmers (economic problems to the farmers) and the likely increased harmful (adverse) effects of pesticides to the environment and human health possibly due to the farmers' increased (excessive) use and application of pesticides and consequent higher potential of pesticide exposure poisoning (pesticide exposure and poisoning) hazards and risks (health problems), which could be exacerbated by the farmers' overall lack of knowledge, awareness, understanding and information on the appropriate and safe use (appropriate and safe use, handling and application) of pesticides and pesticide use (usage) preventive, protective, safety and precautionary measures (pesticide use safety precautions and pesticide use safety practices), lack of current localized optimum insecticide spray frequency for the control of onion thrips on onion, and unavailability of PPE in the study area of the present study. Similar studies had been conducted in different locations of the world especially in developing countries. Mergia *et al.* (2021) in Ethiopia reported that all (100%) interviewed small-scale vegetable (including onion) farmers in their study used chemical pesticides on their farms, most of which were WHO class II pesticides, while none of the vegetable farmers reported using biological or other pest control methods such as integrated pest management (IPM), and they depended on the experience of other farmers to determine the activity level of pesticides, and also, about 45% of the farmers sprayed chemical pesticides up to 12 to 15 times per season, while nearly 12% of the farmers reported applying pesticides more than 15 times per season, and it was shown that application of insecticides and fungicides dominated chemical pest control (management) in the vegetable farms in their study. Similarly, Adjrah *et al*. (2013) in Togo reported that use of 98% exclusively synthetic pesticides (chemical pest control method) by the participant vegetable growers was the main strategy of pest control, while only 2% of them used biological pesticides alone, made from *Azadirachta indica* (neem tree) as the main ingredient to protect their vegetables from insect damage, and 29% of the farmers combined chemical and biological pesticides, and it was also shown in their study that insecticides dominated chemical pest control (management) in all vegetable growing systems, which they noted reflecting the serious problems of insect attack in their study area, and most of the plants were sprayed with pesticides 1–11 times during their cultivation, the highest application frequencies being 7–11, and treatments were weekly for vegetables harvested more than one time. Mustapha *et al*. (2017) in Kuwait showed that WHO toxicity class II pesticides (moderately hazardous) were used by 90% of the farmers, followed by 68% class III (slightly hazardous) pesticides, while a little (slightly) more than 12% of the farmers used class Ib pesticides (highly hazardous), and insecticides were used by 98% of the farmers, followed by fungicides and bactericides (79%), nematicides (24%) and herbicides (5%), and it was also shown in their study that pesticides were indispensable for high crop yield (80%). In a previous study conducted by Mengstie *et al*. (2017) in Ethiopian Central Rift Valley, it was reported that class 1a pesticides such as aldicarb (extremely hazardous), imported for the flower industry, were (have been) found on vegetable farms, and it was also reported the use of banned pesticides such as DDT by vegetable farmers around Lake Ziway in Ethiopia. Also, in the previous study by Negatu *et al*. (2016) around the Rift Valley region in Ethiopia, DDT and endosulfan were shown to be used by 25 and 94% of small-scale irrigation farmers, respectively, within the 12 months before the interview, and by 87 and 98% of small-scale irrigation farmers, respectively, since their involvement in pesticide application work. In the study by Mwabulambo *et al*. (2018) in Tanzania, it was reported that the most common types of pesticides used for pest control (crop protection) were predominantly organophosphates (accounting for about 98%) with small amounts (only about 2%) of carbamates and pyrethroids, in which eighty-one percent organophosphate pesticides (insecticides) and 19% pyrethroid pesticides (insecticides) were used on onion farms (in onion fields), while 75% organophosphate pesticides (mostly (the majority of the pesticides mentioned being) fungicides) and 25% pyrethroid pesticides were used on flower farms (in flower fields), spraying pesticides using manual backpack knapsack pesticide spray (spraying) equipment (pesticide spray tanks) in onions farms, and spraying pesticides using mobile motorized tanks (pesticide spray (spraying) equipment (pesticide sprayer)) with pipes and spray guns in flowers farms, and it was also shown in their study that 54.1% of the pesticides used by the farmers were moderately hazardous (II), 21.6% slightly hazardous (III) and 24.3% were unlikely to present (represent) any acute hazard in normal use (IV/U) according to WHO toxicity classification scheme criteria. Likewise, a study done in Glazoué and Savè townships, in the central republic of Benin, on risk factors of pesticide poisoning and pesticide users' cholinesterase levels among farmers found that 72.96% of pesticides used were organophosphates and pyrethroids constituting the group of pesticides more frequently used by 88% of the farmers (Vikkey *et al*., 2017; Mwabulambo *et al*. (2018). Also, in a study conducted by Anna *et al*. (2014) in Uganda, it was reported that small-scale farmers primarily used WHO class II and III pesticides. In the study by Tambe *et al*. (2019) in Cameroon, it was shown that among the pesticides used by the participants in their study area (fungicides, insecticides, and herbicides), insecticides were the most used while herbicides were the least used pesticides. Similarly, Tandi *et al*. (2014) found that insecticides, fungicides, and herbicides are the most frequently used pesticides to control pests among which insecticides being the most used while herbicide was the least used. Adjrah *et al*. (2013) in Togo also reported that the active ingredients cypermethrin, dimethoate, lambdacyhalothrin (lambda-cyhalothrin), endosulfan and chlorpyrifos-ethyl used in larger amounts by participant market gardeners (market garden cultivators (producers)) of vegetables including onion are insecticides. In America and Europe, however, herbicides are the most commonly used pesticides followed by insecticides, fungicides and others, and this could likely to be due to less expensiveness of using herbicides than hiring (recruiting) human physical labour power (force) during weeding seasons (Ahmed, 2001; Waichman *et al*., 2007; Adjrah *et al*., 2013). Globally, there is a tendency of not considering fungicides and nematicides as harmful like (or as harmful as) insecticides, a practice which may also expose consumers to the risk of pesticide residues (pesticides) in or on vegetables including onion (Adjrah *et al*., 2013).

On the other hand, Yassin *et al*. (2002) in Gaza Strip revealed that all (100%) participant farm workers used pesticides and 96.8% of them (farm workers) knew the names of the pesticides they were using, and the most common insecticides used were organophosphates, carbamates, pyrethroids, and organochlorines, while only about 12.2% and 19.0%, respectively, knew biological and natural control as alternatives to pesticides for pest control, and they showed that (regarding the activities of farm workers with potential for exposure to pesticides) 56.1% farm workers used the recommended concentration of pesticides, 42.9%

used more than the recommended concentration, and only 1.1% did not use specific concentrations, while none used less than the recommended concentration, and it was also reported in their study that 59.3% farm workers were against the use of pesticides for pest control justifying that the use of pesticides is due to lack of knowledge of other successful pest control alternatives (other than pesticides) (as the farm workers stated, they used pesticides due to their lack of knowledge of other successful pest control alternatives (other than pesticides)) as well as absence of such pest control alternatives, while 40.7% stated that use of pesticides is the best and most efficient way for pest control. Kafle *et al*. (2021) in Nepal reported that 84.0% of (the) participant farmers have been using exclusively chemical pesticides, while less than four percent (3.5%) used botanical bio-pesticides (botanical biopesticides) (botanical pesticides) only, and the rest (12.5%) used both botanical and chemical pesticides in agriculture, and also, more than 60 percent of the farmers have been using chemical pesticides for more than 10 years (60.8% had been using chemical pesticides for more than a decade), 62% had no idea about the toxicity and label of pesticides on the pesticide container, a little (slightly) more than one-fifth (20.7%) of farmers used yellow labeled (yellow labelled) pesticides (which are highly toxic with lethal dose 51–500 mg/kg), two percent of farmers used banned pesticides indicated by red labels (extremely toxic with lethal dose 1–50 mg/kg), while blue and green labelled pesticides were used by 6.0 and 9.4 percent of farmers, respectively, and most (96%) farmers took advice from a nearby agro-vet (pesticide retailers) on matters related to pest problems and the choice and use of pesticides. Adesuyi *et al*. (2018) in Nigeria revealed that the majority (84.4%) of the farmers in their study stated that pesticides application is essential for high crop yield and productivity. Use of a considerably larger amounts of pesticides (especially insecticides) and extensive pesticide application have also been (have been also) reported in other countries such as: in Ghana (Ntow *et al*., 2006), vegetable farmers sprayed more than 12 times per crop cultivation; in Benin (Williamson *et al*., 2008), many farmers sprayed pesticides (insecticides) every 3–5 days; in Brazil (Waichman *et al*., 2007), pesticide spraying frequency (rate) ranged from once every 3 days to once a week. Ngowi *et al*. (2007) in northern Tanzania and Nguyen *et al*. (2018) in Vietnam also reported that about 40% to 50% of vegetable farmers interviewed applied pesticides more than 5 to 7 times in one cropping season. Likewise, vegetable farmers in Bangladesh were shown to apply pesticides at concentrations higher than recommended (Akter *et al*., 2018). Vegetable producers particularly of including small-scale vegetable farmers especially in developing countries are in propensity (tended) to use higher quantities of pesticides (particularly insecticides) in order to protect (preserve) their vegetables from pests (especially insect pests) attacks and damages, and wanted to attain and preserve more economic benefits (more economic outputs and more economic returns) and seek to maintain increased and enhanced crop production (Stephenson, 2000; Adjrah *et al*., 2013). Lekei *et al*. (2014) in Tanzania described that farmers reported sources of pesticide handling instructions (farmers' sources of information on pesticide handling) were pesticide labels (70.8%), pesticide retailers (48.2%) and agricultural extension officers (38.6%), while Mohanty *et al*. (2013) in south India showed that about forty five percent farmers got information on pesticides from government agriculture department, about forty percent from pesticide seller and about fourteen percent from media. In a study done by Benjamin *et al*. (2019) in Rwanda, it was described that farmers relied upon different primary sources of information for/about safe pesticide mixing, storage, and application, in which the majority of the farmers relied upon available extension services (33.0%) or pesticide label information (32.5%) when seeking information about appropriate mixing techniques and also stated that many farmers relied upon either personal experience (15%) or their best guess (15%) when mixing pesticides. Farmers in Kuwait rely on pesticide retailers as the primary information and knowledge source on pesticides (Jallow *et al*., 2017; Mustapha *et al*., 2017). Sun *et al*. (2012) pointed out (or concluded) that inadequate government (governmental) agricultural extension services are the most important factor in the over-application (overapplication) and misuse of chemical pesticides.

In the present study, majority of the study participants do not have knowledge, awareness and understanding of the adverse effects (negative impacts) of exposure (exposures) to synthetic chemical pesticides (synthetic chemical insecticides) to the health of the environment (70.9%) and to the health of humans (65.2%) which demonstrates that farmers are in overall lack of (which demonstrated that farmers lack overall) (demonstrating the farmers' overall lack of) knowledge, awareness and understanding of the deleterious side effects of exposure (exposures) to pesticides to the health of humans and to the health of the environment, i.e., farmers do not have knowledge and awareness (they lack knowledge) on overall human health and environmental health problems of exposures to pesticides, which is exacerbated by the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (usage) (the appropriate and safe use (usage), handling and application) of pesticides and harmful effects of inappropriate and unsafe pesticide use (usage) (inappropriate and unsafe pesticide use (usage), handling and application) and misuse of pesticides to the environment and human health that would lead the farmers to have been adopting, operating and exhibiting hazardous and deleterious pesticide use (pesticide use, handling and application) behaviours and practices which may (would) consequently pose an increased and detrimental pesticide exposure environmental health and human health hazards and risks (overall ecosystems health problems) that would ultimately result in greater and potentially threatening, damaging and disasterous health outcomes.

Pesticide use knowledge, awareness, understanding and practices gaps identified in onion cultivating farmers in the present study can be used as a baseline information (or it can contribute to the baseline information) for (and serve as): pre-information for the national (and beyond) pesticide and pesticide use policy makers and decision makers to urgently developing and formulating information-based (better-informed) comprehensive and sound pesticide and pesticide use (including associated (related) occupational health and environmental health and safety issues (environmental health advocacy and occupational health preservations)) policies, policy recommendations, strategies and decision making; for the animal and plant health (including environmental health) regulatory body in the Ministry of Agriculture (MOA) of Ethiopia to promptly reviewing (updating) and developing the pesticide regulatory framework, particularly for urgently reviewing, amending (making inclusive and reinforcing) and developing the existing national pesticide legislations (the present national pesticide laws and regulations) and instantly and stringently enforcing the pesticide laws and regulations at all levels starting at the retail (retailer) level and at the farm (farmer) level; for the national agricultural extension services delivery system in the MOA of the country to immediately incorporating (consolidating) pesticide and pesticide use intervention programs and projects in its content as one of the core themes (pillars) of the national agricultural extension delivery system and strengthening (making inclusive), enhancing and advancing the national agricultural extension services delivery system of Ethiopia, and at instant consequent to establishing and formulating comprehensive (holistic) and appropriate pesticide and pesticide use prevention and protection intervention strategies and intervention measures and urgent implementation schemes including promptly designing appropriate education and knowledge-based practical and specific training (educational training) programs specifically on the appropriate and safe use (on the appropriate and safe use, handling and application) of pesticides, pesticide use preventive, protective, precautionary and safety measures (pesticide use safety precautions and pesticide use safety practices) and on adverse (deleterious) effects of inappropriate (irrational), excessive, extensive, injudicious, indiscriminate, abuse (abused) and unsafe use (use, handling and application) of pesticides and pesticide misuse when using pesticides (during handling (purchasing, storing, preparation (mixing), application (spraying)) of pesticides and when handling and disposal of pesticide wastes particularly of including disposal of empty pesticide containers), and enhanced and advanced agricultural educational extension services including occupational health and environmental health and safety concerns (environmental health advocacy and occupational health preservations) extension services, and immediately addressing and presenting (promptly implementing) to the farmers on continuous and regular (periodic) basis, functionally coordinating other development partners (other national and international governmental and non-governmental organizations (NIGOs and NINGOs), private and governmental pesticide manufacturers and processors (pesticide companies), stakeholders and other concerned parties, to raise the farmers' levels of knowledge, awareness and understanding of the appropriate and safe use (of the appropriate and safe use, handling and application) of pesticides, addressing the overall currently existing pesticide and pesticide use knowledge, awareness, understanding and practices gaps of the farmers to prevent, reduce (minimize and limit) and avoid (eliminate) acute (short-term) pesticide exposure poisoning human health hazards and risks (acute pesticide exposure intoxications) (APP) and chronic human health problems (acute and chronic human health problems) caused by and associated with human acute (short-term) and chronic (long-term or prolonged) pesticide and pesticide use exposure poisonings (pesticide and pesticide use exposure (exposures) and consequent poisonings), and to prevent, minimize and eliminate contamination and pollution of agricultural food commodities particularly onion and other vegetables, and the environment with pesticide residues (pesticides) or to prevent, minimize and eliminate contamination and pollution of agricultural food commodities particularly vegetables including onion, and the environment by pesticides and pesticide residues), i.e., to prevent, reduce and eliminate overall occupational (intentional or deliberate) and environmental (unintentional or non-deliberate) pesticide and pesticide use exposure poisoning and contamination (pollution) environmental health and human health hazards and risks (overall environmental health and human health complications) or to prevent, minimize (limit) and eliminate the overall intentional (occupational) and unintentional (environmental and/or non-intentional) exposure poisoning (exposure and consequent poisoning) and contamination (pollution) human health and environmental health hazards and risks (overall environmental health and human health complications) caused by and associated with pesticide and pesticide use in Ethiopia (and probably beyond) encompassing the study area. And, the education and training (the practically oriented educational training) should also encompass at least agricultural development extension agents or workers (DAs) (agricultural development extension professionals), health extension workers, pesticide distributors (pesticide wholesalers), pesticide vendours (pesticide retailers), and beyond which enables and equips them to adequately give advice and technical support to the farmers on pesticide use, aiding in addressing the knowledge, awareness, understanding and practices gaps (knowledge (information) and practices gaps) of the farmers on appropriate and safe use (on the appropriate and safe use, handling and application) of pesticides. Particularly pesticide retailers are probably the first (frontline) and direct contact points to and with the farmers and may serve as an important information and knowledge source of pesticide use for the farmers, and can play a critical role in the dissemination of such knowledge and information to the farmers, and hence, special emphasis must be (required to be) given to urgently and appropriately educate and train (present appropriate educational training to) pesticide retailers on appropriate and safe use (on proper and safe use, handling and application) of pesticides to enable and equip pesticide retailers to adequately give technically support and advice to the farmers on proper and safe use (on the proper and safe use, handling and application) of pesticides in Ethiopia and perhaps beyond encompassing the study area, and taking the present research as a case study.

Importantly, special priority and emphasis must be given to urgently amending (making inclusive and reinforcing) and developing the existing national pesticide legislations (the present national pesticide laws and regulations) (the present pesticide regulatory framework) of Ethiopia profoundly taking into account and in due considerations of/to the current pesticide and pesticide use national and global challenges and problems, and previewing and consolidating (incorporating) alternative pest control and management methods, approaches and practices (other alternative pest control and management approaches and methods) (other pest control and management alternatives) (other alternative pest control and management approaches, strategies and tactics) such as integrated pest management (IPM) approaches and good agricultural practices (GAP), and pesticide independent (pesticide non-dependent) (pesticide nondependent) farming systems (approaches) and practices such as organic (ecological (eco-friendly)) farming (ecological (eco-friendly) agriculture) (natural-based (nature- based) farming) (natural-based (nature-based) agriculture) approaches and practices, and demands such as questions of how to control migratory pests, and strategies and methods (options) of PPE promotion, provision (supply) and dissemination, and instant (immediate) consequent awareness creation, dissemination and enforcement of the national pesticide legislations (the national pesticide laws (the national pesticide laws and regulations)) (the national pesticide regulatory framework) of Ethiopia at all levels starting at the retail (retailer) and at the farm (farmer) level through surveillance, monitoring and assessment activities as all farmers, other clients and stakeholders, and even concerned and collaborative governmental and non-governmental organizations and development partners lack overall knowledge, awareness and understanding (have overall lack of knowledge, awareness and understanding) of/on the national pesticide legislations (the national pesticide laws (the national pesticide laws and regulations)) (the national pesticide regulatory framework) of the country that aimed at preventing, reducing (minimizing and limiting) and avoiding (eliminating) environmental health and human health hazards and risks (problems) caused by (associated with (related to)) (due to) pesticides and pesticide use (pesticides and pesticide uses) in Ethiopia and probably beyond. Similar studies were undertaken in other countries of the globe, especially in developing countries. Mustapha *et al*. (2017) in Kuwait reported that the majority of farmers in their study were well aware of the harmful effects of pesticides with regard to the environment (65%) and human health (71%). And, in the study by Adesuyi *et al*. (2018) in Nigeria, 71.4% of the farmers agreed that pesticide use poses some potential risk to human health while 63.6% agreed that it poses risk also to the environment. Yassin *et al*. (2002) in Gaza Strip reported that 97.9% respondent farm workers had knowledge about the adverse health effects of pesticides on human health, 83.8% knew that not all pesticides have the same adverse health effects, and regarding knowledge of participants on/about the fate of pesticide residues in their study, 66.7% farm workers reported that pesticide residues may be detected in the soil, 59.8% in the air, 54.5% on leaves and fruits of vegetables and fruits, and/while 42.3% reported that pesticide residues may be detected in groundwater. Also, in the by Dilek *et al*. (2018) in Turkey, 84.0% of the participant farmers indicated that pesticides had a negative effect on human health. In the study by Zyoud *et al*. (2010) to determine pesticide use practices and knowledge of farmers in Palestine, 85% of the farmers stated that pesticides have a detrimental effect on human health. In a study conducted by Recena *et al*. (2006) to determine knowledge, attitudes, and practices of farmers in Brazil on pesticide exposure and pesticide use, 92.0% of the farmers stated that pesticides have a harmful effect on human health. In the study by Mergia *et al*. (2021) in Ethiopia, 89% of the farmers stated that pesticides can affect human health, while 20% of them stated that pesticides can affect the environment, whereas 69% stated that pesticides do not affect the environment. In the study by Mohanty *et al*. (2013) in south India, majority (70%) of the farmers perceived (were aware) that pesticides affect human health; however, three fifth of the respondents were unaware or had wrong belief about effect of pesticides on livestock and environment. Even when farmers know the hazards of pesticides very well, this may not significantly change their practices or attitudes towards safe pesticide use which could be because of lack of education and poor knowledge and understanding of safe practices in pesticide use (Matthews, 2008; Mustapha *et al*., 2017), or they may be more concerned with high economic returns from their crops than with their own health (Jones *et al*., 2009; Mustapha *et al*., 2017). Farmers' knowledge of the potential damage of pesticides is very important in preventing pesticide exposure (Damalas *et al*., 2006; Dilek *et al*., 2018).

Farmer's knowledge of pesticide handling and application as well as risks is essential for improving safety in pesticide use (Mohanty *et al*., 2013; Wang *et al*., 2017). Knowledge and awareness of farmers on the potential risks associated with improper pesticide handling and disposal can be increased through adequate education and training (educational training) (Schreinemachers *et al*., 2017). Appropriate education and training (appropriate educational training) programs on pesticide safety and on the hazards of pesticide exposure be developed to address gaps in farmers' knowledge of/about/on pesticides and pesticide use (uses) (pesticides and use (uses) of pesticides) (Mustapha *et al*., 2017), which leads to increased levels of knowledge about/on safety precautions while handling pesticides (Chen *et al*., 1998; Jones *et al*., 2009; Mustapha *et al*., 2017). Taghdisi *et al*. (2019) in northern Iran found that there was a significant correlation between knowledge and safe use practices of pesticides. Promoting safe pesticide use would also require educating and training farmers and pesticide retailers about the pesticide regulatory framework of a country and the obligations currently in place (Mustapha *et al*., 2017). Pesticide retailers should have, at minimum, a technical advisor with competence in the handling of pesticides and knowledge of their hazards to appropriately advise farmers and other end-users (Mustapha *et al*., 2017). Pesticide retailers can downplay environmental health and human health effects of pesticides when dealing with farmers for greater profit-making (Alam & Wolff, 2016; Mustapha *et al*., 2017), or may be constrained by the lack of knowledge of pesticides (Jin *et al*., 2015; Mustapha *et al*., 2017). Lack of education and training (educational training) of pesticide retailers, who may serve as advisors to farmers and other end-users, have been considered a key factor contributing to occupational exposure to pesticides (Lekei *et al*., 2014; Mustapha *et al*., 2017). In the study in Kuwait, for instance, farmers rely on pesticide retailers as the primary information and knowledge source on pesticides (Jallow *et al.*, 2017; Mustapha *et al*., 2017), and hence, pesticide retailers knowledge of pesticides and pesticide use may matter and impact a lot on the proper use of pesticides by farmers, and in the same study, some farmers lack any knowledge of the regulatory framework of their country (Mustapha *et al*., 2017). Lack of knowledge of farmers on pesticide use increases pesticide usage (higher dosages), yields a lower crop protection outcomes and increased the human and environmental load (Michael *et al*., 2016). Taghdisi *et al*. (2019) in northern Iran found that there was a significant correlation between knowledge and safe use practices of pesticides (there was a significant correlation between knowledge and the adoption of pesticide safe use practice).

An important finding of the present field survey research is that most (93.8%) participant farmers do not have knowledge, awareness and understanding of the importance and use of wearing personal protective equipment (PPE) during pesticide use, i.e., when handling (purchasing, storing, preparation (mixing), application (spraying)) of synthetic chemical pesticides (synthetic chemical insecticides) and handling of pesticide wastes including handling of empty pesticide containers, and none of them did wear (none of them wore) any PPE during pesticide use (during pesticide use, handling and application) except only wearing their ordinary (regular or casual or normal) clothings which demonstrates that the farmers' are in overall lack of (farmers lack overall) knowledge, awareness and understanding of the appropriate and safe use (usage) (the appropriate and safe use (usage), handling and application) of pesticides and harmful (adverse) effects of inappropriate and unsafe pesticide use (usage) (inappropriate and unsafe pesticide use (usage), handling and application) and misuse of pesticides to the health of the environment and to the health of humans (overall negative impacts and problems of inappropriate and unsafe use (inappropriate and unsafe use, handling and application) of pesticides and pesticide misuse to human health and the environment) that would lead the farmers to have been adopting, operating and exhibiting hazardous and deleterious pesticide use (pesticide use, handling and application) behaviours and practices which may consequently pose an increased and detrimental pesticide exposure environmental health and human health hazards and risks (overall ecosystems health problems) that would ultimately result in greater and potentially threatening, damaging and disasterous health outcomes. Particularly this lack of knowledge and awareness of the importance of use of preventive, protective and safety measures (safety precautions) of pesticide use, and inappropriate and unsafe pesticide use practices of the farmers are worrying and threatening to human health due to direct pesticide contact, contamination and diffusion exposure (exposures) to pesticides during unprotected pesticide handling and application (spraying), which would consequently and ultimately result in acute (short-term) pesticide exposure poisoning (acute pesticide exposure intoxications) (APP) of humans and chronic (long-term) pesticide exposure human health problems, and greater human health outcomes, reflecting lack of pesticide use safety education and training (educational training) and technical support to the farmers, which calls for urgent pesticide and pesticide use prevention and protection (preventive and protective) intervention strategies and intervention measures including promptly designing pesticide use and safety educational extension and training (pesticide use safety educational training) programs for the farmers which must immediately be addressed and presented to the farmers (need to be urgently implemented). And, the most study subjects (96.9%) discarded empty pesticide (insecticide) containers on-farm and around in the open environment without any cleansing measures, while a dozen of them collected empty pesticide containers in some materials such as in plastic receptacles and burned on-farm. These disposal practices of empty pesticide containers by the farmers are environmentally, toxicologically and ecologically unsafe and unfriendly way of pesticide waste disposal, because empty pesticide containers are considered hazardous to the environment and human health due to residual pesticides retained in and on them, even after the empty pesticide containers are washed and triple rinsed; hence, those empty pesticide containers left in the environment may likely lead to environmental contamination and pollution, i.e., they will bring about contamination (pollution) of the soil, surface and ground water bodies (community water sources), non-target organisms including humans, and thus empty pesticide containers consequently convey a higher cumulative exposure hazard and risk to the health of humans including farmers and family farmers,farm-workers (pesticide applicators and re-entry farm workers), the agrarian communities and other exposed groups of the human population such as consumers of the proximity water sources and the public at large, and to the health of the environment. Especially young livestock herders who often found on-farm and in the open field are at higher risk of exposure to pesticides due to which they easily pick up empty pesticide containers relentlessly discarded into the open field and play with these vessels, where possibly contaminating, polluting and poisoning themselves that will result in a greater health outcomes. Also, the majority of participant farmers (90.4%) did (do) not clean pesticide sprayers after finishing pesticide spray, which can pose hazards and risks especially to human health and also to the health of the environment due to exposure to and contamination with pesticides and diluted (mixed) pesticide solutions remained on and in the sprayer during mixing and spraying of pesticides, because the farmers kept pesticide sprayers in their living house and in the close vicinity of their homes. Moreover, about 10.1% of the participants stored pesticides (insecticides) in their living houses, which can cause increased potential of exposure and contamination to humans and could consequently harm human health, especially when the areas pesticides are kept in their house are places where the farmers and their families sit, prepare food, feed, and sleep, and also, some respondents finished the diluted (mixed) leftover pesticide solutions on the same treated crop which can increase harmful pesticide residues in harvested crop and environmental contamination (pollution), which could also pose a hazard to both human health and environmental health. Apart from this, 19.2% of the participant farmers mixed pesticides near irrigation water sources (rivers), and the majority of the study participants (89.3%) took bathes and washed their clothes in the same open irrigation water sources (in the rivers) after pesticide spray (application), which could contaminate and pollute the open water sources and affect the environment, posing hazards and risks to the health of living creatures inhabiting in the water sources (in the water bodies) and other living organisms that may use the water bodies including wildlife, livestock and human beings themselves, because these water sources, in most cases, also serve as source of drinking water for the farming community, and a little contamination and pollution from such deleterious chemicals into the water sources, which are potentially consumed, could result in health impairment and difficulties of the entire community and the public at large. Overall, these inappropriate, unsafe and poor pesticide use (pesticide use, handling and application) practices of onion cultivating farmers in the study area of the present study demonstrated and correlated to the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (appropriate and safe use, handling and application) of pesticides, pesticide use preventive, protective, safety and precautionary measures (pesticide use safety precautions like use of PPE and pesticide use safety practices), and adverse (harmful) environmental health and human health effects (negative human health and environmental health impacts) of inappropriate and unsafe pesticide use knowledge and practices, which are detrimental and threatening to human health and the environment due to hazardous and deleterious pesticide exposure and contamination (pollution) risks, and hence, this current alarming issue (problem) requires urgently developing and formulating comprehensive (holistic) and appropriate pesticide and pesticide use prevention and protection (preventive and protective) intervention strategies and intervention measures including instantly and promptly designing appropriate education and practical knowledge-based training (educational training and extension) programs to the farmers specifically on the appropriate and safe use (appropriate and safe use, handling and application) of pesticides, pesticide use preventive, protective, safety and precautionary measures (pesticide use safety precautions and pesticide use safety practices) including promotion, provision (supply), dissemination and use of PPE and deleterious effects of inappropriate, unsafe (unprotected) and abuse (abused) use and misuse of pesticides to the health of the environment and to the health of humans, and immediately addressing and presenting to the farmers on continuous and regular (periodic) basis to elevate their (the farmers') knowledge, awareness and understanding of the appropriate and safe pesticide use (appropriate and safe pesticide use, handling and application) and pesticide use preventive, protective and precautionary measures (pesticide use safety measures including use of PPE and pesticide use safety practices) that aimed at preventing, reducing (minimizing and limiting) and avoiding (eliminating) pesticide and pesticide use exposure and contamination (pollution) environmental health and human health hazards and risks (overall pesticide exposure health problems) (that aimed at preventing, minimizing and eliminating adverse human health and environmental health effects (problems) of pesticide and pesticide use). On the other hand, 85.2% study participants bought needed quantities of pesticides (insecticides) for current uses, and 95.1% respondents mixed the amount of pesticides needed for on spot (current) applications (uses) and applied soon after purchase, in which both operations can be considered as good pesticide use practices because these practices of pesticide use would reduce and minimize human health and environmental health hazards and risks (problems) caused by and associated with pesticide exposure (exposures) and contamination (pollution) due to extended (prolonged) pesticide storage which could be exacerbated by unsafe pesticide storage conditions; hence, these pesticide use practices need to be encouraged for the current sole or combined pesticide use indispensable plant protection including vegetable crop protection practices by selectively delivering and using less hazardous (less toxic) and biodegradable crop protection products. Whitford *et al*. (2006) and Damalas and Koutroubas

(2018) have opined that the best way to manage pesticide leftovers is to plan and use just the amount of product needed, thus reducing leftovers (leftover loads) that could later create an ecological menace (load of hazard). Also, all the respondent farmers in the present study did not eat or drink when mixing and spraying (during preparation and application) of pesticides (insecticides) which would reduce ingestion of pesticide-contaminated and polluted foodstuffs, and hence reduce the risks of human pesticide poisoning and other forms of illnesses of humans caused by and associated with use of pesticides. Similar studies were undertaken in other countries of the world, especially in developing countries. Taghdisi *et al*. (2019) in northern Iran found that there was a correlation between level of education and knowledge of the safe use of pesticides, and showed that there was a significant correlation between knowledge and safe use practices of pesticides (there was a significant correlation between knowledge and the adoption of pesticide safe use practice), but they stated that knowledge could explain only 22% of the variance observed in the pesticide safe use practice, and they reported that although the majority of the studied farmers had a satisfactory level of knowledge of the safe use of pesticides, they did not use what they knew in practice, and nearly half of the participants in their study did not use any kind of protective equipment during pesticide application; the rest only used some protective equipment such as masks, adding (saying) that the know-do gap among the studied farmers would be attributed to several reasons including cost of protective equipment or difficulty associated with their use, such as in humid climate of their study area, and more than half of the participants in their study used unsafe practice, such as using the empty pesticide containers for other purposes or disposing them with ordinary wastes, whilst just a few of the participants buried or burned waste pesticides and empty pesticide containers properly. Aghilinejad *et al.* (2006) believed (opined) that although having a satisfactory level of knowledge is necessary, it is not sufficient for adopting a good practice, and other factors should also be taken into account, and Ghalavandi *et al*. (2018) reported that knowledge cannot predict the safety behavior; instead annual income is the most important independent predictor of farmers' safety behavior, explaining 60% of the observed variance in the adopted practices. The know-do gap is considered to be a major issue in most developing countries (Zyoud *et al*., 2010; Taghdisi *et al*., 2019). Adesuyi *et al*. (2018) in Nigeria reported that over 67% of the farmers indicated using at least one PPE during handling and spraying of pesticides, 11% wore all the recommended six key PPE items (coveralls/overalls, protective boots, glasses/goggles, gloves, respirator, and hat), and the PPE reported as most often used were protective gloves (71.2%), hats (44.2%), and boots (42.3%), while a substantial number of respondents reported not wearing respirators/nose mask (84.6%), coveralls (59.6%), or glasses/goggles (46.1%) at all, and about 32% of the farmers indicated their non-usage of PPE during handling, preparation and spraying of pesticides, and why low levels of adoption of PPE to reduce occupational exposure to pesticides in their study were stated as due to: too expensive (45%), not comfortable in the tropic climate (85%), not available when needed (30%), it make work slower (18%) and no health challenges from using pesticides, also, the majority of the farmers (48.1%) stored pesticides (their pesticides) in the open field, 18.2% stored in open shed meant just for pesticides, and 14.3% locked in chemical stores designated only for pesticides (14.3%), while 6.5% of the farmers reported storing pesticides within their living area, besides, 22.1% of respondents reported storing leftover pesticide solutions in containers to be reused, 11.7% disposed on the field, 7.8% applied the leftover solution on the crops and 5.2% wash off, while about 53.2% of respondents reported mixing only the amount of pesticides needed for the application at hand, and over 83% of the farmers indicated that they buy only the amount of pesticides they needed, and the most common ways of disposing empty pesticide containers were placing in waste collection bins (36.3%), discarding them on farms (6.5%), burning them on the farms (2.6%) and burying the containers within the farms (1.3%), while 53.3% of the farmers reported re-using empty pesticide containers for other purposes like watering, and storing seeds and grains (as stated, with the perception that once these containers are thoroughly washed with soap and water they pose no danger to their health), also, the majority of respondents in their study reported not eating (90.9%), smoking (76.6), drinking (71.4), talking (66.2%) or singing (48.0%) when mixing or applying pesticides, and over 96% of the respondents reported that they do have their bath after application of pesticides while 100% admitted washing their hands with water and soap after application (stating that there is an awareness of the harmful effects of pesticides exposure on humans), and 55.5% of respondents had their bathes along the banks of the lagoon while 44.5% bathed in their houses, and over 35% of the respondents reported that they did not consider wind direction when spraying pesticides, while 24.7% of farmers in their survey study do not wash their used PPE after pesticides application (as described, which further exposes them to health problems such as skin irritation when the used PPE comes in contact with the body). Mustapha *et al*. (2017) in Kuwait revealed that the majority (58%) of the farmers in their study did not use any PPE when mixing or spraying pesticides, which could/would be due to lack of availability when needed (35%), PPE being uncomfortable in the local hot and humid climate (90%), too expensive (65%), slowing down (29%), while 6% respondents stating not experiencing any health problems from using pesticides, and among respondents who reported using PPE, less than 5% wore all the recommended six key PPE items (coveralls/overalls, protective boots, glasses/goggles, gloves, respirator, and hat), and also, the PPE most often used were protective gloves (61%), hats (42%), and glasses/goggles (48%), while a significant number of respondents reported not wearing respirators (70%), coveralls (68%), or protective boots (54%) at all, and they also found that younger and educated farmers were more likely to use PPE compared with older farmers or famers with limited formal education, besides, the majority of respondents reported not eating (72%), drinking (65%) or smoking (59%) when mixing or applying pesticides, and 82% of respondents stated (reported) taking a shower immediately after mixing or spraying pesticides, while over 70% of respondents did not wash work clothing used while/during mixing or spraying pesticides separately from other cloths, and 46% of them reported (stated) that they did not consider wind direction when spraying pesticides, also, the majority of the farmers (59%) stored their pesticides in locked chemical stores designated only for pesticides, in open sheds just for pesticides (34%), and in the open field (30%), while 15% of the farmers reported storing pesticides in an animal house, 8% in a refrigerator with other items, or within their living area (20%) (as they described (stated), demonstrating the farmers’ lack of knowledge of pesticides and the appropriate approach for storing pesticides), and 82% of them stated (reported) that they apply the residual (leftover) pesticide solution on other crops (more than 80% of respondents re-spray treated areas with leftover pesticide solutions), disposed (of) the leftover pesticide solution and/or old pesticide stock in the field (35%), in the sewer (4%) or deliver the solution to the municipality hazardous waste collection sites for disposal (23%), while only 18% of respondents stated (reported) mixing only the amount of pesticides that is needed for the application at hand, and over 60% of the farmers claimed that they bought (buy) only the amount of pesticides they need, also, they disposed of empty pesticide containers placing them in garbage containers and/or dumpsters for disposal at the landfill (50%), incinerating them on the farm (43%), or delivering them to the municipality hazardous waste collection sites for disposal (39%), while 25% buried the containers on-farm or discarded them on the farm (27%), and 6% of the farmers indicated (reported) re-using empty pesticide containers for household purposes (as described, increasing their chances of exposure to pesticides), and also, they observed a significant association between years of farming experience and safe pesticide storage and disposal in their study. Kafle *et al*. (2021) in Nepal reported that most of the farmers (more than 90%) stored the chemical pesticides away from the reach (the access) of children and animals in a separate place (as they stated, there was no lockable container to store pesticides among households, and they packed pesticides tying with a plastic bag and placed at house ceilings to limit the access by children and animals), about three- fourths of the farmers (84.9%) reported (stated) that they checked manufacture and expiry date, 30% and 32% observed (checked) the label of pesticide and information about waiting period before harvest during purchase respectively, less than half of the farmers followed safe practices during mixing and spraying of the pesticides, fifty four percent of the farmers used any of the protective equipment (protective clothes) during mixing and spraying (spray) of pesticides (masks (79.7%), full sleeved clothes (62.1%), and gloves (44.4%)) and less use of protective clothes (PPE) in their study area were (might be) due to the lack of awareness among the farmers, lack of availability when needed, discomfort due to hot and humid climate, and possibly might be due to cost factor, and in Nepal, where the climatic condition is very hot, the cost of PPE ranges from NRs. 3500 to 5000 and are often not available in the local market, while less than thirty percent of farmers considered safety and environment during disposal of pesticides, and some farmers knew the procedure of triple rinsing to clean the pesticide container after the spray (14.4%), and in their study, overall safe practice of pesticides during purchase, spray, storage, and disposal was significantly associated with gender, literacy status, knowledge, and perception of the farmers. In the study by Benjamin *et al*. (2019) in Rwanda, it was shown in self-reported pesticide practices of farmers that all study participants were observed spraying pesticides without wearing shoes or protective boots, with almost everyone wearing their normal clothing (99.5%) (which, as stated, likely poses a risk to individual and family health), less than 11% of the farmers used any PPE and of those who used PPE, glasses/goggles were the most commonly used (6.8%), the majority of study participants (92.7%) used their bare hands to mix the powder pesticides with water before spraying, a higher percentage of study participants (23%) reported using complete PPE during interviews than were observed using complete PPE in the field (a complete set of PPE included goggles for eyes, a respirator, gloves, work boots or rubber "gum" boots, and a plastic apron to protect the farmers from pesticide contact), the majority of interviewed participants (77%) reported using incomplete PPE as they were missing at least one of these protective elements, adding that although age, gender and educational level differed among the study participants, PPE use was similar among the categories for each of these variables, while all study participants stored pesticide in powder or liquid form in their homes, all study participants reported storing pesticides or empty pesticide cans in their premises (house/kitchen), and the empty cans were used for fetching water, serving water to calves, and as containers for drinking water for children (i.e., all study participants stored full, partially full, or empty cans of pesticides in their kitchen or other areas of their homes and were observed using empty pesticide cans for fetching water for domestic purposes such as washing clothes, cooking and drinking), also, the majority of the study participants (99%) in their study believe PPE and regular pesticide safety trainings can protect them from adverse health effects of pesticides; however, only 28% had previously received any information on pesticide use from various agriculture-related stakeholders (government, NGOs, or peers), while only 1.9% farmers received specific training on human health and safety of pesticides, including safe disposal of pesticides, but no trainings were delivered on effects of pesticides on animal and environmental health or on strategies for reducing pesticide use such as integrated pest management (IPM), besides,. some farmers may understand health risks but ignore PPE recommendations due to practical and financial challenges, i.e., farmers participated in their study commonly reported that they did not follow PPE recommendations because (1) the recommended rubber boots (also called gumboots) frequently get stuck in mud when moving across the field during spraying, and (2) they had no financial capacity to purchase PPE. Yassin *et al*, (2002) in Gaza Strip revealed (the knowledge of farm workers about protective gear) that 90.3% farm workers had information that gloves can protect skin of the hands from the adverse health effects of pesticides, 88.1% reported that goggles can protect the eyes from the adverse effects of pesticides, 91.4% believed that wearing a wide brimmed hat and special boots can protect the head and feet from pesticides, 97.3% admitted that wearing an oral–nasal mask can prevent entrance of the pesticide drifts through the mouth or nose into the human body, and 95.7% reported that wearing protective gear as overalls can protect the whole body (19.6% of the farmers wore gloves, 21.7% of them used masks, 14.8% of them wore boots, and 19.0% of them wore protective clothing), but it was shown that despite their knowledge about the adverse health impact of the pesticides, and the majority of them knew that wearing protective gear can protect the body from the adverse health effects of pesticides, the use of protective measures among farm workers was poor (no one took precautions unless they knew about the measures) due to (as stated, could be attributed to) carelessness, discomfort, cost, or unavailability of protective devices; protective measures regularly (almost always) used (wore) by farm workers during preparation and application of pesticides reported in their study were gloves (19.6%), goggles (7.9%), wide brimmed hat (12.2%), oral–nasal mask (21.7%), special boots (14.8%), and overalls (19.0%), also, it was stated that 78.8% farm workers stored pesticide on the farm site, while (whereas) 18.0% stored them in the home (at home), and 64.6% threw the empty pesticide containers on the garbage site or along the street, while 45.0% buried or burned them, and 69.3% farm workers not drinking, 81.5% not eating, 88.9% not smoking while 96.8% not chewing gum during application of pesticides, and 54.0% of them had a water bath directly after applying pesticides, also, 67.6% farm workers in their study believed that their bodies could develop resistance against pesticides, in which, as described, such attitudes may further encourage farm workers to be careless towards the use of protective measures, while/whereas 32.4% had the opposite opinion. Mergia *et al*. (2021) in Ethiopia showed that none of the farmers used any PPE in their field observations, while about three-fourths (68.6%) of small-scale vegetable farmers reported they did not wear boots, 94% did not wear eye protection, nearly 97.5% of farmers with poor pesticide knowledge did not use face masks or gloves, and 92.4% of farmers wore normal clothes during spraying and mixing of pesticides due to inadequate knowledge about safety measures, for/as PPE was uncomfortable in the local hot and humid climate (64.3%), unavailability of protective devices at the local market (45.7%), slows work (43.8%), and high cost at private shops (39.5%), also, 94.5% of farmers stored pesticides in residential rooms under the bed, on the roof, in the kitchen, in the toilet, and in animal shelters with other items, while only 5.7% did not store pesticides stating that they purchased the required amount and used it immediately, and 57.6% of farmers mixed pesticides in the farm, 31.9% mixed near water (community water sources), while 10.5% mixed at home, and most (91.9%) farmers disposed of empty pesticide containers on the farm without rinsing or cleaning (97%), 8.1% of farmers reported reusing empty containers for domestic purposes, nearly half of farmers did not safely dispose of leftover pesticides, and they disposed of leftover pesticide mixtures in the field (6,7%) or applied to other crops (86.7%), while very few farmers (5.7%) reported mixing (mixed) only the needed amount of pesticides, also, (6.2%) (very few) showered or bathed after pesticide mixing and spraying, while 93.8% did not shower or bathe, and only 35% of them considered wind direction during spraying. Mohanty *et al*. (2013) in south India observed that farmers with good knowledge used more protective measures compared to farmers with poor knowledge, and reported that most of the farmers (about 66%) buy and use the pesticide immediately, one third farmers had special storage area for the pesticides, while very few (4%) stored them at home (as stated, a practice which could put other family members at risk), also, nearly half of the farmers disposed of leftover pesticide safely i.e. burying, while one third of the farmers disposed of the leftover pesticide by pouring into the field due to, as stated, lack of knowledge where three fourth of the farmers in their study were ignorant about/of excess of pesticide affecting soil fertility, and more than two third farmers adopted unsafe practice of disposal of empty pesticide containers, adding that this unsafe practice of disposing (disposal) (of) leftover pesticide and empty pesticide container is a concern and could put general population at higher risk because it produces impact on (the) environment by contaminating soil, surface and ground water and also poses risk to non-target organisms, and 80% of farmers with good pesticide knowledge washed their clothes after pesticide spray, while all the farmers took bath after pesticide spray, and nearly 2/3rd of the farmers reported that they do not consume anything during spray and 63% of farmers reported washing clothes worn during pesticide spray, also, significant association was observed between knowledge level and safe disposal practices of pesticides by the farmers, and non-use of personal protective equipment during pesticide spraying varied between 40% and 78%, and there was also a significant association between use of protective equipment and knowledge of the farmers. In the study by Sa'ed *et al*. (2010) in West Bank, Palestine, significant association was reported between good level of knowledge about pesticide and education level, and 19.2% of (the) farmers stored (store) pesticide products at home, 53% (of them) at specific store, 8.7% at animal house, and 11.8% at farm site, while only few farmers (7.3%) bought and used it (pesticides) immediately (directly) (did not store), and (the) majority (60.9%) used the leftover pesticide solutions on the same day, while 29.4% kept (stored) the leftover pesticide in a drinking container (in an unlabeled plastic container) for later use, also, (they) disposed of empty pesticide containers by burning (50%), by burying (7.6%), by washing and reusing at home, such as for holding drinking water (as drinking vessels (as drinking water vessels)) (10%), while 14.4% reused for storage of other pesticide, and 68.5% washed contaminated clothes. Alice *et al*, (2019) in Burkina Faso revealed that the majority of the vegetable farmers (69.4%) re-sprayed the treated fields until the spray tank was empty, 14.7% of them (vegetable farmers) stored the leftover solution for another application, 6.0% (6.0% vegetable farmers) applied the leftover solution over a non-cropped area, and 3.8% (of them (vegetable farmers)) applied the leftover solution to another crop (listed on the label), while the most (99.3%) cotton farmers re-sprayed the treated fields until the spray tank was empty, and 35.9% vegetable farmers buried the empty pesticide containers, 30.4% vegetable farmers burned them (the empty pesticide containers), 16.3% vegetable farmers dumped the empty pesticide containers with other wastes, 8.2% vegetable farmers dumped them (the empty pesticide containers) by the field, 2.7% vegetable farmers dumped the empty pesticide containers into water bodies, 2.2% vegetable farmers used them (the empty pesticide containers) for other purposes (uses), and only 1.1% vegetable farmers collected the empty pesticide containers and sold them (the empty pesticide containers), while 64.3% of the cotton farmers (64.3% cotton farmers) collected and buried the empty pesticide containers, 30.7% cotton farmers burned them (the empty pesticide containers), 16.4% cotton farmers dumped the empty pesticide containers by the field, and 6.4% cotton farmers used them (the empty pesticide containers) for other purposes (uses), also, after washing the pesticide application (spray) equipment (the pesticide spray tank or the pesticide sprayer), majority of cotton farmers (45.7%) applied the rinsate over non-cropped area, 28.6% cotton farmers reapplied the rinsate onto the treated field, 25.7% cotton farmers released the rinsate into pit made for rinsate collection, while 42.9% vegetable farmers reapplied the rinsate onto already treated field, 35.3% vegetable farmers applied the rinsate onto non-cropped areas, 8.2% vegetable farmers released the rinsate into collection pit meant for rinsates water collect, and very few (6.5%) vegetable farmers released the rinsate into or near irrigation canals or streams, and stated that although only a very few vegetable farmers disposed of their rinsate into/near irrigation canal or stream, these water sources, in most cases, also serve as source of drinking water for the farming community, showing that most (95.1%) cotton farmers and the majority of the vegetable farmers (74.6%) used water around the field for consumption and other domestic purposes, and added that a little contamination from such deleterious chemicals (pesticides and pesticide wastes) into the water sources, which are potentially consumed, could result in health impairment of the entire community, while 4.9% cotton farmers and 25.4% vegetable farmers stated that they did not use the water around the field for consumption and other domestic purposes except for irrigation. In the study by Tambe *et al*. (2019) in Cameroon, it was reported that 69.2% of the farmers stored their pesticides on their farms, 26.9% stored in their homes, and 26.9% stored the pesticides in their warehouse, and 53.8% farmers discarded (the) empty pesticide containers/sachets (the waste) on their farms, 37.6% farmers burned them (empty pesticide containers/sachets), 3.5% farmers used the empty pesticide sachets as packaging for the crop, while just only 4.8% of farmers handed their empty pesticide containers/sachets to environmentalists for proper management, also, 35.6% of the participants were trained on the use of PPE, while 64.4% have not received any form of occupational health and safety (OHS) training, and 12.5% used safety boots during the spraying of pesticides, while/whereas 87.5% did not, 31.7% used safety glasses when required while 68.3% did not, 49.0% used gloves during work while 51.0% did not, only 35.6% of the participants put on raincoats during the spraying of pesticides while 64.4% did not wear raincoats or any other form of protective clothing, and the majority (99.0%) of the workers (farmers) did not clean up their body immediately after using pesticides, and showed that the duration between spraying pesticides and harvesting the crop for consumption ranged between 1 and 30 days, depending on the farmer and the type of pesticide used, the mean duration being 9.0 days, adding that the majority of the farmers have poor OHS practices as a result of (due to) inadequate OHS training and use of PPE, and the indiscriminate disposal of the empty pesticide containers in the field could cause the accumulation of pesticide in soil and water sources, and some pesticides' active ingredients might not decompose in the soils or water and can therefore be attributed to as the cause for pesticide residues in the crop for the majority of farmers burned empty pesticide containers or disposed it in the fields in their study. Adjrah *et al*. (2013) in Togo showed that the use of protective clothing (protection measures), (which is very recommended) is very rare, in which 84% (of) participant vegetable growers did (do) not wear gloves, 71% did (do) not wear oro-nasal masks, and 84% did (do) not wear goggles during pesticide spraying, and stated that despite its (in spite of its) significant harmful reduction role played by the protection equipment, vegetable gardeners did (do) not motivate to use the devices due to (because of) their ignorance regarding (their ignorance of) the harmful effects of pesticides, high cost, no availability of these equipment and their discomfort. Lekei *et al*. (2014) in Tanzania also revealed that most farmers (66.9%) reported no PPE use at all, while 33.1% used (use) different PPE items ranged from 1 to 6 (long coats, hats/helmets, hand gloves, overalls, respirators and facemasks), and the PPE most often used were gumboots (38.3%); however, the quality and condition of the PPE were poor, where over 60% of the PPE types reported to be used by the farmers were damaged or extremely contaminated when inspected, for instance, most respirators (4 out of 6) reportedly used by the farmers were actually disposable dust masks unsuitable as PPE to prevent inhalation of pesticide droplets, (and it was noted (they noted) that farmers who use PPE may be more likely to practice better hygiene when handling pesticides, so the direct effect of PPE use may be difficult to establish from cross-sectional data, and longitudinal rather than cross-sectional studies would be better suited to testing this hypothesis), and non-use of PPE might be caused by unavailability or high cost of PPE as the use of dust masks, which are relatively cheap, may suggest that farmers' choices of PPE were influenced by considerations of minimizing costs, and 39.0% stored (store) spraying equipment (sprayers) in (at) general store, 26.0% in equipment store, 16.0% at ceiling board, 13.0% in bedroom, and 6.4% elsewhere on the farm, also, the majority of respondents (81%) stored/kept (keep/store) pesticides within their residential homes, often in rooms used by a number of family members (it was found that 81% of the farmers stored pesticides in the house), where 57.2% (of them) stored (store) in (at) (the) general storage/store within the house (a store containing pesticides, fertilizers, food crops, farm implements and others), 5.9% in (the) toilet, 5.2% in (the) kitchen, 5.1% in (the) (above) ceiling board, 3.0%) in (the) bedroom, 3.0%), in (the) bathroom, 1.8% at (in) (the) chicken shed, and 9.2% stored (store) pesticides elsewhere on the farm, while only 9.2% of respondents reported storing (stored) their pesticides in a dedicated pesticide store, and 25% of the pesticides observed (found) at households were found to have been repackaged into a secondary container such as paper or plastic bags, glass or plastic bottles some of which were originally containers for drinking water or soft drinks without proper labels on them (among the 144 products found at 121 households, 36 products (25%) were found to have been repackaged into a secondary container, and none of the repackaged containers had a proper label), and they added in their study that there was a significant association between storing pesticides in the house and respondents' level of education, and that respondents with high education were less likely to store pesticides in the home, also, in general, the protective effect of higher levels of formal education and knowledge of pesticides among the farmers was modest, and high educated farmers (high level of education of (the) farmers) and farmers with high knowledge were more likely to report practicing equipment calibration and high educated farmers were less likely to report storing pesticides in their homes, farmers with low education and low knowledge would be expected to have less awareness of the health and environmental implications associated with pesticides and more inclined to store pesticides in their homesteads, while about 80% of the farmers reported that they did not calibrate their sprayers (spraying equipment) and appeared not to be conversant with the concept of calibration, and there was a significant association between respondents' knowledge and reporting practice of equipment calibration, and also, there was a significant association between respondents' education and reported practice of equipment calibration, and the association between high poisoning symptoms reported by the farmers and failure to calibrate their equipment supports the argument that poor application practices can result in higher exposure through increased emission rates, also, 34.7% resprayed (respraying) the remaining spray solution on the crop, and 28.9% dumped (dumping) out on (in) the farm, while out of 121 participants 38 buried empty pesticide containers, 33 burned (burning) them, 25 dumped (dumping) on the farm, 7 selling back to pesticide retailers, and 8 of (the) farmers washed (wash) and re-used (re-use) the empty pesticide containers for other household purposes (activities) such as for keeping drinking water, in which, as stated, representing a route of serious non-occupational human exposure, while containers reported as used for mixing pesticides included a special container for this purpose (80.2%), tractor mounted equipment (9.1%), and backpack sprayers (5.8%), besides, it was noted in their study that some pesticide retailers may/might misuse the empty pesticide containers for decanting or repacking of adulterated products (pesticides) instead of returning them (empty pesticide containers) to manufacturers, and the manufacturers have no policy for the collection of empty pesticide containers from the farmers, and if farmers were to sell the empty pesticide containers back to pesticide retailers as a means of disposal, this could be detrimental for safety, particularly with unscrupulous retailers, because it could create a market for empty pesticide containers and hence encourage product adulteration through repacking and decanting, which, in turn, may lead to the distribution of substandard products (substandard pesticides) (substandard crop protection products) to the farmers, and use, handling and application of repackaged, decanted as well as spilled products are highly hazardous practices due to the immediate contact and exposure of pesticide users (farmers (pesticide end-users)) to (the) pesticides, and probably the result of supply/distribution of pesticides in large containers, which are unaffordable for small scale farmers; instead, small-scale farmers who have modest needs for pesticides on their small size farms will/would purchase small amounts decanted into secondary containers including soft drink bottles, which are particularly hazardous, and that the use of empty pesticide containers for refilling pesticides is another potentially unsafe approach for disposal, due to the fact that it can encourage product adulteration and movement of products with misleading instructions or with no instructions at all leading to poor use, handling and application of pesticides. In the study by Dilek *et al.* (2018) in Turkey, it was determined that 64.8% of the farmers wore long sleeved shirts, 61.7% of them wore long trousers, 56.2% wore glasses, 51.0% wore gloves, 30.0% used masks, 27.9% used hats, 14.3% wore overalls, 6.9% wore boots, and 4.5% of them wore aprons, also, 78.6% of the farmers stated that they kept pesticides in the general storeroom at home (in the house), and 41.2% of the farmers burned empty pesticide containers, 31.0% of them threw the empty pesticide containers away, 13.6% of them buried them in the ground, 10.0% of them washed and reused them, while only 4.3% of them took them (empty pesticide containers) to special collection bins or centers, and they stated that farmers are not well informed of and/or insensitive to the environmental and human health hazards of empty pesticide containers. The study by Mekonnen and Agonafir (2002) in Ethiopia found that pesticide sprayers (pesticide applicators) were provided with inappropriate (unfit) and worn-out personal protective devices (PPD), of which 18% of the sprayers had unfit (ill-fitting) goggles, and 29% wore worn-out gloves, 94.9% washed their hands after pesticide handling (after pesticide handling and application), 79.4% eat, drink or smoke during work with pesticides, while 14% did not; 92.6% drink water near pesticide-treated areas; 33.1% took (take) shower after pesticide exposure; 94.9% change clothing before and after pesticide exposure; 29.4% keep meals near pesticides, while 61.8% did not; 63% suggested avoiding applications during windy and sunny weather, 32% suggested the provision and proper use of PPD, while only 3% of them felt medical check-ups and training were important, and 2% suggested risks from spraying were best controlled by leaving their job. In the study by Mwabulambo *et al*. (2018) in Arusha, Tanzania, it was reported that 100% of pesticide applicators of onion farms (about 40% participants) used no any form of PPE (not wearing any protective equipment or clothing while handling pesticides) (like caps, gloves, full-sleeved (full-sleeve) shirts, face masks, and shoes) during mixing, loading and spraying (application) (of) pesticides except putting on only shirts or T-shirts, shorts or trousers and slippers or no shoes at all, and pesticide applicators were exposed to pesticides above the acceptable level, while all pesticide applicators (about 60%) in flower farms used full PPE during pesticide application that protected them from direct exposure to pesticides, and the common PPE used were boots, gloves, full and a half face masks and coveralls, also, 62.7% of pesticide applicators spilled pesticides on their body when they did spraying in flower and onion farms, and other hazardous practices in onion farms included: mixing pesticides with bare hands (40%) or using a stick (22%), applying pesticides with bare hands

(40%) or with a hand-held sprayer (40%), not washing their hands before eating, smoking or using tobacco (5%), and not bathing or changing clothes after working with pesticides (12%), besides, empty pesticide containers were thrown in the field, river and home refuse collection pits in onion farms; however, in flower farms, empty pesticide containers were collected into plastic bags and then transported to the destruction unit identified by Tropical Pesticide Research Institute (TPRI) then transported for destruction, and flower farms followed the procedures of pesticide management as per the direction of the manufacturer, but pesticide applicators in onion farms revealed that 1% of them stored pesticides that was easily accessible by children, 11% stored pesticide in closed containers, 54% stored pesticides in their farmhouse, 9% stored pesticides in the kitchen and 15% stored pesticides in the sleeping room. Cevik *et al* (2020) in Turkey reported that 84.2% participant farmers wore gloves during pesticide preparation, and 77.7% wore gloves while spraying; also, sixty-five point eight per cent wore coveralls while spraying, 57.3% wore protective glasses, 56.1% wore masks, and 41.4% declared a possible contact with liquid pesticides while preparing or spraying them.

Matthews (2008) reported that 27% of 8500 smallholder farmers in 26 countries stored pesticides in the home or in open areas, and nearly half indicated that they rarely or never locked pesticides away; these risky behaviors can be attributed to farmers' lack of technical knowledge and training on safe pesticide use (Mustapha *et al*., 2017). Educated farmers and farmers who have access to training on pesticide use are more likely to store pesticides in locked stores designated for pesticides (Mekonnen & Agonafir, 2002; Mustapha *et al*., 2017), and likewise, they are more likely to be aware of pesticide use associated (pesticide-related) adverse health and environmental effects (Hashemi *et al*., 2012; Mustapha *et al*., 2017).

According to Matthews (2008), an increase in the use of protective measures decreases the probability of poisoning by 44% to 80%. An increase in the use of protective measures decreases the probability of poisoning by 44% to 80% (Keifer, 2000; Matthews, 2008; Mustapha *et al*., 2017; Adesuyi *et al*., 2018), while lack of PPE use increases the potential for dermal and respiratory exposure to pesticides (Hogstedt *et al*., 1997; Mustapha *et al*., 2017). Risk to operators and re-entry workers decreased with 80% when the personal protection equipment was (appropriately (properly)) used (Michael *et al*., 2016). Lack of PPE use is made worse by some farmers not spraying according to the wind direction, and drink, eat and smoke when handling pesticides, all of which increase the danger of poisoning (Matthews, 2008; Mustapha *et al*., 2017), and also, they sprayed more often than required, up to once a week depending on the crop, using pesticides highly hazardous to human health and the environment (Mustapha *et al*., 2017). According to Mustapha *et al*., (2017), education status (educational level) and training in pesticide use and safety are strong determinants of the appropriate use of PPE among farmers using pesticides (among pesticide users (among pesticide end-users)). The perception that PPE were useful to prevent exposure to pesticides was (the use of PPE to prevent exposure to pesticides were found to be) associated with at least a high school education among migrant farm workers in USA (Hwang *et al*., 2000), farmers in India (Weinberger & Srinivasan, 2009), farmers in Mexico (Blanco-Munoz & Lacasana, 2011), farmers in Kuwait (Mustapha *et al*., 2017), farmers in Ghana (Okoffo *et al*., 2016), and farmers in Oyo state, Nigeria (Ugwu *et al*., 2015).

In a study conducted by Cihan *et al*. (2015), 73.2% of the farmers wore gloves, 78.8% of them used masks, 15.6% of them wore boots, and 29.6% of them wore protective clothing. In a study conducted by Khan (2009), it was found that only 6% of the farmers used gloves. In the study by Zyoud *et al*. (2010), it was determined that 48.6% of the farmers wore gloves, 63.5% of them used masks, and 63% of them wore protective clothing. Tuna *et al*. (2012) found that 37.0% of the farmers always or usually used gloves, 35.4% of the farmers always or usually used masks, and 9.5% of the farmers always or usually wore protective clothing. In the study conducted by Damalas *et al*. (2006), it was found that 72.7% of the farmers never wore gloves, 86.8% of them never used masks, 2.5% of them never wore boots, and 81.0% of them never wore protective clothing. In the study conducted by Oluwole and Cheke (2009), it was reported that 88.9% of the farmers applied pesticides without taking any personal precautions, and only 11.1% of the farmers wore boots while preparing and applying pesticides. In the study by Hurtig *et al*. (2003), it was found that 34.2% of the farmers stored pesticides in the house. In the study conducted by Tuna *et al*. (2012), it was determined that 52.5% of the farmers kept pesticides in the storeroom/stock room in their houses, 17.2% kept pesticides in the kitchen, 12.7% kept pesticides in the cellar, 6.1% kept pesticides in their living space, 5.0% kept pesticides in the barn, and 5.0% kept pesticides in other areas of the house. In the study by Oluwole and Cheke (2009), it was found that 98.0% of the farmers stored pesticides in the house. And, in the study conducted by Gaber and Abdel-Latif (2012), 53.0% of the farmers threw away empty pesticide packages, 43.0% of them used them (empty pesticide containers) at home, and 4.0% of them burned them. Hurtig *et al*. found that 68.4% of the farmers threw away empty pesticide packages, 18.0% burned them, 16.2% buried them, and 38.7% of them used them (empty pesticide containers) to transport oil. In the study conducted by Kalıpc¸ı *et al*., it was found that 28.3% of the farmers buried empty pesticide packages in the ground, 23.3% of them burned them (empty pesticide containers), 25.0% of them left them (empty pesticide containers) on the field, 14.1% of them threw them (empty pesticide containers) away, and 9.1% of them washed and reused them (empty pesticide containers). Anna *et al.*, (2014) in Uganda reported that a high percentage of participant small-scale farmers (73%) use ordinary clothing when spraying pesticides, while some farmers use some PPE and the most commonly used PPE were boots (51%), followed by long-sleeved t-shirts (24%), and ninety-eight percent of the farmers take (took) precautions after spraying pesticides. The study by Negatu *et al*. (2016) in the Rift Valley region in Ethiopia showed that less than 5% of farmers used masks or gloves during pesticide application. Findings from the study carried out in Ethiopia reported that PPE use was twice as high among pesticides applicators as among re-entry workers (13 versus 7); while none of the small-scale farm workers used any PPE (Negatu *et al*., 2016).

Lack of personal protective equipment and unsuccessful use of pesticides are major problems during pesticide application, especially in developing (low income) countries (Damalas *et al*, 2006; Dilek *et al*., 2018). The use of effective protective equipment is an important approach to avoid pesticide poisoning (Taghdisi *et al*., 2019). The use of appropriate PPE and the adoption of other safe protective measures (safety protective measures) and attitude during preparation and application of pesticides are important to reduce occupational exposure to pesticides (Adesuyi *et al*., 2018). Protective measures during and after pesticide application are important to reduce exposure to pesticides (Mustapha *et al*., 2017). Zare, *et al* (2015) in southern Iran reported that approximately half of the farmers do not use any kind of protective equipment during pesticide application, which would/could be attributed to humid climate of their study area. Non-use and partial usage of PPE by farmers during pesticides application increases the potential risk of pesticide exposure, with serious health implications (Adesuyi *et al*., 2018). Farmers may be more willing to risk (themselves to) exposure to pesticides than to use PPE under/in tropical (hot) climatic conditions (Adesuyi *et al*., 2018). Education and farming experience had a negative relationship with disposal of pesticide containers after use, the reuse of pesticides containers and burning of used pesticides containers, which implies that as farmers gain more experience in farming with their education level, they are less likely to throw empty pesticide containers on the ground outside the farm, reuse (re-use) or burn used pesticide containers (Adesuyi *et al*., 2018).

The re-use of pesticide containers represents a route of serious non-occupational human exposure, as several traces of pesticides could still be found in the containers even after washing and rinsing (Adesuyi *et al*., 2018). A study by Lawal *et al.* (2015) in Nigeria reported that cocoa farmers (100%) washed their hands after pesticide application. Bathing along or within nearby water bodies is a potential threat and risk to aquatic lives and humans due to pesticides contamination (pollution) (Adesuyi *et al*., 2018). The disregard on wind direction during pesticides application exposes farmers to risk of pesticides intoxication as the wind may blow the chemical towards the body, including the face of the farmer, and (this) might also causes pollution of the environment (soils and nearby water bodies) due to spray drift (Adesuyi *et al*., 2018). Poor spraying practice, such as not taking into account (not considering) wind direction when spraying pesticides presents (represents) great potential to exposure of farmers to chemicals from both dermal contact and inhalation (Okoffo *et al*., 2016). In many developing countries, farmers use empty pesticide containers for other storage purposes or sell them to recycling centers (Taghdisi *et al*., 2019), and widespread reuse (re-use) of pesticide containers (empty pesticide containers) for other household purposes and activities has been reported in other studies (Afari-Sefa *et al.*, 2015; Okoffo *et al.*, 2016; Adesuyi *et al*., 2018), and also, a similar prevalence of re-use of containers (empty pesticide containers) has been reported in other studies in developing countries (Gerken *et al*., 2001; Heeren *et al*., 2003; Lekei *et al*. 2014). A study conducted in northern India showed that most of farmers keep the half-empty pesticide containers out of children's reach, that nearly half of the farmers bury the empty containers (the empty pesticide containers) properly, and that the rest throw them away in nature or sell them to recycling centers (Mahantesh & Singh, 2009; Taghdisi *et al*., 2019). Farmers with higher education levels were significantly less likely to store pesticides in their home (Mustapha *et al*., 2017). Unfortunately, storing of pesticides in residences and in the open is prevalent in many developing countries (Mustapha *et al*., 2017). Unsafe disposal of empty pesticide containers may be an important source of pesticide exposure (Mekonnen & Agonafir, 2002; Mustapha *et al*., 2017). Wearing protective clothes is one of the common safety measures (Kafle *et al*., 2021). Government should consider programs to increase the availability and accessibility of personal protective equipment (PPE) to farmers (Kafle *et al*., 2021). While increasing formal education levels of farmers may enhance their ability to read labels in local languages or English, targeted pesticide safety trainings may be more effective for enhancing safe pesticide practices to protect human, animal, and ecosystem health than formal schooling (Benjamin *et al*. (2019). Poor pesticide handling, application, and storage can negatively impact the health of humans, animals, and ecosystems (Damalas & Eleftherohorinos, 2011; Benjamin *et al*. (2019). Storing pesticides in the home (at home) puts children and adults at risk, and disposing of the empty pesticide containers on the garbage site or along the street could put the general population in danger (at risk) (Yassin *et al*., 2002). Failure to use PPE appeared to be one of the (major) problems generating potential for significant pesticide exposure, and this is supported by the finding of a significant association between high poisoning symptoms and non-usage of PPE, and non-use of PPE might be caused by unavailability or high cost of PPE (Lekei *et al*., 2014). Equipment calibration is important to prevent both over-application, which results in human exposures, excessive residues and threats to local and export produce, as well as under-application, which may result in insect resistance, and failure to calibrate equipment may similarly reflect poorer farmer hygiene practices in general and therefore be a proxy for other factors in farmers' risk behaviour profile (Lekei *et al*., 2014).

Unsafe disposal of unwanted pesticides and empty pesticide containers may be an important source of pesticide exposure; farmers commonly dumped products and containers in unsafe ways, and these practices may lead to environmental contamination (pollution) by runoff, leaching or distribution via aerial distribution to other areas and are typical of (are typical phenomena in) many developing countries (Gerken *et al*., 2001; Lekei *et al*., 2014). The re-use of empty pesticide containers for domestic purposes is prevalent in many developing countries. Studies in Madhya Pradesh, India (Choudhary & Laroia, 2001), Tanzania (Ngowi *et al*., 2001) and South Africa (Heeren *et al*., 2003) found that rural populations made use of empty pesticide containers for domestic purposes, such as for keeping domestic water.

Especially in the developing countries, the use, handling and application of pesticides under unsafe conditions and unsafe disposal of empty pesticide containers not only give harm to agricultural workers' health, but also cause serious damage to the environment and public health (Cevizci *et al*, 2012; Dilek *et al*., 2018). Mekonnen and Agonafir (2002), and Negatu *et al*. (2016) conveyed (made known) comparable results in which many of the farmers did not habitually take a shower after the application of pesticides. Pesticide applicators are mostly young men who work as casual laborers, sometimes/often with no knowledge or training about the environmental and health effects of pesticides and are thus ill-equipped to deal with exposures and their effects (Mwabulambo *et al*., 2018). Uses of protective measures during pesticide application depend on availability, affordability, being comfortable and regulations, and thus are limited in small-scale farming areas, and without proper protection, pesticide exposure risk and the occurrence of adverse health effects increase (Mwabulambo *et al*., 2018).

Wearing PPE is among the behaviours mostly assumed to protect pesticide users from pesticide exposure, and the failure of farmers to use PPE during pesticide application presents (represents) potential risks to pesticide exposure (presents (represents) potential pesticide exposure risks) (Mwabulambo *et al*., 2018). Wearing or putting on full PPE during pesticide application was defined as wearing a nose mask, hand rubber glove, overall, long coat, facemask and boot (rubber boot) at the time of application, whereas/while/on the other hand, applying pesticides without PPE connotes when a farmer uses casual farming clothes without any of (without any use of) the listed PPEs (Mwabulambo *et al*., 2018). A study done on Cambodian farmers showed a reduction of risk of acute pesticide poisoning (APP) by 55% among more highly educated farmers who adopted extra personal protective measures (Jensen *et al*., 2011; Mwabulambo *et al*., 2018). A study on community-based intervention to reduce pesticide exposure to farm workers and potential take-home exposure to their families showed the importance of wearing protective gloves in reducing pesticide exposures among strawberry harvesters (Bradman *et al*., 2009; Mwabulambo *et al*., 2018). A study done in Ghana on farmer perceptions and pesticide use practices in vegetable production showed that pesticide poisoning occurred more often among farmers who generally did not wear protective clothing during spraying of pesticides (Ntow *et al*., 2006; Mwabulambo *et al*., 2018). A study of farmers who used pesticides in rural Indonesia showed that those who wore no mask/respirator, (and wore) wet clothing or short sleeves had greater skin contact with pesticides (Sekiyama *et al*., 2007; Mwabulambo *et al*., 2018).

Clarke *et al*. (1997) reported that, in the tropics, use of PPE is poorly tolerated because of discomfort associated with hot and humid conditions and prohibitive costs, and thinks that there is also a need to develop and provide protective equipment appropriate to the climate and socio-cultural environment. Another study noted that effect of climate can justify discomfort situation, because the sprayers (the pesticide applicators) of Ethiopia said that windy and sunny weather were the major problems faced during pesticide applications (Mekonnen & Agonafir, 2002; Adjrah *et al*., 2013). It was reported that the use of protective clothing has been insufficient, particularly in the developing countries, because of the lack of regulations and due to the lack of education and sensitization (Wilson & Tisdell, 2001; Adjrah *et al*., 2013).

Asongwe *et al*. (2014) revealed that 95% of farmers in Bamenda Municipality of Cameroon do not protect themselves during pesticide applications, and Palis *et al*. (2006) made known that those Filipino farmers (farmers in the Philippines) believe in immunity, saying (meaning) that the youths were not susceptible to the adverse health effects of pesticides, consequently, PPE were not important to them, which is actually a wrong belief (a wrong perception) which exposes the youths to more (increased) pesticide exposure health hazards (risks) (pesticide exposure health problems). Pesticide (pesticide use) interventions (pesticide (pesticide use) intervention strategies and measures) targeting financial and other factors in addition to farmer knowledge may be required to improve PPE use and safe pesticide handling (Benjamin *et al*. (2019).

Exposure to pesticide during pesticide use (during pesticide use, handling and application) (including pesticides exposures through operational habits exhibited by farmers such as drinking water, eating, smoking, singing, talking during and after pesticide handling (preparation (mixing) and application (spraying))) has been one of the most important occupational hazards among farmers in developing countries (Coronado *et al*., 2014; Adesuyi *et al*., 2018). Use of appropriate PPE, such as coveralls (overalls), and the adoption of other protective measures and good personal hygiene such as showering, not smoking, eating or drinking while/when handling pesticides (during handling of pesticides (during pesticide handling)) are considered good practices to reduce occupational pesticide exposure (Matthews, 2008; Mustapha *et al*., 2017).

Use of personal protection equipment is a necessary requirement for a responsible pesticide application and protects the operator, as well as the workers in the field (Michael *et al*., 2016), and this protective equipment needs to be cleaned or replaced regularly to ensure the safe application of pesticides (Li *et al*., 2011; Matthews, 2008). A study by Recena *et al*. (2006) at/in Brazil reported that less than 20% of farmers used mask, impermeable clothes, or gloves during pesticide application, and lack of protective measures can lead to unpredictable hazards when farmers or workers re-enter the treated crops. In the study by Michael *et al*. (2016), operators were aware of the danger of pesticides spillage during mixing, loading and application of pesticides which reflected in the use of gloves, facial protection and boots; however, uncomfortable (unsuitable) environmental conditions and the cumbersome (large (heavy) and difficult to handle or use) equipment tempt (lead (enforce) or be persuaded) some farmers to ignore the safety measures, increasing the danger of poisoning. To minimize pesticide exposure (the exposure to pesticides) a re-entry interval has to be determined and respected which reduces the occupational pesticide poisoning of horticulture workers (Michael *et al*., 2016). A short re-entry period represents high dislodgeable foliar residues, potentially putting the workers at risk (Korpalski *et al*., 2005; Beauvais *et al*., 2010; Dong and Beauvais, 2013; Doan Ngoc, 2014; Michael *et al*., 2016). Knowledge and attitudes alone are not enough to change the behaviour of farmers to work in a healthy and safe way (Michael *et al*., 2016), and the gap between knowledge and practice needs to be bridged by more interactive and participatory training model (Calliera *et al*., 2013; Yuantari *et al*., 2015;

Michael *et al*., 2016). Warm climate was one of the causes of low use of PPE in a study in the United States (Garrigou *et al*., 2020; Mergia *et al*, 2021).

The use of gloves and overalls efficiently reduces (minimizes) the risk of pesticide exposure (pesticides exposures) to operators and re-entry worker (re-entry workers), and risk of pesticide exposure (pesticide exposures) to living creatures inhabiting in water bodies and contamination (pollution) of aquatic organisms can be reduced (minimized) by implementing buffer strips and using drift reduction techniques (Michael *et al*., 2016). Implementing (the) pesticide mitigation actions will minimize (reduce) the environmental load, reduce (minimize) (limit) the human exposure and improve the farmers' outlook on his horticultural production (Michael *et al*., 2016). To minimize pesticide resistance development of plant pest populations (crop plant pest populations), resistance management techniques should be included to set integrated pest management strategies (Michael *et al*., 2016); resistance management is essential in order to retain effective products in the field (Horst, 2013; Michael *et al*., 2016). Pesticide users (farmers (pesticide end-users)) who use (who use and handle (mix (prepare) and apply (spray)) pesticides without using PPE were more likely to develop neurological symptoms compared to those who used PPE, and therefore, the use of PPE is unavoidable and should always be encouraged during application of pesticides (Mwabulambo *et al*., 2018).

Storage and disposal of empty pesticide containers are critical points of intervention to enhance the awareness of safety during the application of pesticides (Matthews, 2008; Michael *et al*., 2016). Storing pesticides in the home (at home) can easily contaminate drinking water and food, and can threaten especially the health of children (Michael *et al*., 2016). In a high income agricultural setting like North-Eastern Italy, more than 90% pesticide applicators used PPEs such as gloves, masks and post-spraying personal hygiene practices (Riccò *et al*., 2018). Improper disposal of pesticide containers and over-application of pesticides to the same (treated) field are common unsafe and poor pesticide use practices particularly among farmers in many developing countries.

Re-spray treated areas with leftover pesticide solutions or disposing of leftover pesticide solutions and old pesticide stock (old pesticide stocks) in the field are poor pesticide handling practices, and can lead to harmful residues in harvested produce, and soil and water contamination, posing a threat to both human and environmental health (Atreya *et al*., 2012; Mustapha *et al*., 2017). Unsafe disposal of empty pesticide containers may be an important source of pesticide exposure (Mekonnen & Agonafir, 2002; Mustapha *et al*., 2017). Adopting unsafe behaviors (practices) of empty pesticide containers disposal such as discarding, incinerating or burying empty pesticide containers on-farm may/can lead to environmental contamination and a risk to human health, and have been reported as a major problem in a number of studies (Matthews, 2008; Osborne *et al*., 2015; Mustapha *et al*., 2017). Inappropriate (improper or incorrect) disposal of empty pesticide containers is common among farmers from developing countries; for instance, farmers in the rural regions of Pieria in northern Greece were reported to either burn, bury or dump empty pesticide containers on their farms, while a larger number repeatedly used the same empty pesticide containers for spraying (Damalas *et al*., 2008; Alice *et al*., 2019). In Ghana, about 60% of vegetable farmers were reported to dispose of empty pesticide containers on the field (in the field), with evidence of empty pesticide containers littering the field (Ntow *et al*., 2006; Alice *et al*., 2019). Worryingly (still a worsening practice), farmers especially in developing countries have been reported to re-use (reuse/use) empty pesticide containers for storing (to store) food and drinking water (Coppola *et al*., 2007; Mengistie *et al*., 2016; Huici *et al*., 2017; Alice *et al*., 2019). After they have been used and emptied, if not rinsed properly, empty pesticide containers are considered hazardous due to residual pesticides retained in them (Elfvendahl *et al*., 2004; Buczynska and Szadkowska-Stanczyk, 2005; Ntow *et al*., 2006; Huici *et al.*, 2017; Alice *et al*., 2019), and can cause damage to human health and the environment (Alice *et al*., 2019).

General lack of education, awareness and facilities for safe collection and disposal of empty pesticide containers could be reasons for farmers' reuse (re-use) or inappropriate (improper or incorrect) disposal of empty pesticide containers especially in developing countries (Damalas *et al*., 2008; Sharafi *et al*., 2018; Alice *et al*., 2019). It has been shown that previous training provided to farmers on pesticide use has been associated with increased safety behavior among farmers, thus contributing to lower occupational exposure to pesticides (Damalas & Koutroubas, 2017; Bondori *et al*., 2018; Alice *et al*., 2019).

Developed countries have strategies for collecting empty pesticide containers; however, such strategies are lacking in developing countries; for instance, in 2003, France and Australia (developed countries) collected about 25% and 35%, respectively, of the total number of empty pesticide containers (Huici *et al*., 2017; Alice *et al*., 2019), whereas Ecuador and Uruguay (developing countries) managed to collect 0% and 4%, respectively, of the total number of empty pesticide containers generated in 2004 (Alice *et al*., 2019). Jones (2014) has opined that the key to solving the problems associated with empty pesticide containers is to train farmers and to establish multi-stakeholder empty pesticide container management programs, which remove empty pesticide containers from the environment, re-process and recycle them into appropriate end uses. In 2014, a Bolivian non-governmental organization implemented a project which installed collection centers for empty pesticide containers where they collect, properly empty and secure the final disposal through actions such as the triple rinse (Huici *et al*., 2017; Alice *et al*., 2019).

Accidental or deliberate (intentional) release of pesticide residues into the environment can harm humans as well as non-target organisms such as plants, soil microbes, beneficial insects, fish and other aquatic life (Damalas & Koutroubas, 2017; Alice *et al*., 2019). Sharafi *et al*. (2018) reported that about 12% of the farmers released the rinsate into streams; while Damalas *et al*. (2008) reported that about 66% of farmers disposed of the rinsate into irrigation canals and streams. Over-application of pesticides or re-applying pesticide leftovers (mixed and diluted leftover pesticide solutions (mixtures), remained pesticide stocks and/or old pesticide stocks) or rinsate could pose more detrimental effect by increasing the amount of pesticide residues (pesticides) that will drift into non-target areas, or be absorbed into the soil (Raupach *et al*., 2001; Woods *et al*., 2001). Also, excessive application of pesticides may lead to high pesticide residues (pesticides) retained on the plant, which may be hazardous (deleterious) to the health of farmers and vegetable/fruit consumers (Nguyen *et al*., 2018).

A more environmentally-friendly (a more environmentally friendly, safe and sound) means of removing pesticide residues from the environment is by employing the use of a *biobed* (Alice *et al*., 2019). Biobed, originally designed in Sweden, was intended to collect and degrade pesticides arising from filling operations, pesticide wastes, spray tank leftovers and wash residues (Torstensson and Castillo, 1997; Alice *et al*., 2019). The biobed comprises of a biomixture of straw, peat and soil in a 2:1:1 ratio (Torstensson and Castillo, 1997; Alice *et al*., 2019). *Straw* is the main component for ligninolytic fungal growth; the *peat* contributes to the sorption capacity and helps to regulate moisture in the biomixture; the *soil* provides the site for pesticide sorption and favors microbial activity (Torstensson and Castillo, 1997; Castillo and Torstensson, 2008; Alice *et al*., 2019). Several studies have demonstrated that this biological system can effectively retain and degrade a wide variety of pesticides (Vischetti *et al*., 2006; Coppola *et al*., 2007; Castillo and Torstensson, 2008; Tortella *et al*., 2012; Alice *et al*., 2019). However, the biobed is a technology that has not been tested in many developing countries (Alice *et al*., 2019). According to Khanal and Singh (2016) not considering the wind direction can result in bad odor, difficulty reaching the targeted crop with the spray, as well as inhalation by the person spraying the pesticides. With the most careful pesticide application (spraying), spray drift to off-target areas is inevitable (Alice *et al*., 2019). Unsafe and poor practices of pesticide storage and disposal of leftover pesticides, mixed and diluted leftover pesticide solutions (mixtures) and empty pesticide containers were considered to be among the main concerns (among the major problems) associated with pesticide use, its management and control (pesticide management and control) in developing (low income) countries (Wesseling *et al*., 1997). Especially the re-use of pesticide containers represents a route of serious non-occupational human exposure, as several traces of pesticides could still be found in the containers even after washing and rinsing (Adesuyi *et al*., 2018). A study in Howrah (India) reported only 37% of farmers taking bath after pesticide use; however, all the farmers washed their hands after pesticide spray (Das & Dey, 2005; Mohanty *et al*., 2013).

Pesticides enter the environment both through diffusion (and through runoff, leaching, infiltration and percolation) and direct losses (Holvoet *et al*., 2008; Fevery *et al*., 2015; Michael *et al*., 2016). Pesticide direct losses originate from, for instance, drift, cleaning of spray equipment and leaking tools, and can account for 30 to 90% of the pesticide load in smaller water streams (Holvoet *et al*., 2008; Michael *et al*., 2016). Spraying within 1 m of water bodies and throwing pesticide waste in water streams will further increase this load, decrease economical aquatic outlook, and increase the cost to produce drinkable water (Helweg *et al*., 2002; Toan *et al*., 2013; Michael *et al*., 2016). Even after triple rinsing, the empty pesticide container, the canister should be disposed of correctly as triple rinsed empty pesticide containers are still able to harm the environment (Osborne *et al*., 2015; Michael *et al*., 2016). A nation-wide program to collect and recycle empty pesticide containers need to be implemented to reduce this environmental pollution (Cook, 1998; Briceo, 2014; Michael *et al*., 2016). Good practices in occupational health and safety (OHS) generally require farmers to comply with OHS practices during the execution of their duties and lead to more positive health and safety culture among the workers and can significantly reduce both injury rates and costs at the workplace (Wolska & Namies'nik, 2007; Tambe *et al.*, 2019). For effective protection, PPE should be chosen based on the information given on the pesticide label (Adesuyi *et al*., 2018). In the study by Michael *et al*. (2016) in Vietnam, personal protection equipment, especially gloves, are used by approximately all of the farmers and workers.

Knowledge and attitudes alone are not enough to change the behaviour of farmers to work in a healthy and safe way (Michael *et al*., 2016); the gap between knowledge and practice needs to be bridged (channeled) by a more interactive and participatory training model (Calliera *et al*., 2013; Yuantari *et al*., 2015; Michael *et al*., 2016). Continued education and raising awareness is necessary to inform operators (Phung *et al*., 2013; Kearney *et al*., 2015; Yuantari *et al*., 2015; Michael et al., 2016). Although a good crop protection is essential during the rainy season, application of pesticides only a few hours before rainfall has a limited effect as up to 90% of the pesticides are washed off the plant (Reddy *et al*., 1994; Willis *et al*., 1994; Willis *et al*., 1996; Hunsche *et al*., 2007; Michael *et al*., 2016). Pesticide run-off into surface water results in a serious negative impact on the aquatic life (Khatri and Tyagi, 2015; Michael *et al*., 2016). Pesticides should be applied when no rainfall is predicted (expected) for several hours, allowing the pesticides to be taken up by the crop and the crop pest. Moreover, the use of systemic or semi-systemic pesticides is preferred over (preferred to) contact pesticides as these pesticides do not need to be reapplied after a certain amount of precipitation. Adjusted pesticide formulations and a wide variety of tank-mix adjuvants can be used to overcome some of these issues (Castro *et al*., 2014; Michael *et al*., 2016). Several products can be added to the spray liquid to increase the adhesion to the foliage, to increase the rainfastness (rain fastness) or to reduce the post application dissipation of active ingredients (Pannacci *et al*., 2010; Houbraken *et al*., 2015; Sun *et al*., 2015; Michael *et al*., 2016). Reducing pesticide losses to these process results in a lower environmental pesticide load and a more efficient crop protection. Nevertheless, the current practice of periodic pesticide spraying is undesirable as no pest or disease is targeted specifically, no monitoring is performed and no damage thresholds are established (Horst, 2013; Michael *et al*., 2016). Several products contain the same active ingredient, creating an illusion that the farmers are rotating between products (Michael *et al*., 2016). The use of only a few pesticide product (pesticide formulation) groups stimulates resistance development and reduces the efficacy of the pesticide products (IRAC, 2010; Michael *et al*., 2016). Canonical coordination analysis indicated that education was less important than the age of the farmer to explain risk awareness; crop type and number of experienced illnesses explained the awareness of farmers more (Michael *et al*., 2016).

Farmers may have preferred to declare socially approved (socially respected) behaviours, rather than their actual behaviours in responses such as use of PPE, i.e., the actual rate of protective equipment farmers used might (would) often be lower than they did report, or farmers might (would) state that they used protective equipment correctly although they might (did) not (Cevik *et al*., 2020). Protective equipment may not be effective in preventing pesticide exposure if not appropriately used (Jensen *et al*., 2011; Cevik *et al*., 2020). In a study in South Korea, it has been shown that the risk of pesticide poisoning increases if gloves or masks are not worn as personal protective equipment (PPE) during pesticide spraying (Kim *et al*, 2013; Cevik *et al*., 2020). The rate of implementing protective measures such as reading the pesticide label, wearing protective clothing (gloves, work overalls (coveralls), masks, hats, glasses) was higher in those with 15 years and over farming experience (Cevik *et al*., 2020). In the study in Brazil, it was reported that complex mixtures of multiple pesticides are commonly sprayed by manual pumping or backpack tanks by smallholder family farmers (Pedlowski *et al*., 2012; Bendetti *et al*., 2014; Buralli *et al*., 2020), which might result in potentially harmful effects, and greater health outcomes (Alavanja, 2009; Buralli *et al*., 2020). In the same study in Brazil by Buralli *et al*. (2020), findings emphasize the role of protection equipment and technical support in human acute and chronic pesticide exposure poisoning prevention (in preventing acute and chronic pesticide exposure poisoning human health hazards and risks (human health problems)). The issue of farmers' unsafe practices of pesticide use, found in many studies, is complex because it needs (demands) urgently designing and implementation of comprehensive (holistic) and appropriate pesticide and pesticide use intervention strategies and intervention measures to change farmers' behaviours (Lekei *et al*., 2014). Training of the farmers on safety practices (on pesticide use safety practices) (on safe use of pesticides) is recommended but should be practically-oriented involving farmer field schools because evidence shows that these schools are the most effective ways to change farmer behavior (Lund *et al.*, 2010; Lekei *et al*., 2014), also, training should be complemented by measures that reduce cost barriers to the adoption of safe behaviours (safety behaviours) (Lekei *et al*., 2014). A training program on proper disposal of rinsate waste is also required for farmers to prevent future occurrence of such behavior (Alice *et al*., 2019).

Pesticides, by their nature, are potentially toxic (poisonous) to humans and many other organisms other than their target audience; therefore, pesticides must be used appropriately and safely applying and operationalizing pesticide use (usage) (pesticide use (usage), handling and application) preventive, protective, precautionary and safety measures (pesticide use (usage) safety precautions and pesticide use (usage) safety practices), and pesticide wastes should be disposed of appropriately and in an environmentally friendly, safe and sound manner. Particularly synthetic chemical pesticides (synthetic chemical insecticides) are very harmful organic chemical compounds for the health of humans and for the health of the environment, and their environmental health and human health adverse (deleterious) effects (their human health and environmental health negative impacts) are exacerbated especially when chemical pesticides are used inappropriately and in an unsafely way, and when pesticide wastes including particularly of empty pesticide containers, old pesticide stocks and obsolete pesticides (obsolete pesticide stockpiles) are disposed of inappropriately and in an environmentally unfriendly, unsafe and unsound way. Pesticides entering the human body can cause acute (short-term) pesticide exposure poisonings (acute pesticide exposure intoxications) (APP) and chronic (long-term or prolonged) pesticide exposure human health problems (chronic (long-term) pesticide exposure human poisonings), i.e., pesticides entering the human body can cause acute and chronic human health hazards and risks, and detrimentally greater health outcomes. Occupational (intentional or deliberate) and unintentional (non-intentional and/or environmental) pesticide and pesticide use exposure poisoning (occupational and environmental pesticide and pesticide use exposure and consequent poisoning) is a major public health concern globally, particularly in developing countries, and specifically occupational (intentional) pesticide exposure poisoning is an important public health concern worldwide, especially in low-and middle-income (LMIC) (developing countries). In the present study, common symptoms of self-reported health problems (common self-reported toxicity health symptoms) encountered by onion cultivating farmers during and after synthetic chemical pesticide (synthetic chemical insecticide) use and handling (preparation (mixing) and application (spraying)), who have been using chemical pesticides (chemical insecticides) inappropriately and without any pesticide use safety measures and without any pesticide use safety practices (with non-use of any pesticide use safety precautions) because of the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides and unavailability of pesticide use preventive and protective measures, were dermal irritation (38.7%), headache (21%), problem of eyesight (blurred vision) (17.1%), internal burning sensation (stomach and heart) (12%), and nausea (11.2%), which demonstrated that there would be prevalence of acute (short-term) pesticide exposure poisoning human health hazards and risks (toxicity health problems of humans) (acute pesticide exposure intoxications) (APP), and the likely chronic (long-term or prolonged) pesticide and pesticide use exposure human health problems in/among onion producing farmers in the study area of the present study, probably including unrecognized, unrecalled and/or unreported (or not clearly reported) pesticide and pesticide use exposure health problems particularly chronic human health conditions (illnesses) by the farmers who have been using synthetic chemical pesticides (synthetic chemical insecticides) for years and have been exposed to the pesticides since the beginning of the farmers' pesticide use because of the farmers' lack of knowledge of the nature of pesticide-associated human health problems (pesticide-related health problems on humans) and the farmers' inability to recognize and differentiate (understand) confusions of similarities of symptoms of the pesticide-associated human health conditions (human health problems) with other types of human illnesses. There would also be non-specific health symptoms of certain human illnesses. Especially the likely chronic health problems among/in the farmers in the present study would/could be in deleterious and life-threatening conditions and could result in greater health outcomes.

Hence, continuous and regular (periodic or seasonal) monitoring and surveillance of the health status of farmers, and immediately designing and instantly implementing pesticide and pesticide use prevention and protection (preventive and protective) intervention strategies and intervention measures are urgently required (mandatory) in the study area of the present study. And, it can be justified that all or most of these health symptoms faced by onion growing farmers during and after pesticide (insecticide) use and application in the study area of the present study would be indications and outcomes of pesticide exposure, as most of these symptoms of health problems are considered to be common manifestations of depletion and inhibition, respectively, of the levels and activities of cholinesterase enzymes (especially acetylcholinesterase (AChE) and butyrylcholinesterase (BChE) enzymes) (ATSDR, 1993; Yassin *et al*., 2002; USEPA, 2013; Mergia *et al*., 2021), which would particularly be caused by and associated with exposure to organophosphate (OP) and carbamate (CM) pesticides (organophosphate/carbamate pesticides (OP/CM pesticides)), which are mainly used as insecticides (Bendetti *et al.*, 2014; Mwabulambo *et al*., 2018; Buralli *et al*., 2020; Ramírez-Santana *et al*., 2020), and the mechanism of action of OP/CM pesticides (OP/CM insecticides) is through inhibition of AChE in insects, but also OP/CM pesticides similarly affect the human enzymes (Fukuto, 1990; Nigg & Knaak, 2000; Ramírez-Santana *et al*., 2020). Acute exposure to high concentrations of OP/CM pesticides produces an accumulation of acetylcholine (ACh) (ACh is a neurotransmitter) at central and peripheral synapses triggering cholinergic symptomatology (cholinergic syndrome) (Marrs, 1993; Casida, 2009; Ramírez-Santana *et al*., 2020). It has been indicated that cholinesterase-inhibitor (inhibiting) pesticides, such as OP and CM pesticides, represent (present) an important risk for human health and are considered the main chemical pesticide groups (classes) (agents) responsible for pesticide poisoning in LMIC (developing countries)

(Muñoz-Quezada *et al*., 2017; UN, 2017; Buralli *et al*., 2020). Cholinesterase enzymes are useful for screening of OP and CM pesticides poisoning or continuous monitoring (Bendetti *et al*., 2014; Buralli *et al*., 2020), and erythrocyte AChE level is indicative of exposures to cholinesterase inhibiting OP and CM insecticides (Mwabulambo *et al*., 2018). AChE and BChE inhibition, respectively, are biomarkers of chronic and acute exposures to OP and CM pesticides (Buralli *et al*., 2020), and the AChE and BChE biomarkers are useful for an initial screening of pesticide poisoning (Bendetti *et al*., 2014; Buralli *et al*., 2020). In the study by Ramírez-Santana *et al*. (2020) in Chile, the inhibitions of AChE and BChE activities were used to demonstrate acute exposure to OP/CM pesticides during the spray season, and in the study by Mwabulambo *et al*. (2018) in Tanzania, inhibition in AChE activity exhibited the exposure to OP and CM pesticides among pesticide applicators. Hence, continuous and regular (periodic or seasonal) monitoring, surveillance, investigation and evaluation of the health status of farmers, i.e., the status of acute and chronic health conditions including probably latent and potentially detrimental and silently killing chronic health problems of small-scale (smallholder) onion cultivating farmers, family farmers and farm workers (pesticide end-users) caused by and associated with pesticide and pesticide use exposures in the study area is urgently required through biomonitoring analysis and evaluation (particularly) of the levels and activities of human cholinesterase enzymes as most of the currently commonly used chemical pesticides (chemical insecticides) by the farmers for the control and management of onion including other vegetables pests are predominantly OP pesticides, and because the farmers are occupationally (intentionally) and non-intentionally (unintentionally and environmentally) deleteriously highly exposed to pesticides due to inappropriate and unsafe use (inappropriate and unsafe use, handling and application) of pesticides by the farmers because of the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides, and pesticide and pesticide use safety measures.

Overall, the findings of the present study require and necessitate urgent and mandatory designing and formulation, and immediate implementation of pesticides and pesticide use prevention and protection intervention strategies and intervention measures (pesticide and pesticide use preventive and protective intervention strategies and intervention measures) such as interventions on encouraging reduced (minimal) use and non-use of pesticides through use and promotion of other alternative pest control and management approaches (methods) and practices (other pest control and management alternatives (options)) such as principles and procedures of good agricultural practices (GAP), integrated pest management (IPM) principles and approaches, and promotion and scaling-up of pesticide-independent (pesticide non-dependent) farming systems (approaches) and practices such as organic (ecological or eco-friendly) farming (ecological (eco-friendly) agriculture), founding and facilitating initiatives (thematic areas) for discovery, innovation and invention of other and new pest control and management principles, approaches, methods and practices, and on applying principles (guidelines and procedures) of appropriate and safe use (appropriate and safe use, handling and application) of pesticides including provision and strict practical application of pesticide use preventive, protective, precautionary and safety measures (pesticide use safety precautions and pesticide use safety practices) during use and application of pesticides, and by selectively providing and using less toxic and easily biodegradable pesticides for the current pesticide use indispensable plant including vegetable crop protection practices. And, continuous and regular (periodic) monitoring, investigation (testing), surveillance and evaluation of the health status (the status of acute (short-term) and chronic (long-term) health conditions (health problems)) including probably latent and potentially deleterious and silently killing chronic health problems (chronic health conditions) of smallholder (small-scale) onion cultivating farmers, family farmers and farmworkers (pesticide end-users) caused by and associated with pesticide and pesticide use exposure poisonings (pesticide and pesticide use exposures and consequent poisonings) through biomonitoring analysis and evaluation (particularly) of the levels and activities of human cholinesterase enzymes is urgently required in Ethiopia (and probably beyond) encompassing the study area, and taking the present research as a case study. High-income countries have overcome the acute pesticide exposure poisonings and are more concerned about/on chronic human health effects and long-term pesticide exposure (high-income (developed countries) are more concerned with chronic human health effects of long-term pesticide exposure rather than acute pesticide exposure poisoning human health problems, for they have overcome the acute pesticide exposure poisonings (acute pesticide exposure poisoning human health problems)) (Buralli *et al*., 2020), but acute and chronic pesticide exposure poisonings still persist and are growing problems for LMIC (developing countries) (Negatu *et al*., 2018; Buralli *et al*., 2020). According to the WHO, an acute pesticide poisoning (APP) must present clear signs of exposure, temporal cause-effect relationship, and at least three symptoms compatible with the exposure (Thundiyil *et al*., 2008; Buralli *et al*., 2020). An acute pesticide poisoning is any illness or health effect resulting from suspected or confirmed exposure to a pesticide within 48 hours (Thundiyil *et al*., 2008). A review revealed (found) that a higher prevalence of mental health outcomes, notably depression, anxiety, and suicide attempts, were found positively associated with exposure to pesticide among farmers in high-income countries such as the USA, England, South Korea, and Spain (Khan *et al*., 2019; Buralli *et al*., 2020). Depression was significantly associated with a history of pesticide poisoning, but not low or high cumulative exposure in spouses of pesticide applicators in the USA (depression was significantly associated with a history of pesticide poisoning, but not low or high cumulative exposure, in spouses of pesticide applicators in the USA) (Beseler *et al*., 2006; Buralli *et al*., 2020). Cumulative pesticide exposure was operationalized as the number of years working in an agricultural setting requiring pesticide use for occupationally exposed (OE) group, or number of years living within that agricultural setting for environmentally exposed (EE) group (Ramírez-Santana *et al*., 2020). Cumulative effects of pesticide exposure over long periods could constitute a significant risk to farmers, family farmers, farm workers (such as pesticide applicators and agricultural (farming) labourers) (pesticide end-users), and also, the farming community and the public at large (Clarke *et al*., 1997; Adjrah *et al*., 2013), their skin is the most exposed organ in this condition (Kapka-Skrzypczak *et al*., 2011; Adjrah *et al*., 2013). It was indicated that most occupational exposure to pesticides occurs from skin absorption and through inhalation (WHO, 1993; Iorizzo *et al*., 1996; Yassin *et al*., 2002). The non-protection of farmers and agricultural workers involved in mixing and spraying of pesticides (unprotected use of pesticides by farmers and agricultural workers such as in mixing and spraying of pesticides) may encounter much higher dermal and respiratory exposures to pesticides (Van der, 1996; Adjrah *et al*., 2013). It was also indicated that inhalation is the most important pathway (one of the most important pathways) by which pesticides enter the body, because pesticides have a distinct odour which signals its airborne state, but which is also associated with strong chemicals as solvents (Michael *et al*., 2016); however, uptake through inhalation has been calculated to be low compared to dermal uptake or indirect oral intake (Doan Ngoc, 2014; Doan Ngoc *et al.*, 2015; Michael *et al*., 2016). Restriction of highly toxic pesticides has been shown to be a successful strategy in reducing mortality in Sri Lanka (Saiyed *et al*., 2003; Lekei *et al*., 2014). Continued education and raising awareness is necessary to inform pesticide applicators (pesticide operators) (Phung *et al*., 2013; Kearney *et al*., 2015; Yuantari *et al*., 2015; Michael *et al*., 2016). According to WHO (1999), no individuals or groups of people are completely protected against pesticide exposures and the potentially serious health effects, which often affect people of the developing countries. Apparently, there are no groups in the human population that are completely unexposed to pesticides (Meyer-Baron *et al*., 2015). Similar studies have been undertaken around the world particularly in developing countries. In the study by Mustapha *et al*. (2017) in Kuwait, it was reported that the most common routes of exposure to pesticides as stated by the farm workers were inhalation (86%), dermal (54%), oral (42%), eye contact (26%), while about 14% of the farmers indicated lack of knowledge of any route of exposure to pesticides, and also, 82% of the farmers reported at least one symptom of acute pesticide poisoning (APP) in the previous year immediately after applying or handling of pesticides, and the most frequently self-reported toxicity symptoms related to pesticides were headaches (82%), itchy eyes (79%), skin irritation (58%), fatigue (50%), nausea (49%), dizziness (41%), and coughing (22%), and others: excessive sweating (10%), vomiting (10%). shortness of breath (8%), stomach ache (4%), and poor vision (3%), while 18% of them did not ascribe any health problem encountered to pesticide exposure, and the majority (75%) of them took no action considering the incident as minor or requiring only self-medication, while only 5% of them reported a serious poisoning incidence that required medical attention in a hospital. Adesuyi *et al*. (2018) in Nigeria revealed that the most common routes of exposure to pesticides as stated by the vegetable farmers were oral (79.2%), dermal (50.6%), inhalation (32.5%), and eye contact (19.5%), while about 14.2% of the farmers indicated their lack of knowledge of any route of exposure to pesticides, and also, 78% of the farmers self-reported at least one symptom of acute pesticides poisoning during the last one year of pesticides handling and usage, while 22% of the respondents did not ascribe any significant health effect to pesticides exposure, and the most self-reported symptoms related to pesticides were headaches (78%), skin irritation (71%), itchy eyes (62), fatigue (55%), dizziness (40%), and coughing (19%), and others, excessive sweating (18%), nausea (13%), poor vision (12%), vomiting (10%), shortness of breath (9%), and stomach ache (8%). The study by Kafle *et al*. (2021) in Nepal reported that nearly one-fifth of farmers (18.7%) had experienced one or more acute symptoms of health problems after handling pesticides during the previous 12 months, which they related to the use of chemical pesticides, and the most common symptoms were dizziness and headache (11.1%), skin allergies (skin irritation) (9.9%), and eye irritation/burning of eyes (5.2%), and others, nausea/vomiting (5.1%), blurred vision, and swelling of body and muscle cramps (3.0%), also, they showed in their study that farmers with unsafe practice of pesticide handling were two times more likely to suffer from acute poisoning and the acute problems were significantly higher among those with unsafe spray practice, but most (89.5%) of the farmers with acute health symptoms perceived these symptoms as normal or usual phenomena while handling pesticides, and therefore ignored and did not see any health facility accepting that such health problems are normal to the farm workers. In the study by Tambe *et al*. (2019) in Cameroon, participants' work-related health complaints were: 24% complained of (complaining) skin irritation after spraying of pesticides, 16.3% reported visual problems, 10.6% complained of backache, 9.6% reported nervous system injuries such as headache and dizziness, and 4.8% complained of respiratory difficulties. Benjamin *et al*. (2019) in Rwanda reported that although few participants were formally trained on health impacts of pesticides, all participants recognized acute changes in their health after starting to use pesticides including skin, eyes and nasal passage irritations, headache and stomach cramps, and all study participants reported adverse health effects during or after pesticide spraying in the field, and farmers reported experiencing one or more of the following symptoms: itchy skin, headaches, difficulty breathing, and nausea or stomach upset, but only three farmers (1.5%) could explain the relations between pesticide use and negative impacts on aquatic life and the environment; however, it is stated in their study that all participants directly observed or had heard reports of cows, birds or fish showing signs of pesticide intoxication (such as uncoordinated movement, weakness, and death) within 30 minutes to six hours after consumption of pesticide or presence in recently sprayed areas, and almost half of study participants (48.5%) reported seeing small fish dying (of) a few minutes after applying the pesticides, especially during plot preparations before planting the crop. In the study by Yassin *et al*. (2002) in Gaza Strip, it was shown that 93.1% of farm workers claimed that inhalation is the route of entry, and 88.4% reported that skin (dermal absorption) is the route of entry (more aware of inhalational and dermal absorption of pesticides than other routes of exposure), while 87.8% claimed that the mouth is the route of entry of pesticides into the body, and a total of 83.2% had self-reported toxicity symptoms associated with (related to) pesticides among farm workers with burning sensation in the eyes/face (64.3%), dizziness (32.4%), cold/breathlessness/chest pain (28.1%), itching and skin irritation (27.0%), headache (26.5%), watering eyes (18.9%), skin rash (17.3%), abdominal pain/diarrhoea (diarrhea) (9.7%), salivation and vomiting (8.6%), weakness (5.4%), fever (3.2%), loss of libido (2.7%), and forgetfulness (1.6%)) (i.e., it was reported in their study that 64.3% of the farmers had irritation in the eyes and face, 32.4% of them had dizziness, 28.1% of them had chest pain, 27.0% of them had skin irritation, 26.5% of them had headache, 9.7% of them had abdominal pain, 8.6% of them had vomiting, 5.4% of them experienced weakness, 3.2% of them had fever, 2.7% of them has loss of libido, and 1.6% of them experienced forgetfulness), also, 67.6% farm workers believed that their body has developed resistance to pesticides, while 32.4% had the opposite opinion, and 4.2% farm workers kept first aid equipment, besides, all farm workers reported that there were neither medical nor health care centres which provided medical services or cared for farm workers' health. Lekei *et al*. (2014) in Tanzania reported that farmers' self-reported knowledge of routes of pesticide absorption included mainly dermal (75.2%) and inhalational (72.7%), while about 10% stated lack of knowledge of any route of absorption, and approximately 93% of respondents reported previous poisoning by pesticides in their lifetimes (with the year preceding their study inclusive) with frequency ranging from 1 to a maximum of 7 times (prevalence of self-reported past poisoning among farmers was high (92.5%)); 76.4% of the poisoned respondents reported two or more poisonings, and 63.5% reported 3 or more poisonings at some point in the past, and all study farmers with past acute pesticide poisoning (APP) reported approximately 432 past poisonings in total, and actions taken after poisoning (not mutually exclusive) included drinking milk (25%), attending a health facility (21%), consulting a pharmacist (13%), applying cream to the affected area (6%), and washing the affected part of body (3%); however, most respondents (60%) reported taking no action following the poisoning, and lifetime poisoning signs and symptoms reported as experienced by the farmers were or included skin irritation, headache, flu, eye irritation, throat irritation, dizziness, excessive sweating, excessive salivation, blurred vision, breathing with difficulty (difficulty breathing), lacrimation (watering of eyes or excessive tearing), sleepless nights, chest pain, coughing, nausea,, high fever, stomachache, loss of appetite, nose bleeding, pain during urination, wheezing, diarrhoea (diarrhea), unconsciousness, hands trembling, tiredness, and vomiting, and there were 875 symptoms associated with the 432 past poisonings reported by all farmers, and also, 60% of poisoned respondents did nothing about their symptoms, and 81% did not report going to a health care facility, stating that poisoned farmers may not report their injuries to a health care facility for a number of reasons including (i) inability to afford payment for their medical bills; (ii) the majority of poisonings being of mild severity; (iii) anticipated difficulties in diagnosis and treatment deter attendance; (iv) distance to health care facility or poor access to health services and, (v) anticipation of lack of appropriate drugs or medical services in the majority of the health facilities, and poisoned farmers may not also be aware of the long term adverse health effects of pesticides, further contributing to a lack of motivation to attend health facilities, describing that facility-based surveillance is likely to miss poisoning cases among farmers who do not access services for their poisoning, and even when attending, cases may not be recorded in hospital databases due to poor recording systems, and 18 of the 23 farmers who reported attending a health facility due to poisonings in the past year could not be traced in medical records at the facilities they claimed to have attended, suggesting that a large proportion of cases presenting to health facilities (78.2%) are unreported in hospital information systems and even larger proportion (95.9%) of all farmers who claimed to have experienced a previous poisoning (both those who attended and did not attend facilities for the poisonings) are unrecorded in hospital-based surveillance due to underreporting or misclassification particularly because the symptoms were not specific, besides, it was shown in their study that there were marginally significant associations between high poisoning and: (i) washing spraying equipment close to water sources; and (ii) unsafe pesticide disposal practices, and there were marginally significant associations between reporting high number of symptoms (over 10 poisoning symptoms) and a number of risk behaviours (such as): (i) failure to use PPE; (ii) failure to practice equipment calibration (iii) equipment wash area; (iv) equipment storage area; (v) pesticide storage area; and (vi) age, while there was a significant inverse association between high poisoning with storage of pesticides in living house; the active ingredients most commonly reported by farmers as associated with poisoning in their study were mancozeb (80%), profenofos (72%), chlorpyrifos (48%), endosulfan (35%), lambda cyhalothrin (5%) and cypermethrin (5%). In the study by Dilek *et al*. (2018) in Turkey, symptoms of health problems experienced by the farmers after pesticide application were reported as: 3.3% of the farmers stated that they had headache, 3.3% of them had dizziness, 1.4% of them had vomiting, 1.2% of them had respiratory distress, 0.7% of them had nausea, and 0.5% of them experienced abdominal pain, diarrhea, fever, skin pruritus (itchy skin) and eye burning, and 5.0% of the farmers stated that they had a medical complaint and 1.0% of them had been poisoned due to use of pesticides. In the study conducted by Oluwole and Cheke (2009), 91.3% of the farmers reported that either themselves or their families experienced health symptoms associated with pesticides during or after pesticide application. In the study by Zyoud *et al*. (2010), it was reported that 37.5% of the farmers experienced itchy skin, 37.0% of them had headache, 24.9% of them experienced excessive sweating, and 21.3% of them had diarrhea. In the study conducted by Gaber and Abdel-Latif (2012), 4.0% of the farmers stated that they had experienced poisoning. In the study by Ngowi *et al*. (2007), it was found that 15.0% of the farmers have been poisoned. In the study conducted by Hurtig *et al*. (2003), it was reported that 51.8% of the farmers experienced acute poisoning. In the study by Mergia *et al*. (2021) in Ethiopia, the most frequent routes of exposure to pesticides reported by farmers were inhalation (50%), oral (46%), and dermal (17%), while about 17% of farmers stated a lack of knowledge of any route of exposure to pesticides, and the most common health problems related to exposure to agrochemicals (particularly pesticides) reported by small-scale farmers included skin problems, headache, teary and eye irritation, seizure, sore throat and respiratory disorder, fatigue, nausea, and stomachache. In the study conducted by Mwabulambo *et al*. (2018) in Arusha, Tanzania, which aimed to assess neurological health symptoms associated with pesticide exposure among flower and onion pesticide applicators, it was shown that majority of pesticide applicators (75%) suffered from one or more forms of pesticide associated health symptoms (symptoms of health problems associated with pesticide exposure), and their study demonstrated a significantly high proportion of neurological health symptoms associated with pesticide exposure in onion pesticide applicators compared to pesticide applicators in flower farms due to lack (non-use) of personal protective equipment (PPE) for pesticide applicators in onion farms (a situation which exposed them (onion pesticide applicators) to a high level of pesticide exposure) compared to those of flower farms, which poses (posed) a greater risk of cholinesterase (acetylcholinestrase (AChE)) inhibition and neurological health symptoms to onion pesticide applicators, and the onion farmers reported more neurological health symptoms, with higher prevalence of body weakness (91.1%), pain in part of the body (64.3%), headache (58.9%), abnormal tiredness of the body (55.4%), dizziness (53.6%), irritation (46.4%), poor appetite (46.4%), nausea (39.3%), excessive sweating (32.1%), ringing in ears (30.4%), vomiting (28.6%), feeling cold or hot (23.2%), nervousness or shakiness inside (23.2%), loss of concentration (17.9%), depression (17.9%), and trouble falling asleep (14.3%), while flower farmers showed a lower prevalence of neurological health symptoms with excessive sweating (46.4%), body weakness (34.5%), abnormal tiredness of the body (28.6%), headache (27.4%), pain in part of the body (21.4%), poor appetite (17.9%), depression (15.5%), irritation (13.1%), nervousness or shakiness inside (11.9%), nausea (8.3%), trouble falling asleep (7.1%), feeling cold or hot (7.1%), dizziness (7.1%), ringing in ears (7.1%), loss of concentration (4.8%), and vomiting (3.6%), also, about 39% of onion farmers and 19% of flower farmers had acetylcholinesterase levels below the normal range, whereas 60.7% from onion farms and 81% from flower farms had cholinesterase level above the limit level, and about 27% of pesticide applicators in overall had an acetylcholinesterase level below the limit value in the study of theirs. Buralli *et al.* (2020) in Brazil reported that study participant smallholder family farmers were occupationally and environmentally exposed to multiple pesticides, and had a high prevalence of acute and mental health symptoms among which 27% had between one and three acute pesticide symptoms (acute pesticide poisoning symptoms), 45% between four and nine, and 16.7% more than 10 symptoms, while only 11.5% of participants did not report any acute symptom, and the symptoms most commonly reported were: mucosal irritation (41%), headache (40%), tachycardia (fast heart rate) (36%), lower limbs fatigue and palpitation (33%), dizziness and blurred vision (29%), stomach pain (28%), cramps (27%), and had more cholinesterase changes due to their cropping activities starting from early ages; lived near crop areas, worked without safety training, technical support, and full recommended PPE. Cevik *et al*. (2020) in Turkey revealed that approximately one out of ten farmers experienced (experience) acute pesticide poisoning (APP) with a total APP prevalence of 11.3%, and 75% of the farmers presented to a health institution due to symptoms, in which more than half of APP cases (59.4%) presented to the hospital emergency room due to their symptoms and 15.6% of them presented to their family physicians, while 25% did not apply, and of the farmers who presented to the health institution, 17.2% were hospitalized, and 82.8% underwent outpatient treatment; the factors associated with increased risk of APP were: illiteracy, 14 years and less farming experience, not reading the pesticide labels, and contact with liquid pesticides, where illiteracy increased the APP risk 2.5 times; farming duration below 15 years increased the risk 3.3 times; not reading the label on the pesticide package increased the risk 6.4 times (the APP risk increased 6.3 times in those who did not understand the label), and direct contact with pesticides (especially direct contact with liquid or diluted (mixed) pesticides) during pesticide preparation (mixing) or application (spraying) increased the risk 2.3 times (the risk of APP was more than doubled), and the most frequent APP symptoms suffered by the farmers were respiratory symptoms (32.2%), gastrointestinal symptoms (31.6%), neurological signs (19.5%) and ocular symptoms (8.0%), and specifically the most commonly reported symptoms were cough (14.9%), dyspnea (shortness of breath or breathlessness) (12.6%), abdominal cramping (11.5%), headache (10.9%) and vomiting (10.3%), in which 61.9% had mild symptoms, 36.0% had moderate symptoms, and 2.0% had severe symptoms. Ncube *et al*. (2011) in northwestern Jamaica revealed that approximately 16% of participant farmers reported one or more incidents of acute pesticide poisoning (APP) within the last two years, and the majority (68%) of farmers who reported pesticide poisoning never sought medical attention for poisoning, while only 32% consulted a clinic, hospital or private doctor following the accidental poisoning, and there was a significant difference in report of acute pesticide poisoning by farmers in relation to whether they read the instructions on the pesticide bags before applying pesticides, where among farmers who reported acute pesticide poisoning, only 50% stated that they always read the instructions on the bag before applying pesticides, while (in comparison) 86% of farmers who reported no incidents of acute pesticide poisoning stated that they always read instructions on the bag before applying pesticides, also, similar results were obtained for use of the recommended rate of pesticide by farmers and acute pesticide poisoning, where among farmers who reported acute pesticide poisoning, approximately 51% reported using the recommended amount of pesticides, while (in comparison) 71% of farmers who did not report acute pesticide poisoning reported using the recommended amount of pesticides, and farmers who reported using pesticides in their houses to kill pests accounted for 21% of participants who reported acute pesticide poisoning (in which twelve of nineteen farmers (63%) who reported using pesticides in their houses to kill pests reported incidents of acute pesticide poisoning) and 2.3% of those who reported no poisoning in their study. In the study conducted by Ramírez-Santana *et al*. (2020) in northern Chile to evaluate the effect of cumulative or chronic exposure to OP/CM pesticides on the neurobehavioral performance of agricultural workers (occupationally exposed (OE) group) and rural inhabitants (environmentally exposed (EE) group), and to determine if changes in the neurobehavioral performance are associated to changes in blood biomarkers of OP/CM pesticides during the spray season, when exposure is higher, it was shown that long-term occupational or environmental exposure to OP/CM pesticides caused impairment in neurobehavioral functioning (were associated with a reduced neurobehavioral functioning), and lower neurobehavioral performance was observed in the pre-spray evaluation of EE and OE groups compared to the non-exposed, OE being the worst performing group; seasonal exposure impaired performance in both exposure groups, and worsened during the spraying season, mainly in EE. Negatu *et al*. (2018) in Ethiopia showed that overall acute pesticide poisoning (APP) prevalence among pesticide applicators was 16% that differed between farming systems and was strongly associated with neurobehavioural symptoms, and more neurobehavioural symptoms were reported independent of cumulative pesticide exposure, while cumulative exposure to pesticides appeared to be associated with neurobehavioural symptoms among applicators without and with APP, and also, intensity of exposure was clearly associated with these symptoms. In the study by Adjrah *et al*. (2013) in Togo, 34% participants reported intoxication accidents during pesticide spraying (felt faint after spraying pesticides), while 66% did not state, and symptoms often quoted were: feelings of burns on the face and hands, headaches, cold, conjunctivitis, giddiness (dizziness, shakiness), constipation, general weakness and pains of the thorax. In the study by Michael *et al*. (2016) in Vietnam, farmers indicated inhalation as the most important pathway by which pesticides enter the body. In the study by Mohanty *et al*. (2013) in south India, majority of the farmers (70%) perceived that pesticides affect human health; however, three-fifth of the respondents were unaware or had wrong belief about effect of pesticides on livestock and environment, while sixty two percent of farmers were aware that pesticides enter into human body through nose and affect lungs, and only two fifth were aware about skin as a route of entry for pesticides. In the study by Anna *et al*. (2014) in Uganda, the most commonly self-reported symptoms due to pesticide usage were skin irritation, headache, extreme tiredness, excessive sweating, blurred vision and dizziness, and also, muscular weakness, loss of appetite, abdominal pain, nausea, respiratory difficulties, salivation, vomiting and lack of coordination.

The safe production and marketing of food is a major step towards food security; however, many farmers put themselves at risk from pesticide poisoning during the production process Ncube *et al*., 2011). A case of previous acute pesticide poisoning (APP) was defined as any self-reported short-term illness or health effects associated with the farmer in the preceding pesticide exposure (Lekei *et al*., 2014), and this approach has been used in other studies in developing countries (Sivayoganathan *et al*., 1995; Atkin & Leisinger, 2000; Yassin *et al*., 2002; Lekei *et al*., 2014). Unsafe pesticide use practices increase the risk of pesticide exposure, thereby increasing the risk of clinical and subclinical adverse health effect (Lekei and Ngowi, 2016; Adesuyi *et al*., 2018). The high incidence of adverse symptoms (intoxication) such as cephalea (headache), dizziness, vomiting, and skin problems have been reported among farmers after pesticide use in different studies (Recena *et al*., 2006; Ngowi *et al*., 2007; Doan Ngoc *et al*., 2015; Michael *et al*., 2016). In a study, 62.5% of the participants experienced burning sensations in the eyes or face and 37.5% experienced itching or irritated skin after spraying organophosphate insecticides (Mourad, 2005; Ncube *et al*., 2011). A previous study in Tanzania identified acute pesticide poisoning (APP) as a major problem in the farming community (Ngowi, 2002; Lekei *et al*., 2014), and another previous research in the same country found that 68% of farmers reported episodes of feeling sick after routine application of pesticides and their pesticide-related health symptoms included skin problems and neurological symptoms (Ngowi *et al*., 2007; Lekei *et al*., 2014). Use of pesticides in agriculture (agricultural) activities expose pesticide users particularly pesticide end-users (farmers, family farmers and farmworkers (such as pesticide applicators)) to risk factors for neurological health symptoms; neurological health symptoms include excessive sweating, body weakness, and headache (Mwabulambo *et al*., 2018). Biomonitoring studies included gloved and ungloved harvesters allowed to estimate dermal absorption to be about 25µg/hour (Krieger, 1995; Adjrah *et al*., 2013). It is likely that farmers may have acquired their knowledge after being poisoned, in that increased symptoms led to both increased awareness and less willingness to store pesticides in their living (residential) house (at home) (Lekei *et al*, 2014). Pesticides are designed to affect pests of plants (pests of crop plants including vegetable crop pests) (such as diseases, insect pests, weeds, rodents, pest avians and other pests), are insurmountably (in a way unable to overcome) toxic, and should be stored safely; accidental deaths by pesticides poisoning occur, but pesticides are also often used to commit suicide because they are easily accessible (Zhou *et al*., 2011; Aggarwal, 2015; Michael *et al*., 2016); as patients rarely purchased pesticide especially for the regretful act, it is important to reduce the accessibility of toxic pesticides in the domestic environment (Mohamed *et al*., 2009; Hvistendahl, 2013; Michael *et al*., 2016). In a study done in Zimbabwe at Kwekwe district on health effects of agrochemicals, headache (66.7%), cold/flu (62.2%), weakness (45.9%), dizziness (41.1%) and skin irritation (39.0%) were reported among farm workers in commercial farms (Magauzi *et al*., 2011; Mwabulambo *et al*., 2018). In South Korea, the risk of poisoning increased by 1.61 times in those who did not read the pesticide label (Kim *et al*., 2013; Cevik *et al*., 2020). When one works with pesticide products, it is expected that contamination (pollution) caused by direct contact of the skin, nose, mouth or eyes with pesticides will increase his/her acute pesticide poisoning (APP) risk (Cevik *et al*., 2020); to prevent direct contact with pesticides, when pouring and mixing the concentrated product, and to prevent splashing or spillage on the skin or clothing, it is recommended that every effort be made, to applying pesticide use preventive, protective, safety and precautionary measures (pesticide use safety precautions) and pesticide use safety practices by promptly washing out the pesticide in case of contact with the body and by carefully cleaning the contaminated clothing (FAO, 1990; Cevik *et al*., 2020). Under-reporting (underestimating (underestimation)) of APP has important implications for surveillance, which is key to prioritizing and evaluating interventions to control the problem, and strategies to ensure that the full spectrum of cases of pesticide exposure poisoning is captured by surveillance are therefore urgently needed, particularly in developing countries where the exposures and risks are highest (Lekei *et al*, 2014). In Kenya, the frequency of pesticide poisoning episodes was that 61.1% of farmers reporting 4 or more previous poisonings (Ohayo-Mitoko *et al*., 2000; Lekei *et al*, 2014), and in South African, 95% of APP cases were unreported in the Western Cape Province in a study of 1994–1995 (London & Bailie, 1999; Lekei *et al*, 2014). Hazards from exposure to pesticides can be resulted from improper use of highly toxic substances, lack of adherence to preventive principles, lack of protective measures, or use of defective protective equipment during exposure (exposures) to chemical pesticides (Damalas & Eleftherohorinos, 2011).

5.2 Analytical Experiment

The second part of the main objective of the present research was analysis (analytical determination and evaluation) of organochlorine and organophosphate pesticide residues (pesticides) in onion samples taken from Shewa Robit in Kewet district, central Ethiopia. Thirteen organochlorine and two organophosphate pesticides were analyzed for their residues in onion. The results of the present analytical experimental study do not demonstrate an unacceptable health condition (health outcome) (health problem) for Kewet district consumers ingesting and digesting onions bought from Shewa Robit as all the detected pesticide residues are below the maximum residue limits (the maximum residue levels) (MRLs) set by international MRL setting bodies and internationally recognized regional and national MRL setting organizations including Codex (FAO/WHO), EU, Japan, and USA. From the results of the present analysis (analytical study) that no residues were detected from about three-fourth (73%) of the organochlorine and organophosphate pesticides analyzed in onion samples may likely be due to decrease in the historical use of the pesticides especially organochlorine pesticides particularly organochlorine insecticides, possibly because most of these pesticides may not be supplied sufficiently or in excess, and may not reach the end-users (particularly farmers, family farmers and farm workers such as pesticide applicators) in larger quantities to use the pesticides excessively and extensively as their manufacturing and processing sought to be or forced to be discontinued or limited for many of these pesticides are banned or restricted for use globally. And, the level of already persistently present (and bioaccumulated or biomagnified) organochlorine pesticides specifically organochlorine insecticides with long-lifetimes in the natural physical environment and in the biota may have fallen over years (may have fallen over many years) of application through some environmental processes such as photochemical (biophotochemical) degradation even though it is very slow. Persistent organochlorine pesticides are characterized by their long lifetimes (persistence) in the water, soil, sediments or air, and the Stockholm Convention defined and set (specified) that a contaminant (a chemical) specifically an organochlorine pesticide is said to be persistent (specifically an organochlorine pesticide is persistent) if its half-life in water is greater than two months, or that its half-life in soil is greater than six months, or that its half-life in sediment is greater than six months, or when (if) the organochlorine pesticide migrates significantly through the air, its half-life in air is greater than two days, and it takes a very long time to break down (to undergo degradation (chemical degradation), biodegradation, biological decomposition, biochemical degradation (photobiochemical degradation) and disintegration (nuclear disintegration and/or spontaneous disintegration)) and stop being harmful (to become harmless), i.e., criteria for persistence of organochlorine pesticides were determined and established, and an organochlorine pesticide is said to be persistent when the half-life of the chemical in water is greater than two months, its half-life in soil is greater than six months, its half-life in sediment is greater than six months, and if (when) the chemical (organochlorine pesticide) migrates significantly through the air, its half-life in air should be greater than two days, and it takes a very long time to break down (to undergo degradation (chemical degradation), biodegradation, biological decomposition, biochemical degradation (photobiochemical degradation) and disintegration (nuclear disintegration and/or spontaneous disintegration)) and to become (or become) harmless (stop being harmful) (Basel Convention, 1989; Willet *et al*. 1998; Stockholm Convention, 2001; Ashenafi, 2009; Greenpeace, 2015) (Half-life is the time it takes for a chemical pesticide (any pesticide or any other chemical) to be reduced in its amount by half which may be through break down (degradation (biodegradation)) or dissipation). Moreover, it may possibly be due to the fact that the morphological features of onion crop plant may contribute at least some role for reduced accumulation of contaminants (pesticides (pesticide residues)) on/in onion during application (spraying) of pesticides for the control of onion pests, and hence, there might be minimal contamination (pollution) of onion produce (onion harvest) by the pesticide residues (pesticides) since the most edible part of onion, the bulb, is found underground, and there may/might not be much direct contact of onion bulb with OCPs and OPPs during pesticide spraying (application), unlike some other vegetable crop plants, such as cabbage, tomato, lettuce and sweet pepper, in which almost all the edible parts are exposed to pesticide contact during application (spraying) of pesticides for the control of pests of these vegetable crops, and may contribute to a higher accumulation of pesticide residues (pesticides) on/in the vegetable crops, and hence, there might be an increased contamination (pollution) of the vegetable produce (vegetable harvest) by the pesticide residues and pesticides. Tri Thanh *et al*. (2020) in Canada described twelve fruits and vegetables with the highest pesticide residues, named ‘dirty dozen’, of the year 2019 as: strawberry, spinach, kale, nectarine, apple, grape, peach, cherry, pear, tomato, celery and potato. Furthermore, it may probably due to that the labile (unstable) and reactive nature of sulphur-containing compounds that are found in onion (including in other alliums such as garlic), which are responsible for the complex biochemistry of onion flavour and the fundamental principles and parameters of nutritional and medicinal properties (benefits) of onion (Brewster, 2008), may undergo ‘self-preventing’ (‘self-protecting’) and neutralizing reactions with (may undergo ‘self-defense mechanisms’ against) pesticides especially with organochlorine pesticides (organochlorine insecticides); however, this hypothesis needs further investigation and confirmation (needs further research).

However, the detection of pesticide residues (pesticides) from slightly more than a quarter (from about 27%) of analyzed pesticides (organochlorine insecticides) in onion, i.e., the detection of residues of α–HCH, β-HCH, DDE, and heptachlor epoxide pesticides in the present analytical experimental study (analysis (analytical determination and evaluation) of pesticide residues and pesticides), even so lower than MRLs, demonstrates that these chemical pesticides are pervasively present at least in small (trace) amounts on the market, or in the hands of pesticide users especially pesticide end-users particularly farmers and farm-workers (pesticide applicators), or, otherwise, pervasively and persistently present in the environment (there has still been at least small (trace) amounts of these chemical pesticides on the market, or in the hands of pesticide users, especially pesticide end-users particularly farmers and farmworkers (pesticide applicators), or otherwise, pervasively and persistently present in the environment) despite these chemical pesticides have been globally strongly regulated pesticides within the framework of international conventions of chemicals specifically using instruments of international chemical pesticides conventions, the main ones being the Basel Convention (1989), the Rotterdam Convention (1998) and the Stockholm Convention (2001), which had been founded (and that have been periodically reviewed) to regulate, manage, control, curb or eliminate the chemical pesticides and their manufacturing and processing, and to facilitate information exchange of relevance among parties (trade partners) regarding the chemical pesticides transboundary movement (transactions across boundaries), particularly to enhance and advance safe and healthy world agricultural food production, preserving the environment, and more specifically to ascertain safe and fair marketing of agricultural food commodities, addressing food safety (quality of food) issues in international trade to protect the health of consumers. And, the detection and presence of these pesticide residues (pesticides) in onion in the present analytical experimental study, even though in smaller quantities and are lower than MRLs, this does not automatically imply (or may not undoubtedly mean) a guarantee to human food safety (this may not imply onion is undoubtedly not unsafe for consumption) and may not mean a warranty to human health (may not imply a warranty for human health), and should not be ignored. Hence, these pesticide residues and pesticides may have the potential to harm human health (these pesticide residues (pesticides) may have the potential to pose harm to human health) at least in chronic (prolonged) use and application of the pesticides on onion and long-term consumption of onion, which could be resulted from (or which might be attributed to) additive, synergic and cumulative pesticide exposure detrimental health effects (negative health impacts) of pesticide residues (pesticides) and their metabolites and degradation products, which might be exacerbated by the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides, and where immediate farm produce (fresh field harvest and/or fresh garden harvest) of onion including other vegetables are often consumed raw in Ethiopia including the study area of the present study. And thus, concern should be given to address the issue through promptly implementing comprehensive, continuous, regular (at appropriate regular intervals) and periodic (seasonal) investigation (testing and examination), monitoring, surveillance and evaluation of acute (short-term) and chronic (long-term) human health conditions (acute (short-term) and chronic (long-term) health problems of humans) caused by and associated with pesticide and pesticide use (use and application of pesticides), holistic, continuous, periodic (seasonal) and regular (at appropriate regular intervals) monitoring, surveillance and analysis (analytical determination and evaluation) of pesticide residues, pesticides and their metabolites and degradation products on/in agricultural food commodities particularly on/in onion and likely on/in other vegetables, which must be expanded in nationwide level (which must be expanded at national level), and comprehensive, regular (at appropriate regular intervals) and periodic (seasonal) and continuous monitoring, surveillance and assessment of pesticide use dynamics on onion and likely on other vegetables production systems and production belts, where pesticide use and application is immense due to the prevalence of numerous (ubiquitous) pests especially of insect pests of onion and likely of other vegetable crop plants, and where consequent occupational (intentional), environmental and non-intentional (unintentional) pesticide and pesticide use exposure (exposures) environmental health and human health hazards and risks (overall pesticide exposure ecosystem (ecosystems) health problems) would be alarmingly greater and threatening because of (or which might (could) be exacerbated by) the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides, that aiming at preventing, reducing (minimizing and limiting), avoiding and eliminating potentially higher human health hazards and risks (overall pesticide and pesticide use exposure human health problems) and greater health outcomes (alarmingly greater and threatening health outcomes) of onion cultivating farmers and onion consumers caused by and associated with pesticide and pesticide use in Ethiopia and probably beyond encompassing the study area, and taking the present research as a case study. Besides, MRLs are not safety limits and exposure to pesticide residues and pesticides in less of MRL at a point in time (exposure to pesticides and pesticide residues in less of an MRL established at a point in time) may not mean a guarantee to safety to human health, because continuous (persistent) acute (short-term) and chronic (long-term) exposure, cumulative exposure and multiple exposures to pesticide residues and pesticides due to onion consumption in the present study might have additive, synergic and cumulative deleterious effects to human health. Exposure to pesticide residues (pesticides) in excess of an MRL does not automatically imply (or may not imply) a hazard to health (Ellis, 2005; Ashenafi, 2009). A pesticide residue in food (a food pesticide residue) can have higher level than MRL but can still be safe for consumption; safety limits are assessed in comparison with acceptable daily intake (ADI) for long-term (chronic or prolonged) pesticide exposure, and acute reference dose (ARfD) for short-term (acute) exposure to pesticides (Keikotlhaile & Spanoghe, 2011). And, pesticide short-term (acute) intake ought not to exceed the acute reference doses (ARfDs), and long-term (chronic) intake of pesticides should be below the acceptable daily intake (ADI) limits recommended by the FAO/WHO Joint Meeting on Pesticide Residues (JMPR) to avoid negative human health effects (JMPR, 2011; ECPA, 2014; Codex, 2016; Marlene *et al*., 2017). Acute (short-term) human exposure to pesticides and pesticide residues covers a period of up to 24 h (hours), and chronic (long-term) exposure to pesticide residues and pesticides covers average daily exposure over the entire lifetime (FAO/WHO, 2009; Szpyrka *et al*., 2015). Human intake of toxic substances due to pesticide residues in food commodities (in agricultural food commodities) can be much higher than intake of these substances related to water consumption and air inhalation (Juraske *et al.*, 2007; Szpyrka *et al.*, 2015).

Above all, endosulfan, which is one of certain highly controversial organochlorine pesticides (organochlorine insecticides) due to its threats to human health and the environment, and is being phased out globally and banned in many countries of the world, was not detected in onion in the present study although it is registered in Ethiopia to control the notorious insect pest, African bollworm (*Helicoverpa armigera*), particularly on cotton (Rotterdam Convention, 1998; MOA, 2018). This insecticide (endosulfan) has the probability of reaching the farmers (end-users) in the study area of the present study due to its availability on the market, and even as indicated in the survey study part of the present research, the use of endosulfan by farmers was reported except may be for its insufficient stock (may not reach farmers excessively). Endosulfan is included in the list of Prior Informed Consent (PIC) treaty (Rotterdam Convention (1998)) due to its deleterious environmental health and human health effects. It has already been banned in 56 countries because of its high toxicity and environmental impact (PAN Asia and Pacific, 2008; Lekei *et al*., 2014). In terms of acute toxicity, endosulfan is highly toxic to aquatic life (Sutherland *et al*., 2004; Lekei *et al*., 2014), and there have been a number of human deaths associated with endosulfan exposure, particularly in Africa and India (Roberts *et al*., 2003; Lekei *et al*., 2014). An intervention study in Sri Lanka showed that after an endosulfan ban in 1998, over a 3-year period following the ban, deaths due to APP fell more than 15-fold in the selected district hospitals (Saiyed *et al*., 2003; Lekei *et al*., 2014). In terms of chronic health problems (chronic toxicity), endosulfan is an endocrine-disruptor, mimicking estrogen (oestrogen) at very low levels of exposure and is implicated in breast cancer (Lekei *et al*., 2014). It is also a neurotoxin (it is also neurotoxic) and has been linked to Parkinson's disease, birth defects and immunotoxicity (immune-toxicity (immuno-toxicity)) effects) (Sutherland *et al*., 2004; Lekei *et al*., 2014). Endosulfan has been associated with developmental and reproductive harmful health effects in children environmentally exposed on/to cashew nut plantations in India (Saiyed *et al*., 2003; Lekei *et al*., 2014). Based on this ample accumulated evidence base of harmful human health and environmental health effects of endosulfan, the Review Committee of the Rotterdam Convention (1998) joined in Rotterdam in October, 2008, and concluded that endosulfan met the criteria for inclusion in the list of Prior Informed Consent (PIC) treaty (Lekei *et al*. 2014) despite several countries exporting the pesticide, including India, tried to block its addition to the PIC schedule (UNEP, 2010; Lekei *et al*. 2014). Also, cypermethrin is moderately toxic through skin contact or ingestion, and it may irritate the skin and eyes; symptoms of dermal exposure include unresponsiveness, stinging, itching, burning sensation, and its ingestion exposure symptoms include loss of bladder control, noncoordination (lack of coordination), seizures, and possible death (Yassin *et al*., 2002; Mergia *et al*., 2021), and exposure to lambda-cyhalothrin (lambdacyhalothrin or λ-cyhalothrin) also caused up to 20% and 57.1% of inhibition in the activity of the brain cholinesterase enzyme (Khan *et al*., 2003; Mergia *et al*., 2021).

Therefore, endosulfan should stringently be regulated, managed and controlled in Ethiopia, starting from authorizing its importation and processing, and it is required to urgently designing and setting a strategy of periodic (regular) and continuous monitoring, assessment and surveillance systems and programs for endosulfan use and application in the country, and promptly implementing the scheme (strategy) to ascertain the use and application of endosulfan for its intended purpose in Ethiopia, in line with encouraging use of other pesticide use minimizing, avoiding and eliminating pest control and management alternative approaches and methods such as integrated pest management (IPM) approaches and biological control (bio-control) methods (bio-control methods such as biopesticides including natural enemies), and immediately investigating and innovating (researching) other new environmentally friendly pest control and management alternatives which, in particular, prevent, reduce and eliminate use of chemical pesticides. Study results were also reported in other countries. David *et al*. (2008), in their study of multi-residue pesticide analysis in onion in USA, analyzed 46 pesticides (46 pesticides that are commonly used on onion crops) for their residues in onion using modified QuEChERS sample preparation procedures (guidelines) and analysis performed using Ion Trap GC/MS, and most of the pesticide residues detected were lower than MRLs. In the study by Kumelachew *et al*. (2020) to determine pesticide residue levels in vegetables including onion and surface waters at the Central Rift Valley region in Ethiopia, profenofos was detected in all onion samples analyzed, and 5% of the samples were found to exceed the European MRL of 50 μg/kg (EC (European Commission) Regulation No. 396/2005, 2005) (a concentration up to 350 μg/kg was found in their study due to, as noted, a reason that profenofos might be applied almost exclusively); metalaxyl was detected in onion samples analyzed with 7.5% of the samples exceeded the MRL of 500 μg/kg (EC Regulation No. 396/2005, 2005); λ-cyhalothrin was detected in all onion samples, and 5% of them exceeded the MRL of 20 μg/kg (EC Regulation No. 396/2005, 2005); 4,4′-DDT and 4,4′-DDE were found in onion samples, detected at concentrations of 130 μg/kg and 160 μg/kg, respectively, however, none of the residues found were above the Codex MRL of 3500 μg/kg (Codex, 2009), and both α-endosulfan and β-endosulfan were detected in all onion samples and 2.5% of the samples have a concentration above MRL of 50 μg/kg (EC Regulation No. 396/2005, 2005). Likewise, in the Study by Mohamed *et al*. (2020) for evaluating pesticide residues in vegetables including onion in Asir region, Saudi Arabia, from 20 onion samples analyzed, 25% were pesticide residue free, 65% were with residues less than MRLs, and 10% with residues higher than MRLs. Also, Tereza *et al*. (2020) in their study of evaluating pesticide residue dynamics in lettuce, onion, leek, carrot and parsley in Czech Republic analyzed 29 active substances in onion. However, no pesticide residues were detected in onion in studies by Marlene *et al*. (2017) in Bolivia and by Szpyrka *et al.* (2015) in south-eastern Poland.

The investigations of the present analytical experimental study, i.e., analysis (analytical determination and evaluation) of pesticide residues and pesticides in onion can be used as a baseline information (or it can contribute to the baseline information) for establishing and setting MRLs and MRL database in onion at national level in Ethiopia, and a turning and demarcating point of questions of concern regarding harmful effects of pesticide residues and pesticides especially in agricultural food commodities particularly in onion and other vegetables in domestic use in the country, i.e., detrimental effects of consumption of agricultural food commodities particularly onion and other vegetables contaminated with pesticide residues (pesticides) to the health of humans, and their (the agricultural food commodities contaminated with pesticide residues and pesticides) negative impacts to the country's involvement, competition and foreign exchange earnings (foreign currency earnings) in international trade in this running over, ever-dynamic and competitive world, and the study may initiate and inspire other researchers for further investigation (research) on this issue.

Overall, the present research is the first work of its kind in the study area, and the analytical experimental study (experimental analysis) part of the research, i.e., analysis (analytical determination and evaluation) of pesticide residues and pesticides in onion alone are the first work in Ethiopia. The findings of the present research demonstrated that onion cultivating farmers in the study area, and likely farmers of other vegetables production systems and production belts in Ethiopia (and probably beyond) are in overall lack of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides, use and application of pesticide use preventive, protective, precautionary and safety measures (safety precautions and safety practices of pesticide use) with no any provision, availability and use of PPE, and deleterious effects of inappropriate and unsafe use (inappropriate and unsafe use, handling and application) of pesticides. Therefore, it is imperative to urgently developing and formulating sound and comprehensive national pesticide and pesticide use and associated occupational health and environmental health and safety (occupational health and environmental preservation) policies, policy recommendations and strategies, promptly reviewing (updating) and developing the existing national pesticide regulatory framework, particularly immediately reviewing, amending (making inclusive and reinforcing) and developing the existing national pesticide legislations (the present national pesticide laws and regulations) and instantly stringently enforcing the pesticide laws and regulations at all levels starting at the retail (retailer) level and at the farm (farmer) level, and urgently establishing and formulating comprehensive (holistic) and appropriate pesticide and pesticide use intervention strategies and intervention measures including promptly designing appropriate education and practical knowledge-based training (educational training) programs specifically on the appropriate and safe use (on the appropriate and safe use, handling and application) of pesticides (on safe pesticide use knowledge and practices (on safe use knowledge and practices of pesticides)), use and application of pesticide and pesticide use preventive, protective, safety and precautionary measures (safety precautions and safety practices of pesticide use) when handling (purchasing, storing, preparation (mixing), application (spraying)) of pesticides, and during handling and disposal of pesticide wastes particularly of during disposal of empty pesticide containers, on adverse (harmful) effects of inappropriate (irrational), excessive, extensive, injudicious, indiscriminate, abuse (abused) and unsafe pesticide use (inappropriate and unsafe pesticide use, handling and application) and misuse of pesticides, and on use, application and implementation of other pesticide use preventing, optimizing, reducing (minimizing and limiting), avoiding and eliminating pest control and management alternative strategies, principles (approaches) and methods such as integrated pest management (IPM), good agricultural practices (GAP) and biological control (bio-control) methods (bio-control methods such as bio-pesticides including natural enemies), and pesticide use (pesticide) independent (pesticide (pesticide use)) non-dependent) farming systems and approaches such as organic (ecological or eco-friendly) farming (ecological or eco-friendly agriculture) systems (approaches), in line with developing, enhancing and advancing the National Agricultural Extension (educational extension) Delivery System of Ethiopia (NAEDSE), incorporating pesticide and pesticide use intervention programs and projects as one of the milestone themes (pillars) in the contents of NAEDSE including occupational health and environmental health and safety extension (extension education) and advocacy services specifically with regard to pesticide and pesticide use, and immediately addressing and presenting (instantly implementing) to the farmers on continuous and regular (at regular intervals) and periodic (seasonal) basis to raise the farmers' levels of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides, addressing the overall existing and current pesticide and pesticide use knowledge, awareness, understanding (information) and practices gaps of the farmers, in line with creating (raising) awareness (creating and raising awareness) on pesticide users especially pesticide end-users particularly farmers and farmworkers (pesticide applicators and re-entry farm workers) and encouraging them (pesticide users) to use PPE during pesticide use and application (when handling (purchasing, storing, preparation (mixing), application (spraying)) of pesticides and during handling and disposal (when handling and disposal) of pesticide wastes particularly of during handling and disposal of empty pesticide containers to prevent and protect the health of pesticide users from pesticide use exposure (pesticide use exposures) hazards and risks (health problems) (to prevent and protect pesticide users from pesticide use exposure (pesticide use exposures) and the pesticides' consequent human health hazards and risks) (to prevent and protect them (pesticide users) from pesticide use exposure (pesticide use exposures) and their (the pesticides') consequent hazards and risks to human health) (to prevent and protect pesticide users from pesticide use exposure (pesticide use exposures) human health problems) (to prevent and protect health hazards and risks of pesticide users caused by and associated with pesticide use exposure (pesticide use exposures)) through promotion, provision (facilitating supply) and dissemination of PPE, and to prevent, reduce (minimize and limit), avoid and eliminate contamination (pollution) of agricultural food commodities particularly onion and likely other vegetables produce (harvest of onion and other vegetables) by pesticide residues and pesticides, that in overall aimed at preventing, reducing (minimizing and limiting), avoiding and eliminating pesticide and pesticide use exposure (exposures) including exposure (exposures) to pesticide residues and pesticides (exposure (exposures) to pesticides) due to consumption of pesticide residues and pesticides contaminated (polluted) onion and likely other vegetables produce (due to consumption of pesticide residues and pesticides contaminated (polluted) onion and likely other vegetables field and/or garden harvests) (including exposure (exposures) to pesticide residues and pesticides (exposure (exposures) to pesticides) due to consumption of onion and likely other vegetables produce (due to consumption of onion and likely other vegetables field and/or garden harvests) contaminated (polluted) with pesticide residues and pesticides) (including exposure (exposures) to pesticide residues and pesticides (exposure (exposures) to pesticides) especially due to consumption of pesticide residues and pesticides contaminated onion and likely other vegetables immediate field and/or garden harvest) (including exposure (exposures) to pesticide residues and pesticides (exposure (exposures) to pesticides) especially due to consumption of onion and likely other vegetables immediate field and/or garden harvest contaminated (polluted) with pesticide residues and pesticides) environmental health and human health hazards and risks (overall ecosystem health problems), i.e., that inclusively aimed at preventing, reducing (minimizing and limiting), avoiding and eliminating overall occupational (intentional) and environmental (unintentional (non-intentional)) pesticide and pesticide use exposure (exposures) (pesticide exposure (pesticide exposures)) including exposure (exposures) to pesticide residues and pesticides (exposure (exposures) to pesticides) due to consumption of pesticide residues and pesticides contaminated (pesticide-contaminated) agricultural food commodities particularly onion and likely other vegetables (pesticide and pesticide use exposure (exposures) (pesticide exposure (pesticide exposures)) including exposure (exposures) to pesticides (exposure (exposures) to pesticide residues and pesticides) due to consumption of agricultural food commodities particularly onion and likely other vegetables produce (field and/or garden harvests of onion and other vegetables) contaminated with pesticide residues and pesticides) (including exposure (exposures) to pesticide residues and pesticides (exposure (exposures) to pesticides) particularly due to consumption of onion and other vegetables immediate field and/or garden harvests contaminated with pesticide residues and pesticides in raw) environmental health and human health hazards and risks (overall occupational (intentional) and environmental (unintentional) pesticide and pesticide use exposure (exposures) (overall pesticide exposure (pesticide exposures)) ecosystem health problems) in Ethiopia and probably beyond encompassing the study area, and taking the present research as a case study. And, the education and training (the educational training) on pesticides and appropriate and safe use (appropriate and safe use, handling and application) of pesticides must also encompass at least agricultural development extension workers (agricultural development extension professionals), health extension workers, pesticide distributors (pesticide wholesalers), pesticide vendours (pesticide retailers), development (particularly agricultural development) partners such as community-based governmental and non-governmental organizations (GOs and NGOs) and community-based development (particularly agricultural development) programs and projects, and other actors and support service providers of pesticide use to enable and equip them to adequately give technical support and advice to the farmers on the appropriate and safe use (on appropriate and safe use, handling and application) of pesticides and on harmful (adverse) effects of inappropriate and unsafe use (detrimental effects of incorrect and unsafe use, handling and application) of pesticides to (on) the health of the environment and to (on) the health of humans (overall ecosystem health problems), aiding in addressing the knowledge, awareness and understanding (information) gaps of farmers on the appropriate and safe pesticide use (on the appropriate and safe pesticide use, handling and application) and help elevate farmers' levels of knowledge, awareness and understanding of the appropriate and safe use (appropriate and safe use, handling and application) of pesticides, and for proper distribution of pesticides. Particularly pesticide retailers are probably the first (front-line) and direct contact points to and with the farmers and may serve as important sources of information and knowledge on pesticide and pesticide use for the farmers, and can play a critical role in the dissemination of such knowledge and information to the farmers, and hence, special emphasis is required to be given to immediately and appropriately educate and train (promptly offer appropriate educational training) to pesticide retailers on the appropriate and safe use (on the appropriate and safe use, handling and application) of pesticides to enable and equip pesticide retailers to adequately give technical advice and support to the farmers on the appropriate and safe use (on the appropriate and safe use, handling and application) of pesticides in Ethiopia (and probably beyond) encompassing the study area.

Importantly, urgent priority and emphasis must be given to promptly updating (reviewing) and developing the existing national pesticide regulatory framework, particularly reviewing, amending (making inclusive and reinforcing) and developing the existing national pesticide legislations (the present national pesticide laws and regulations) of Ethiopia (Proclamation No. 674/2010) profoundly considering the current pesticide and pesticide use national, regional and global challenges and problems, and previewing and incorporating other environmentally safe, sound and friendly, and pesticide use reducing, minimizing, avoiding and eliminating pest control and management alternative tactics, strategies, methods and approaches, such as integrated pest management (IPM) principles (approaches), biological control methods including natural enemies and procedures of good agricultural practices (GAP), and also, pesticide use independent (pesticide non-dependent) farming systems and approaches such as organic (ecological or eco-friendly) farming (ecological or eco-friendly agriculture) approaches (systems) and practices including their promotion (implementation) schemes, thematic initiatives (thematic initiations) of exploring, investigations, innovations (research) and promotion of new environmentally friendly pest control and management alternative approaches, and demands such as questions of how to control and manage migratory pests, and strategies and methods of PPE promotion, provision (supply) and dissemination among pesticide users especially pesticide end-users particularly farmers and farm-workers (pesticide applicators) in the country encompassing the study area, and then instantly implementing awareness creation and awareness raising (raising of awareness and creation of awareness), dissemination and stringent enforcement of the national pesticide legislations (the national pesticide laws and regulations) (the national pesticide regulatory framework) of Ethiopia at all levels starting at the retail (retailer) level and at the farm (farmer) level through surveillance, monitoring and assessment activities to guide and support regulation, governance, transactions, management, control, surveillance and monitoring of pesticide and pesticide use, support and guide implementation of appropriate and safe use and application (appropriate and safe use, handling and application) of pesticides, guide and support monitoring, surveillance, assessment and analysis (analytical determination and evaluation) of pesticide residues and pesticides on/in agricultural food commodities particularly on/in onion and other vegetables, and support and guide appropriate and safe disposal of pesticide wastes including obsolete pesticides (obsolete pesticide stockpiles), old pesticide stocks and particularly of supporting and encouraging appropriate and safe disposal of empty pesticide containers with establishing a mechanism of on-site collection and disposal of empty pesticide containers appropriately and safely, such as through organizing and forming (founding) a direct link between farmers and pesticide manufactures (pesticide companies or pesticide registrants or their agents) or bridging a connection (a connective) channel between and among these parties such as by national or international governmental or non-governmental organization or collaterally or other volunteer and dedicated organization to enable farmers to return their empty pesticide containers directly to pesticide manufacturers or pesticide companies to be recycled in the country and perhaps beyond that aimed at preventing, reducing (minimizing and limiting), avoiding and eliminating environmental health and human health hazards and risks (overall ecosystem health problems) caused by and associated with pesticide and pesticide use in Ethiopia and probably beyond, as all farmers, other clients and stakeholders, and even concerned and collaborative governmental and non-governmental organizations (GOs and NGOs) and development (particularly agricultural development) partners such as community-based development (specifically agricultural development) programs and projects are in overall lack of knowledge, awareness and understanding of the national pesticide laws (the national pesticide regulatory framework) of the country, and especially because particularly onion and other vegetables farmers in the study area in the present study and likely in other areas (similar agro-ecologies) of Ethiopia have overall lack of knowledge, awareness and understanding of the appropriate and safe use (appropriate and safe use, handling and application) of pesticides, and the farmers in the present study have been disposing of empty pesticide containers inappropriately and in an unsafe way, mainly discarding them (empty pesticide containers) relentlessly on-farm and in the open field (unknowingly throwing empty pesticide containers on-farm and in the open field), which is hazardous (deleterious) and threatening to the health of the environment and to the health of humans, especially to the health of the farmers, the agricultural (farming) communities and the public at large because empty pesticide containers retain considerable (non-ignorable) amounts of diffusible pesticides even after triple rinsing.

Good agricultural practices (GAP) in the use of pesticides are the nationally authorized safe uses of pesticides under actual conditions necessary for effective and reliable pest control. It encompasses a range of levels of pesticide applications up to the highest authorized use, applied in a manner which leaves a residue which is the smallest amount practicable. Authorized safe uses are determined at the national level and include nationally registered or recommended uses, which take into account public and occupational health and environmental safety considerations. Actual conditions include any stage in the production, storage, transport, distribution and processing of food commodities (agricultural food commodities) and animal feed. Integrated pest management (IPM) is an established part of good agricultural practices (GAP), and in IPM approach, use of chemical pesticides is in a controlled way and intended to be reduced (sought and intended to be minimized and limited) and ultimately avoided and eliminated (need to be substituted with other environmentally safe, sound and friendly pest control and management tactics, strategies, approaches and methods) (Codex, 2011). IPM has been shown to reduce the use of pesticides and improper practices, and IPM focuses on the significance of the production of healthy crops and natural pest control systems (Ntow *et al*., 2006; FAO: AGP- IPM, 2013). IPM has shown to have an effect on minimizing the use of pesticides and improper practices during use and application of pesticides; it emphasizes the importance of the growth of healthy crops and encourages natural pest control systems (Anna *et al*., 2014). IPM keeps the use of pesticides to a level that is affordable for the farmers and reduces the risk to humans and the environment while still yielding the expected outcome (Jors *et al*., 2006; Ntow *et al*., 2006; Konradsen, 2007; Jensen *et al*., 2011; FAO: AGP-IPM, 2013; Anna *et al*., 2014). IPM includes sound farming practices to reduce the use of pesticides to a minimum such as crop rotation, seed selection, pest identification, intercropping and the use of alternative non-chemical pest management methods (DIALOGOS, 2010; FAO: AGP-IPM, 2013; Anna *et al*., 2014).

The detection of pesticide residues and pesticides from a slightly more than a quarter of analyzed pesticides (organochlorine insecticides) in onion in the present experimental study, even so lower than MRLs, demonstrates that these chemical pesticides are pervasively present at least in small amounts on the market, or in the hands of pesticide users, especially pesticide end-users particularly farmers and farm-workers (pesticide applicators), or otherwise, still persistently present in the environment despite these chemical pesticides have been globally strongly regulated pesticides within the framework of international conventions of chemicals specifically using instruments of international conventions of chemical pesticides, the main ones being the Basel Convention (1989), the Rotterdam Convention (1998) and the Stockholm Convention (2001), which had been founded (and that have been periodically reviewed) to regulate, control, manage, curb and eliminate the chemical pesticides and their manufacturing and processing, and to facilitate information exchange of relevance among parties (trade partners) regarding the chemical pesticides transboundary movement (global transactions), particularly to enhance and advance safe and healthy world agricultural food production, preserving the environment, and more specifically to ascertain safe and fair marketing of agricultural food commodities, addressing food safety (quality of food) issues in international trade to protect the health of consumers. And, the detection and presence of these pesticide residues (pesticides) in/on onion in the present study, even though in smaller quantities and are lower than MRLs, this does not automatically imply (may not undoubtedly mean) a guarantee to human food safety (this may not imply onion is undoubtedly not unsafe for consumption) and may not mean a warranty to human health (may not imply a warranty for human health), and should not be ignored. Hence, these pesticide residues and pesticides may have the potential to harm human health (these pesticide residues (pesticides) may have the potential to pose harm to human health) at least in chronic (prolonged) use and application of the pesticides on onion and long-term consumption of onion, which could be resulted from (or which might be attributed to) additive, synergic and cumulative pesticide exposure detrimental health effects (negative health impacts) of pesticide residues (pesticides) and their metabolites and degradation products, which might be exacerbated by the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides, and where immediate farm produce (fresh field harvest and/or fresh garden harvest) of onion including other vegetables are often consumed raw in the country including the study area of the present study. And therefore, concern should be (need to be) given to address the issue through promptly implementing comprehensive, continuous, regular (at regular intervals) and periodic (seasonal) investigation (testing and examination), monitoring, surveillance and evaluation of acute (short-term) and chronic (long-term) human health problems (acute (short-term) and chronic (long-term) health conditions of humans) caused by and associated with pesticide and pesticide use (use and application of pesticides), holistic, continuous, periodic (seasonal) and regular (at regular intervals) monitoring, surveillance and analysis (analytical determination and evaluation) of pesticide residues, pesticides and their metabolites and degradation products on/in agricultural food commodities particularly on/in onion and likely on/in other vegetables, which must be expanded in nationwide level (which must be expanded at national level), and comprehensive, regular (at regular intervals), periodic (seasonal) and continuous monitoring, surveillance and assessment of pesticide use dynamics on onion and likely on other vegetables production systems and production belts, where pesticide use and application is immense due to the prevalence of numerous (ubiquitous) pests especially of insect pests of onion and likely of other vegetable crop plants, and (where) consequent occupational (intentional) and environmental (non-intentional (unintentional)) pesticide and pesticide use exposure environmental health and human health hazards and risks (overall pesticide exposure human health and environmental health problems) would be alarmingly greater and threatening because of (or which might be exacerbated by) the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides, that aiming at preventing, minimizing, avoiding and eliminating potentially higher human health hazards and risks (overall pesticide and pesticide use exposure human health problems) and greater health outcomes (worryingly greater and threatening health outcomes) of onion cultivating farmers and onion consumers caused by and associated with pesticide and pesticide use in Ethiopia and probably beyond encompassing the study area, and taking the present research as a case study. Besides, MRLs are not safety limits and exposure to pesticide residues and pesticides in less of MRL at a point in time (exposure to pesticides and pesticide residues in less of an MRL established at a point in time) may not mean a guarantee to safety to human health, because continuous (persistent) acute (short-term) and chronic (long-term) exposure, cumulative exposure and multiple exposures to pesticide residues and pesticides due to onion consumption in the present study might have additive, synergic and cumulative deleterious effects to human health. Exposure to pesticide residues (pesticides) in excess of an MRL does not automatically imply (or may not imply) a hazard to health (Ellis, 2005; Ashenafi, 2009). A pesticide residue in food (a food pesticide residue) can have higher level than MRL but can still be safe for consumption; safety limits are assessed in comparison with acceptable daily intake (ADI) for long-term (chronic or prolonged) pesticide exposure, and acute reference dose (ARfD) for short-term (acute) exposure to pesticides (Keikotlhaile & Spanoghe, 2011). And, pesticide short-term (acute) intake ought not to exceed the acute reference doses (ARfDs), and long-term (chronic) intake of pesticides should be below the acceptable daily intake (ADI) limits recommended by the FAO/WHO Joint Meeting on Pesticide Residues (JMPR) to avoid negative human health effects (JMPR, 2011; ECPA, 2014; Codex, 2016; Marlene *et al*., 2017). Acute (short-term) human exposure to pesticides and pesticide residues covers a period of up to 24 h (hours), and chronic (long-term) exposure to pesticide residues and pesticides covers average daily exposure over the entire lifetime (FAO/WHO, 2009; Szpyrka *et al*., 2015). Human intake of toxic substances due to pesticide residues in food commodities (in agricultural food commodities) can be much higher than intake of these substances related to water consumption and air inhalation (Juraske *et al.*, 2007; Szpyrka *et al.*, 2015). The investigations (results) of the present experimental study, i.e., analysis (analytical determination and evaluation) of pesticide residues and pesticides in/on onion can be used as a baseline information (or it can contribute to the baseline information) for establishing and setting MRLs and MRL database in onion at national level in Ethiopia, and a turning point on questions of concern regarding negative impacts of pesticide residues (pesticides) particularly in agricultural food commodities in domestic use in the country and its (the country's) involvement and competition in international trade in this running over, ever-dynamic and competitive world, and the study may initiate and inspire other researchers for further investigation (research) on this issue.

Continuous, regular (at at appropriate regular intervals), periodic (seasonal) investigation (testing and examination), monitoring, surveillance and evaluation of the health status (the status of acute (short-term) and chronic (long-term) health conditions (the status of acute (short-term) and chronic (long-term) health problems) including probably latent and potentially detrimental and silently killing chronic health problems (chronic health conditions) of occupationally (intentionally), and environmentally and non-intentionally acutely (in short-term) and chronically (in long-term) pesticide and pesticide use deleteriously exposed farming people especially pesticide end-users particularly smallholder (small-scale) onion and likely other vegetables cultivating farmers and farm workers (pesticide applicators and re-entry farm workers) including their (the farming peoples') spouses and children, and consumers that are at greater risk of and highly vulnerable to pesticide and pesticide use exposures, and also, environmentally and unintentionally pesticide and pesticide use exposed human (sub) populations including the agrarian communities and the public at large, i.e., periodic (seasonal), regular (at appropriate regular intervals) and continuous monitoring, examination and evaluation of the status of acute (short-term) and chronic (long-term) health problems (the status of acute and chronic health conditions) of human societies caused by and associated with acute (short-term) and chronic (prolonged) occupational (intentional), and environmental and unintentional pesticide and pesticide use exposure (exposures), and ingestion and digestion of pesticide residues and pesticides through consumption of onion, which might be exacerbated by the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides, and where immediate farm produce (fresh field harvest and/or garden harvest) of onion including other vegetables are often consumed raw in Ethiopia including the study area, is urgently required through biomonitoring analysis and evaluation (particularly) of the levels and activities of human cholinesterase enzymes in Ethiopia (and perhaps beyond) at national level encompassing the study area, and taking the present research as a case study.

The present research necessitates and requires stringent regulation and control of pesticide and pesticide use, and urgently designing, developing and establishing a strategy of continuous and regular (periodic (seasonal)) monitoring, surveillance and assessment systems and programs of pesticide and pesticide use and immediately and extensively implementing the scheme (strategy) in onion and likely in other vegetables production systems and production belts, where pesticide use and application is immense due to the prevalence of numerous (ubiquitous) pests especially of insect pests of these vegetable crop plants, and where consequent occupational (intentional), and non-intentional and environmental pesticide and pesticide use exposure (exposures), and pesticide residues and pesticides consumption exposure due to ingestion and digestion of pesticide contaminated (pesticide-contaminated) onion and likely other vegetables human health and environmental health hazards and risks (pesticide exposure environmental health and human health problems) would be alarmingly greater and threatening, which might (could) be exacerbated by the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (appropriate and safe use, handling and application) of pesticides, that aimed at preventing, reducing (minimizing and limiting), avoiding and eliminating occupational (intentional) and environmental (non-intentional) pesticide and pesticide use exposure environmental health and human health hazards and risks (overall ecosystem health problems) in Ethiopia (and probably beyond) encompassing the study area of the present study, and taking the present research as a case study.

A limitation of the present research is that a limited number of organophosphate pesticides were included in the analytical experimental study (experimental analysis), i.e., analysis (analytical determination and evaluation) of pesticide residues (pesticides) in onion due to restricted number of pesticides (restricted list of pesticide types) that have been handled for pesticide residue analysis by the pesticide residue analysis laboratory, where the laboratory has mainly been focusing on analytical determination of residues of selected organochlorine pesticides specifically selected organochlorine insecticides because of the global concern of human health and environmental health deleterious effects (overall ecological (biosphere) health problems) caused by and associated with exposure to these pervasive organochlorine pesticides due to the organochlorine pesticides' peculiar characteristics of extreme environmental (ecological) persistency, their (the organochlorines pesticides') distinctive behaviours of bioaccumulation, biomagnification and bioconcentration in the biota, and the organochlorine pesticides' strong buffer resistance to natural ecological (environmental) processes (reactions) such as photolysis and biological (and biochemical (photobiochemical)) processes including biodegradation, biological decomposition and biochemical (photobiochemical) degradation.

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The quantitative field survey study of the present research investigated the levels of chemical pesticide (chemical insecticide) use knowledge and practices of small-scale (smallholder) onion cultivating farmers in controlling onion thrips on onion in Kewet district, central Ethiopia. The findings of the study revealed that the farmers are in overall lack of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides and detrimental effects of inappropriate and unsafe pesticide use (inappropriate and unsafe pesticide use, handling and application) (negative impacts of exposure to pesticides) to the health of the environment and to the health of humans, and the farmers often adopt (influenced to adopt) risky behaviours and practices when handling pesticides that could pose especially human health hazards and risks, and would consequently result in dangerous health outcomes. Knowledge gaps in farmers included lack of awareness and understanding of the importance of protecting themselves, i.e., lack of awareness on the use and application of pesticide use safety measures (safety precautions and safety practices of pesticide use) including lack of knowledge and awareness of the importance of wearing PPE when handling and application of pesticides. And, the farmers have been practicing pesticide use and application with non-use of any PPE, in which, farmers practiced non-use of any PPE in any stages of pesticide use including purchasing, storing, preparation (mixing), application (spraying) and disposal, and concerning disposal of pesticide wastes, the farmers practiced unsafe disposal of pesticide wastes including particularly of unsafe disposal of empty pesticide containers, mostly discarding them (empty pesticide containers) relentlessly on-farm and in the open field. The pesticide use knowledge, awareness, understanding and practices gaps explored and identified among farmers in the present study can be used as a pre-information for prompt pesticide and pesticide use policy development, formulation and recommendation, immediate amendment and development of the national pesticide legislations (the national pesticide regulatory framework), and urgent development and formulation of pesticide and pesticide use intervention strategies and intervention measures including immediately designing pesticide and pesticide use (pesticides and appropriate and safe use of pesticides) education and training (educational training) programs for the farmers, pesticide distributors (pesticide wholesalers), pesticide retailers, agricultural development extension workers (agricultural development extension professionals), health extension workers, development (particularly agricultural development) partners such as community-based governmental and non-governmental organizations (GOs and NGOs) and community-based development (particularly agricultural development) programs and projects, and other actors and support service providers of pesticide use, and instantly addressing and presenting (immediately implementing) to the farmers and beyond that aiming at preventing, reducing, avoiding and eliminating pesticide and pesticide use exposure environmental health and human health hazards and risks (overall ecosystem health problems) in Ethiopia (and probably beyond) encompassing the study area, and taking the present research as a case study. The analytical experimental study of the present research, i.e., analysis (analytical determination and evaluation) of pesticide residues and pesticides on/in onion indicated the presence of four organochlorine pesticide residues and pesticides in onion. Even though these pesticide residues (pesticides) detected in onion in the present experimental study were in small quantities and are lower than MRLs, this does not automatically imply (or may not undoubtedly mean) a guarantee to human food safety and may not mean a warranty to human health, and these pesticide residues and pesticides detected in onion, though lower than MRLs, may have the potential to pose harm (may have the potential to harm) human health at least in prolonged consumption of onion. Thus, the presence of these pesticide residues and pesticides in onion should not be ignored, and hence, concern should be given to address the issue. The investigations of the present analytical experiment, i.e., analysis (analytical determination and evaluation)) of pesticide residues (pesticides) in onion can be used as a baseline information and starting point for founding grounds of concern on pesticide residues in onion, and a turning point for establishing and setting of national MRLs and MRL database in onion in Ethiopia and perhaps beyond.

6.2 Recommendations

Based on the findings of the present study, the following recommendations are suggested:

- Urgent priority and emphasis must be given to immediately establishing and formulating comprehensive (holistic) and appropriate pesticide and pesticide use intervention strategies and intervention measures including urgently designing appropriate education and practical knowledge-based training (educational training) programs specifically on the appropriate and safe use of pesticides (on safe pesticide use knowledge and practices), pesticide use preventive, protective and safety measures use and application (use and application of safety precautions and safety practices of pesticide use) including particularly of use of PPE when handling (purchasing, storing, preparation (mixing), application (spraying)) of pesticides, and during handling and disposal of pesticide wastes including particularly of during disposal of empty pesticide containers, and on deleterious effects of inappropriate (irrational), excessive, extensive, injudicious, indiscriminate, abuse (abused) and unsafe pesticide use (inappropriate and unsafe pesticide use, handling and application) and misuse of pesticides, and immediately addressing and presenting (instantly implementing) to the farmers on continuous, periodic (seasonal) and regular (at regular intervals) basis to raise the farmers' levels of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides, and the education and training (the educational training) must also encompass at least agricultural development extension workers (agricultural development extension professionals), health extension workers, pesticide distributors (pesticide wholesalers), pesticide retailers, development (particularly agricultural development) partners such as community-based governmental and non-governmental organizations (GOs and NGOs), community-based development (particularly agricultural development) programs and projects, and other actors and support service providers of pesticide and pesticide use to enable and equip them to adequately give technical support and advice to the farmers on appropriate and safe use (on correct and safe use, handling and application) of pesticides that help elevate farmers' levels of knowledge, awareness and understanding of the appropriate and safe pesticide use (the appropriate and safe pesticide use, handling and application), and for proper distribution of pesticides, that aimed at preventing, reducing (minimizing and limiting), avoiding and eliminating pesticide and pesticide use exposure (exposures) including preventing, minimizing, avoiding and eliminating exposure to pesticides due to consumption of agricultural food commodities contaminated with pesticide residues and pesticides (preventing, reducing, avoiding and eliminating exposure to pesticides due to consumption of pesticide-contaminated agricultural food commodities) particularly onion and other vegetables environmental health and human health hazards and risks, i.e., that aimed at preventing, reducing (minimizing and limiting), avoiding and eliminating overall occupational (intentional) and environmental (unintentional) pesticide and pesticide use exposure ecosystem health problems.

- And, in line with the above, it is imperative to urgently developing and formulating sound and holistic (comprehensive) national pesticide and pesticide use, and associated occupational health and environmental health and safety (occupational health and environmental preservation) policies, policy recommendations and strategies, promptly updating (reviewing) and developing the existing national pesticide regulatory framework, particularly reviewing, amending (making inclusive and reinforcing) and developing the existing national pesticide legislations (the present national pesticide laws and regulations) profoundly considering the current pesticide and pesticide use national, regional and global challenges and problems, and previewing and incorporating other environmentally safe, sound and friendly, and pesticide use preventing, reducing (minimizing and limiting), avoiding and eliminating pest control and management alternative strategies, tactics, methods and approaches, such as integrated pest management (IPM) principles (approaches), biological control (bio-control) methods (bio-control methods such as bio-pesticides including natural enemies) and procedures of good agricultural practices (GAP), and also, pesticide use independent (pesticide non-dependent) farming systems (approaches) such as organic (ecological or eco-friendly) farming (ecological or eco-friendly agriculture) approaches (systems) and practices including their promotion and implementation schemes, thematic initiatives (thematic initiations) of investigations, innovations and explorations (research) of new environmentally friendly pest control and management alternative approaches as well as their promotion and implementation schemes, and demands such as questions of how to control and manage migratory pests, and strategies and methods of PPE promotion, provision (supply) and dissemination among pesticide users especially pesticide end-users particularly farmers and farm-workers (pesticide applicators) in the country encompassing the study area, and instantly stringently enforcing and implementing the pesticide laws and regulations at all levels starting at the retail (retailer) level and at the farm (farmer) level to deliver regulatory and support services to prevention, governance, transaction, control and management of pesticide and pesticide use in Ethiopia (and probably beyond) encompassing the study area, and taking the present research as a case study.

- Urgent promotion, provision (supply) and dissemination of personal protection devices (PPE) to pesticide users especially pesticide end-users particularly farmers and farm-workers (pesticide applicators and re-entry farmworkers) across the country encompassing the study area is necessary.
- Promotion and implementation of pesticide and pesticide use preventing, optimizing, minimizing (limiting), avoiding and eliminating pest control and management approaches and methods including integrated pest management (IPM) principles (approaches), good agricultural practices (GAP) and biological control (bio-control) methods including bio-pesticides (bio-control methods such as bio-pesticide formulations including natural enemies), and pesticide independent (pesticide non-dependent) farming systems and approaches such as organic (ecological or eco-friendly) farming (ecological or eco-friendly agriculture) approaches (systems) and practices is urgently required.
- Research into new environmentally friendly pest control and management alternative strategies and approaches (methods) which prevent, minimize, avoid and eliminate pesticide and pesticide use (use and application of pesticides) need to be urgently thought of, investigated and innovated.
- It is necessary to urgently designing, establishing and implementing a mechanism of on-site collection and disposal of pesticide wastes including obsolete pesticides (obsolete pesticide stockpiles), old pesticide stocks and particularly of empty pesticide containers, such as through organizing and forming (founding) a direct link between farmers and pesticide manufactures (pesticide companies (pesticide registrants) or their agents) or channeling a bridge (or bridging a (connection) channel) between and among farmers and

pesticide manufacturers such as by national or international governmental or non-governmental organization (organizations) (GOs & NGOs) or collaterally or other volunteer and dedicated organization (organizations) to enable farmers to safely return their (the farmers') pesticide wastes particularly for safe disposal of their (the farmers') empty pesticide containers directly to pesticide manufacturers and/or pesticide companies to be appropriately eliminated (incinerated) and/or recycled (for recycled use) that aimed at preventing, reducing (minimizing and limiting), avoiding and eliminating environmental health and human health hazards and risks (overall ecosystem health problems) caused by and associated with pesticide and pesticide use occupational (intentional) and environmental (non-intentional) exposure (exposures) in Ethiopia (and probably beyond) encompassing the study area, and taking the present research as a case study.

- The present research requires and necessitates stringent regulation, management and control of pesticide and pesticide use, and urgently designing, developing and establishing a strategy of continuous, regular (at appropriate regular intervals) and periodic (seasonal) monitoring, surveillance and assessment systems and programs of pesticide and pesticide use and immediately and extensively implementing the scheme (strategy) in onion and likely in other vegetables production systems and production belts, where pesticide use and application is immense due to the prevalence of numerous (ubiquitous) pests especially of insect pests of these vegetable crop plants, and where human health and environmental health hazards and risks (overall ecosystem health problems) would be alarmingly greater and threatening due to potentially higher consequent occupational (intentional), environmental and non-intentional exposure (exposures) to pesticides, and because of consumption exposure to pesticide residues and pesticides due to ingestion and digestion of onion and likely other vegetables contaminated (polluted) with pesticide residues and pesticides, which might (could) be exacerbated by the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (appropriate and safe use, handling and application) of pesticides, that aimed at preventing, reducing (minimizing and limiting), avoiding and eliminating occupational (intentional), unintentional and environmental pesticide and pesticide use exposure environmental health and human health hazards and risks (overall ecosystem health problems), in Ethiopia (and probably beyond) encompassing the study area, and taking the present research as a case study.

- Importation, distribution, transaction and use of especially highly toxic pesticides, particularly more toxic synthetic chemical pesticides specifically high toxicity synthetic chemical insecticides such as endosulfan must stringently be regulated and restricted for use (the pesticides must be restricted to the intended purpose use they are approved for (the pesticides must be restricted for the purpose they are intended (approved) for)) in Ethiopia encompassing the study area.
- Research into critical and peak time pesticide (insecticide) particularly synthetic chemical insecticide spray frequency for the control of onion thrips on onion in the study area, and likely in other parts of Ethiopia, is promptly needed to optimize quantity of insecticide to be used, and hence to reduce human health and environmental health problems caused by and associated with pesticide and pesticide use through minimizing, avoiding and eliminating increased and excessive pesticide use and application exposure (exposures) hazards and risks, and to minimize and alleviate farmers' economic issues (problems), i.e., to reduce unnecessary extra pesticide purchase cost.
- Designing, establishment and formulation of national pesticide residues and pesticides monitoring and surveillance programs and implementation of continuous, periodic (seasonal) and regular (at regular intervals) monitoring, surveillance and analysis (analytical determination and evaluation) of pesticide residues, pesticides and their metabolites and degradation products, especially of organochlorine and organophosphate pesticide residues (pesticides) particularly of residues of currently and commonly (currently commonly) used pesticides in agricultural food commodities particularly in onion and likely in other vegetables is urgently required, and must be expanded in nationwide level (must be expanded at national level). And, MRL and MRL database in onion must urgently be established (set) at national level in Ethiopia taking the present research as a case study to protect the health of consumers.
- Continuous, regular (at appropriate regular intervals), periodic (seasonal) investigation (testing and examination), monitoring, surveillance and evaluation of the current health

status, i.e., the status of acute (short-term) and chronic (long-term) health conditions (health problems) including probably latent and potentially detrimental and silently killing chronic health problems of farming people particularly pesticide end-users specifically smallholder (small-scale) onion cultivating farmers and farm workers (pesticide applicators and re-entry farm workers) including their (the farming peoples') spouses and children caused by and associated with acute (short-term) and chronic (long-term/prolonged) occupational (intentional), environmental and non-intentional, deleterious exposures to pesticides, and onion consumers that are at greater risk of and highly vulnerable to pesticide exposure due to consumption of onion contaminated (polluted) with pesticide residues and pesticides, and also, environmentally and unintentionally pesticide and pesticide use exposed human (sub) populations including the agrarian communities and the public at large, which might be exacerbated by the farmers' overall lack of knowledge, awareness and understanding of the appropriate and safe use (the appropriate and safe use, handling and application) of pesticides, and where immediate farm produce (fresh field harvest and/or garden harvest) of onion including other vegetables are often consumed raw in the country including the study area, is urgently required through biomonitoring analysis and evaluation particularly of the levels and activities of human cholinesterase enzymes in Ethiopia (and perhaps beyond) at national level encompassing the study area, and taking the present research as a case study.

- National public and private pesticide residue analysis laboratories must be supported, developed and expanded, and need to be continuously and regularly monitored and upgraded in their expertise and facility for their efficient and effective capacity and appropriateness of method of analysis for the intended purpose performance, i.e., analysis (analytical determination and evaluation) of pesticide residues in agricultural food and commercial commodities particularly in onion and other vegetables in Ethiopia.
- Special public and official mass media channels concerned on transmitting (displaying) programs on appropriate and safe use (appropriate and safe use, handling and application) of pesticides and detrimental effects of inappropriate and unsafe pesticide use (inappropriate and unsafe pesticide use, handling and application) including current

national, regional and global pesticide and pesticide use challenges, problems and alternative pest control and management solutions (options) addressing especially to the farming communities (rural communities) particularly to pesticide users specifically to pesticide end-users with special reference to farmers and farmworkers (pesticide applicators and re-entry farm workers) need to be operationalized and delivered to raise knowledge and awareness of pesticide users on this alarming and threatening issue (problem).

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8 APPENDICES

Appendix 1: Field survey study interview questions and discussion points

Part I: Interview questions for respondent small-scale onion cultivating farmers

These interview questions are designed to assess and evaluate levels of pesticide (insecticide) use knowledge and practices of smallholder onion producing farmers in controlling onion thrips on onion in Kewet district, central Ethiopia.

A. Demographic and socioeconomic characteristics of respondent farmers

1 General demographic information

i. Interview date ______

ii. Name of respondent ___________________________

iii. Sex: Male__________Female___________________

iv. Age___________________

v. Name of kebele ________________________

vi. Name of village _________________

vii. Educational background

Illiterate (unable to read and write)____

Literate (can read and write)

- Formal education (primary or above) (grade)_______

- Informal (adult) education)_____

2. Questions related to socioeconomic characteristics of study subjects

i. Do you produce onion every year?

Yes

No

ii. What is your onion production land tenure status (situation)?

Landowner

Rented landholder

iii. What is your cultivated land size of onion (hectare (ha))?

0.25 to 0.75 ha

> 0.75 to 1.25 ha

iv. How do you produce onion (onion production season)?

Using Irrigation

Rain fed

v. How many times do you produce onion per year?

One time

Two times

Three times

vi. Your years of onion cultivation (production) experience

<15 years

15 to 25 years

> 25 years

vii. What are the current serious pests of onion production in your onion field?

Onion thrips

Others (specify)

viii. Do onion thrips attack onion in every onion growing season (year)?

Yes

No

ix. How much yield loss (%) of onion by onion thrips do you estimate (guess) per one production season (year) if untreated?

20- 30%

31-50%

>50%

x. How do you control onion thrips on onion in your onion farm?

Chemical control (using chemical pesticides (chemical insecticides))

Others (specify)

B. Questions related to pesticide (insecticide) use knowledge and practices of smallholder onion cultivating farmers in controlling onion thrips on onion

1. **Questions related to pesticide (insecticide) use knowledge of small-scale onion growing farmers in controlling onion thrips on onion**

i. Do you know synthetic chemical pesticides (synthetic chemical insecticides) you purchase and use by name?

Yes

No

ii. Do you think that exposure to pesticides can cause (can pose) harmful effects to (on) human health?

Yes

No

iii. Do you think that exposure to pesticides can affect the environment?

Yes

No

iv. How do you mix pesticides, i.e., what are your information sources for pesticide mixing (pesticide dosage)?

Pesticide vendors (pesticide retailers)

Agricultural extension workers

Past personal experience

Pesticide labels

v. Do you think synthetic chemical pesticides (synthetic chemical insecticides) currently are indispensable for onion production?

Yes

No

vi. Do you have knowledge, awareness and understanding of the importance and use of wearing personal protective equipment (PPE) during pesticide use, i.e., when handling (purchasing, storing, preparation (mixing), application (spraying)) of pesticides, and handling and disposal of pesticide wastes including handling and disposal of empty pesticide containers?

Yes

No

No availability or supply (provision) of PPE

vii. Have you ever received any formal training (any formal educational training) and technical support on the appropriate and safe use (on appropriate and safe use, handling and application) of pesticides and pesticide use safety measures?

Yes

No

viii. What are the common health symptoms (frequent symptoms of health problems) you encounter during or immediately after pesticide handling and application?

Dermal

Ocular

Headache and other internal body symptoms (inhalational and ingestional)

Others (specify)

ix. Have you ever visited (have you ever been presented to) any health facility or have you ever been admitted to any health institution due to health symptoms you faced during or immediately after pesticide use and application?

Yes

No

x. Do you have knowledge and awareness of the pesticide legislation of Ethiopia particularly one of its provisions which states that no person shall dispose of any pesticide or pesticide waste in a way that may harm human or animal health or the environment?

Yes

No

2. Questions related to pesticide (insecticide) use practices of smallholder onion producing farmers in controlling onion thrips on onion

i. Where do you buy pesticides (insecticides) and pesticide sprayers?

Pesticide vendors (pesticide retailers)

Others (specify)

ii. What type of pesticide spray equipment do you use?

15 L (litre) backpack (knapsack) sprayer

20 L (liter) backpack (knapsack) sprayer

iii. Where do you store pesticides (insecticides)?

Do not store pesticides-buy needed quantity (quantities) of pesticides for current uses and apply soon after purchase

In living house

Transfer (give or lend) the remained (leftover) pesticides to a friend for current uses

iv. What do you wear during pesticide handling and application?

Ordinary clothings

Personal protective equipment (PPE)

v. Where do you mix pesticides (insecticides)?

On-farm (in the field)

Near irrigation water sources (rivers)

vi. What do you do with mixed (diluted) leftover pesticide solutions?

No leftover of diluted pesticide mixtures-mix needed amount of pesticides for current applications and spray

Finish on the same treated crop

vii. What do you do with empty pesticide containers?

Discard on-farm

Burn on-farm

Use for other purposes

viii. Do you eat or drink while using pesticides (during handling (preparation (mixing), application (spraying)) of pesticides)?

Yes

No

ix. Do you clean pesticide sprayer immediately after finishing spraying of pesticides?

Yes

No

x. Do you take bath (do you bathe yourself) and wash your clothes (keep your hygiene) immediately after completing pesticide applications (pesticide spray)?

Yes

No

xi. Where do you store pesticide spray equipment?

In kitchen

In grain (or grain and fertilizer) store

In the living house

Part II: Discussion points for focus group discussion (FGD) on chemical pesticide (chemical insecticide) use knowledge and practices of smallholder onion growing farmers in controlling onion thrips on onion in Kewet district, central Ethiopia

A. General information

1. Discussion date _______________
2. Name of participants, sex, age, responsibility in the community and/or organisation, educational background and profession __
3. Place of discussion ___________________

B. Discussion points on synthetic chemical pesticide (synthetic chemical insecticide) use knowledge and practices of small-scale onion producing farmers in controlling onion thrips on onion

1. How often (regularly) is onion produced in Kewet district?
2. How is onion grown in the area?
    - Rain fed

- Using irrigation (traditional, using established irrigation schemes, mixed)

3. How many times do farmers produce onion per year in the district?
4. How much economically valuable is onion for farmers in Kewet district?
5. What are the current economically important pests of onion in the district?
6. What is the major and serious insect pest of onion in onion production area in the district?
7. What is the trend of occurrence and degree of infestation of onion thrips on onion in Kewet district, i.e., is onion thrips economically damaging insect pest of (on) onion?
8. What are the current methods used to control and manage onion thrips on onion applied by onion farmers in Kewet district?
9. What are the types of pesticides (insecticides) currently used by farmers to control onion thrips on onion in the district?
10. Where do onion growing farmers buy chemical pesticides (chemical insecticides) and pesticide sprayers, and do farmers have knowledge of choosing (buying) and using approved (appropriate) pesticides (insecticides) for the control of onion thrips on onion in Kewet district?
11. Have onion cultivating farmers ever received any formal traning and technical support on the appropriate and safe use and application of chemical pesticides, and handle and apply pesticides using pesticide use safety measures (applying pesticide use safety precautions) like use of personal protective equipment (PPE)?

12. Do onion farmers have knowledge and awareness of the use and importance of wearing personal protective equipment (PPE) during chemical pesticide use (when handling (purchasing, storing, preparation (mixing), application (spraying)) of chemical pesticides and disposal of pesticide wastes including empty pesticide containers) in Kewet district?
13. What do onion producing farmers wear during chemical pesticide (chemical insecticide) use and application (when handling and application (spraying) of

chemical pesticides and disposal of pesticide wastes including empty pesticide containers) in Kewet district?

14. Is there any availability (provision) of PPE in the district?
15. What is the frequency of application of chemical pesticides (chemical insecticides) by onion growers to control onion thrips on onions in Kewet district?
16. Where do onion producers dispose of empty pesticide (insecticide) containers?
17. What are environmental health and human health problems observed associated with (related to) use and application of synthetic chemical pesticide (synthetic chemical insecticide) to control onion thrips on onion in Kewet district?

Appendix 2: Analytical sample chromatograms and calibration curves

Part III: Sample chromatograms of the studied pesticides with their retention time (minute)

α-HCH

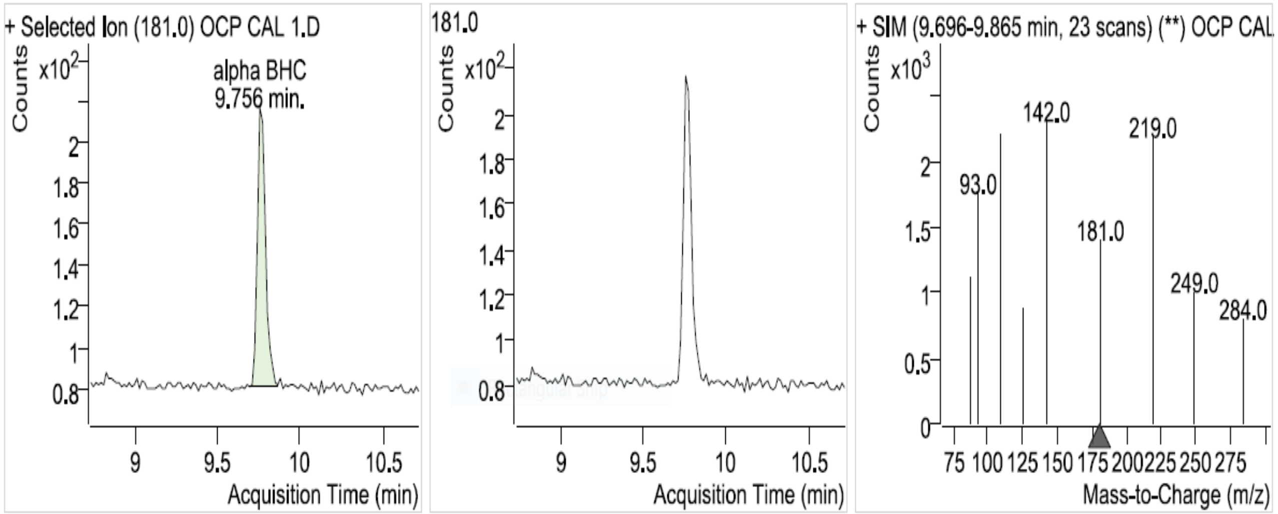

Figure 7: Sample chromatogram of α-HCH

β-HCH

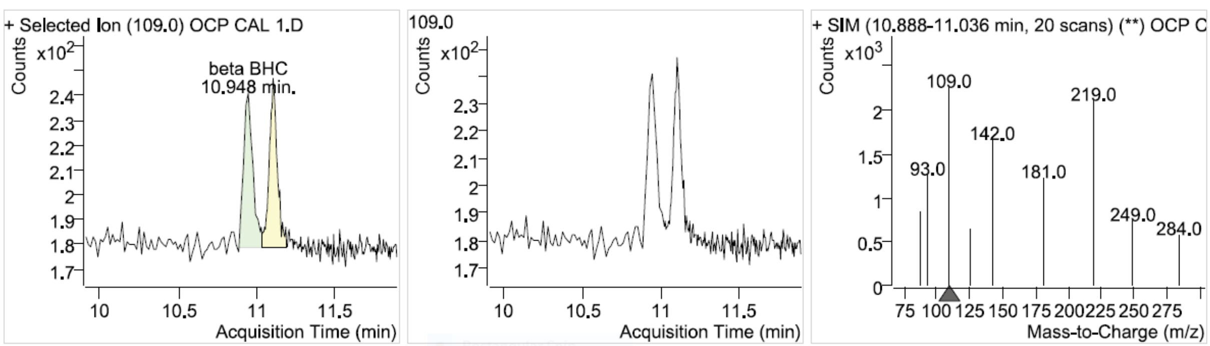

Figure 8: Sample chromatogram of β-HCH

Aldrin

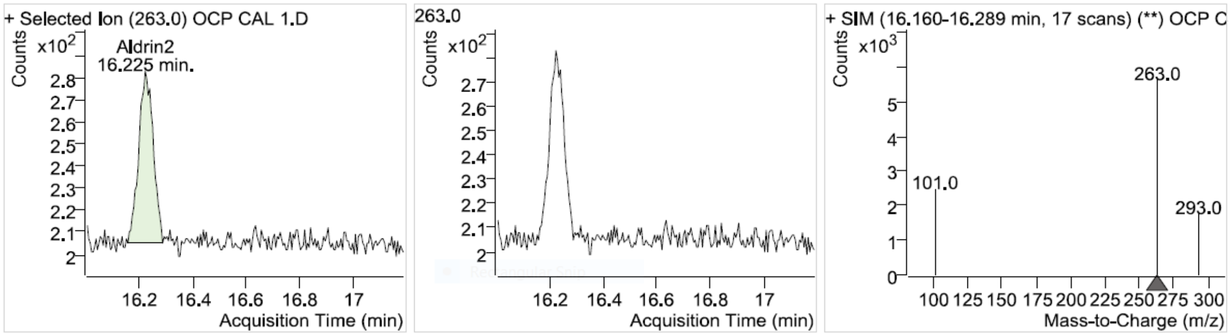

Figure 9: Sample chromatogram of aldrin

Heptachlor epoxide

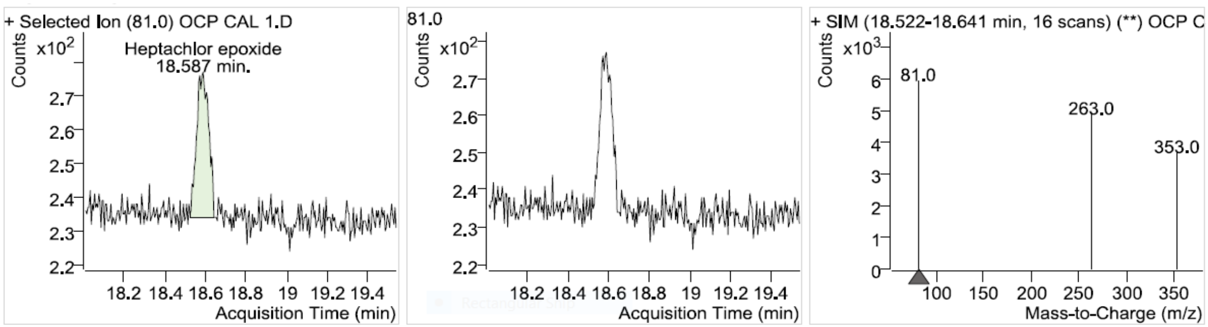

Figure 10: Sample chromatogram of heptachlor epoxide

Endosulfan I

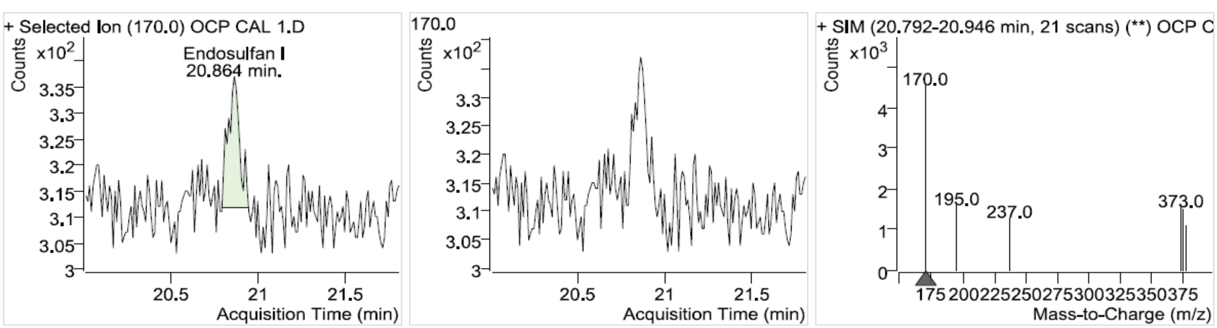

Figure 11: Sample chromatogram of endosulfan I

Chlordane

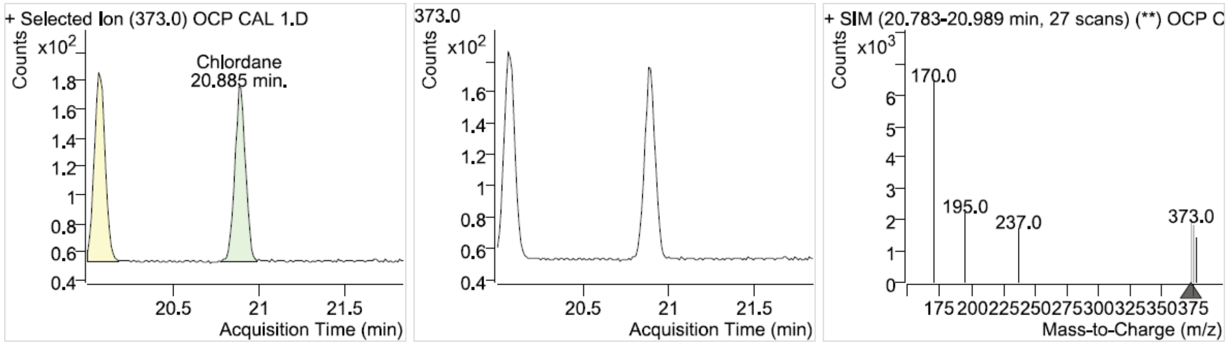

Figure 12: Sample chromatogram of chlordane

Endosulfan II

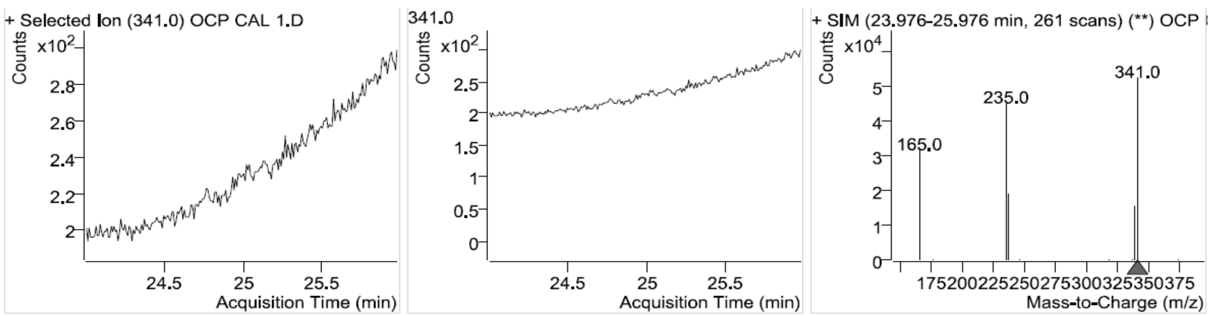

Figure 13: Sample chromatogram of endosulfan II

DDD

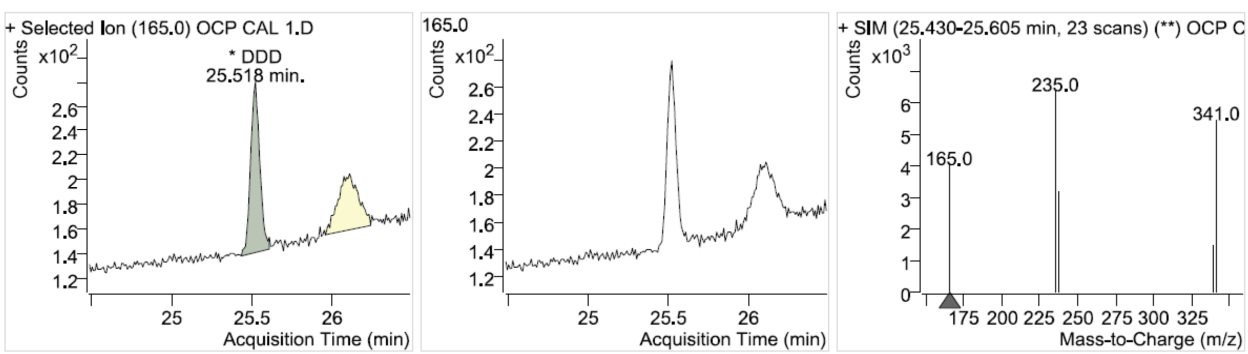

Figure 14: Sample chromatogram of DDD

DDT

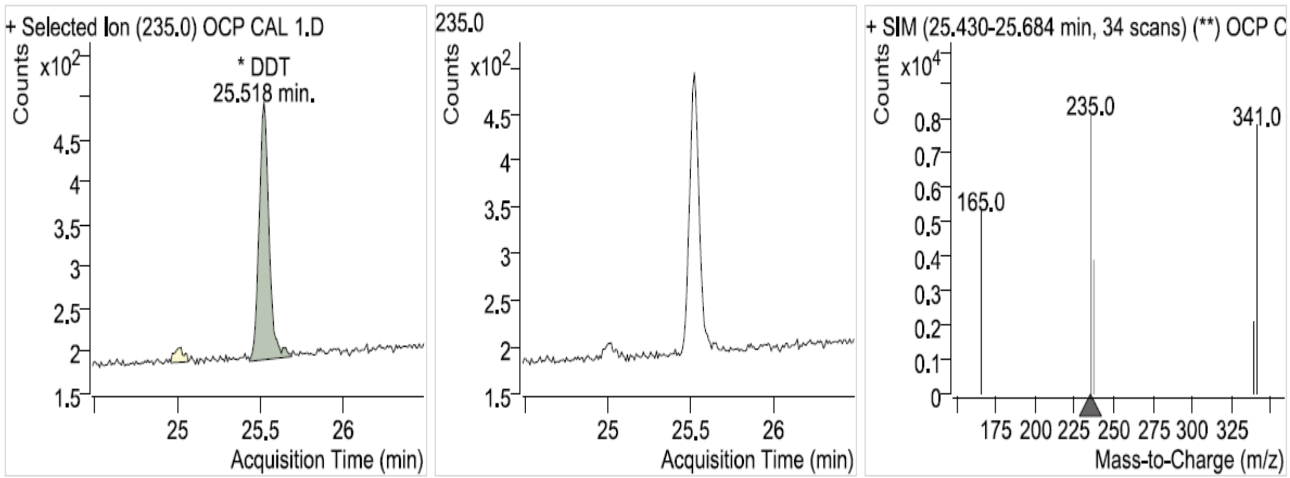

Figure 15: Sample chromatogram of DDT

Methoxychlor

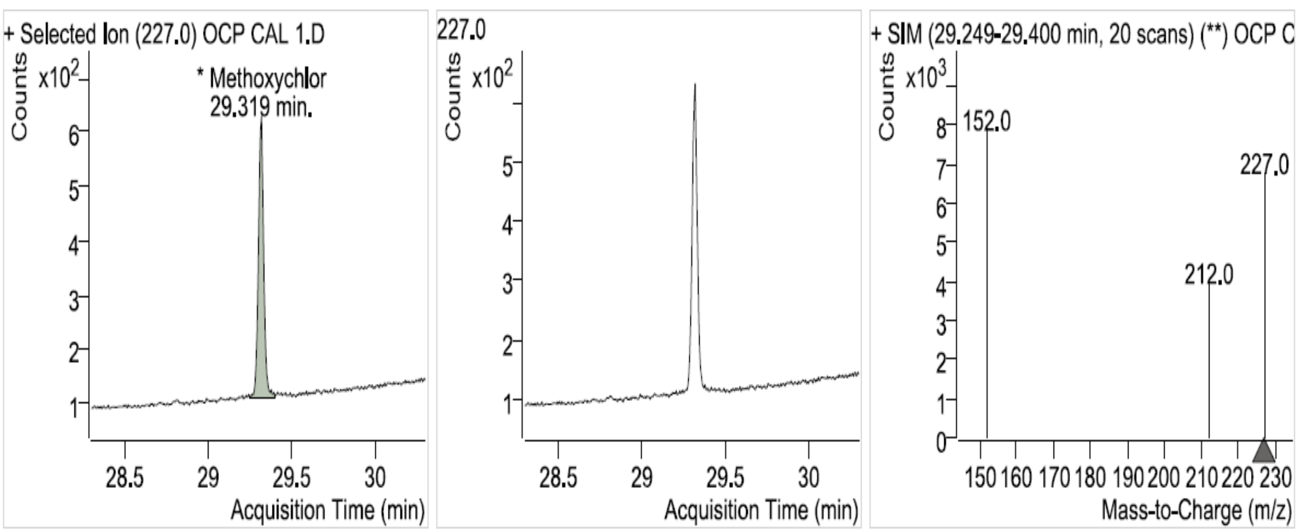

Figure 16: Sample chromatogram of methoxychlor

Part IV: Calibration curves of the target pesticide analytes (pesticide residues) studied and their characteristics

α-HCH

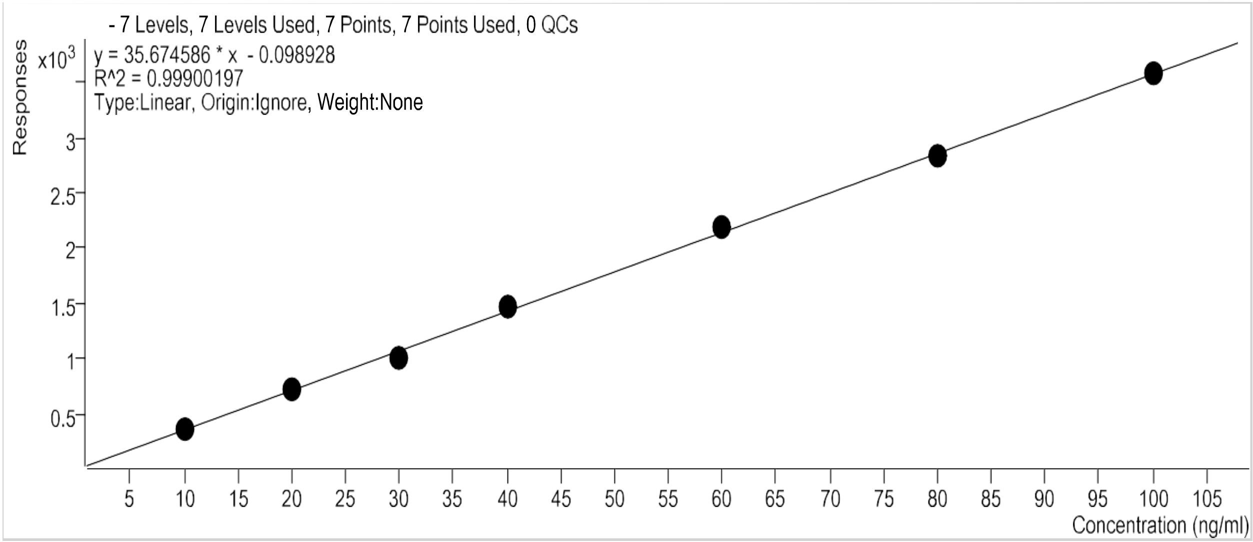

Figure 17: Calibration curve for α-HCH

β-HCH

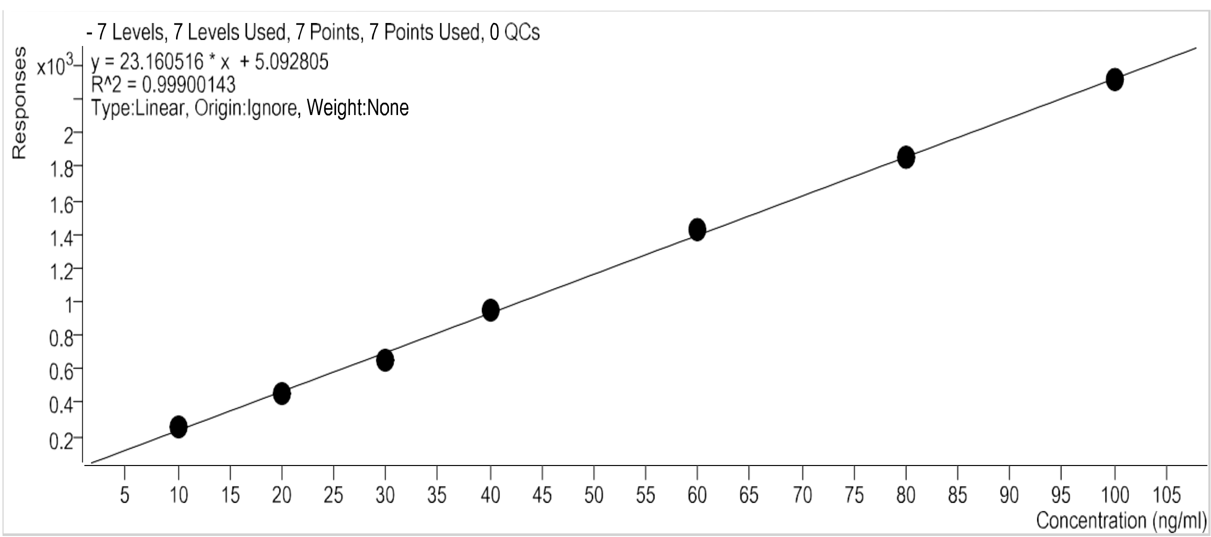

Figure 18: Calibration curve for β-HCH

Heptachlor

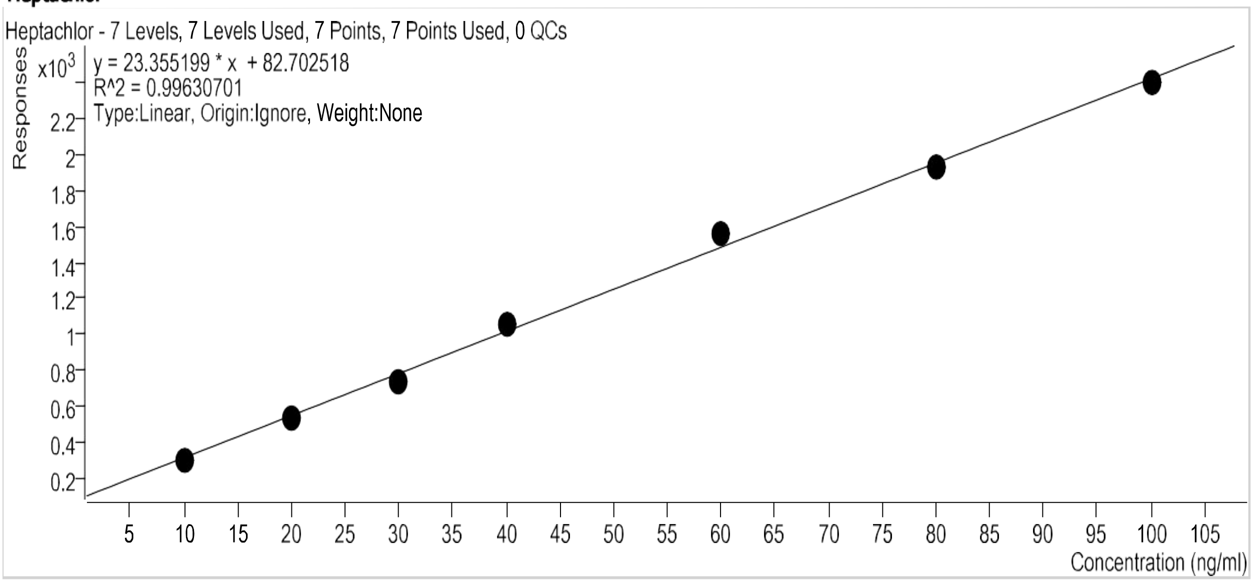

Figure 19: Calibration curve for heptachlor

Aldrin

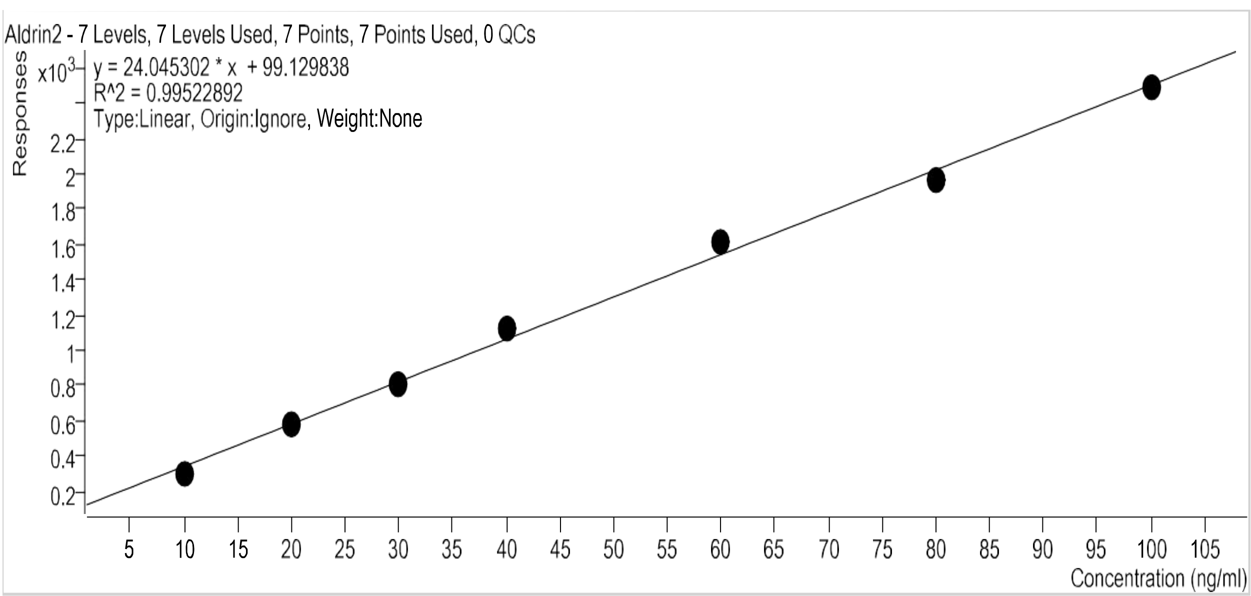

Figure 20: Calibration curve for aldrin

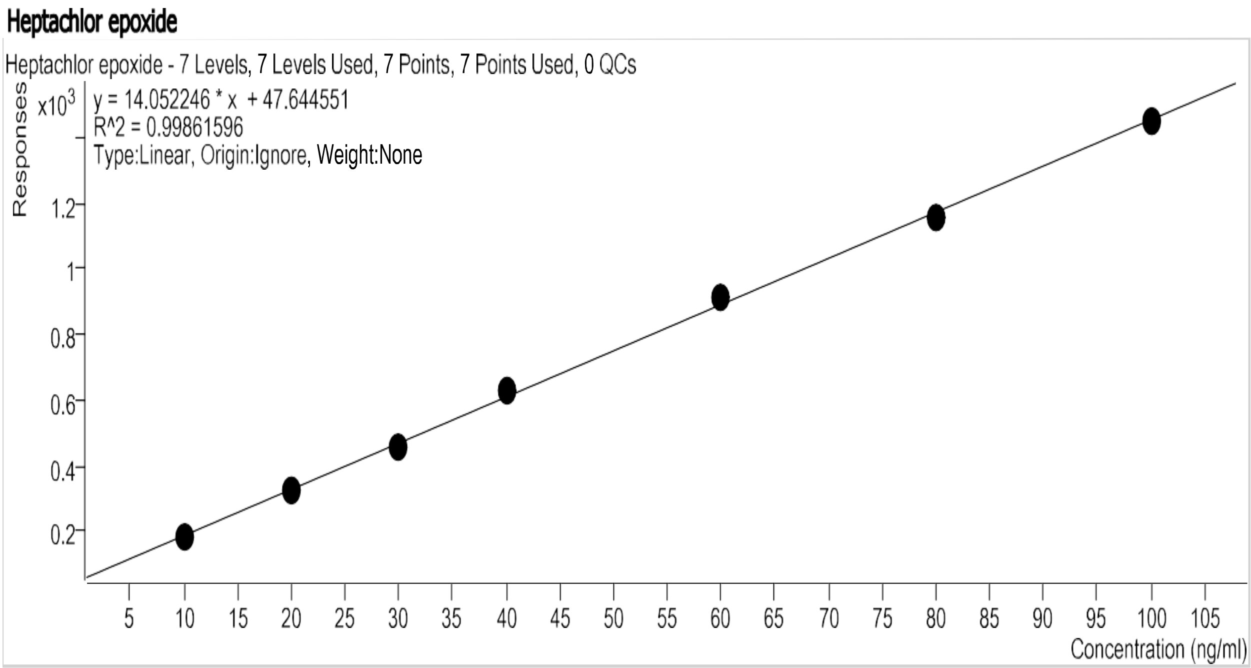

Figure 21: Calibration curve for heptachlor epoxide

Endosulfan I

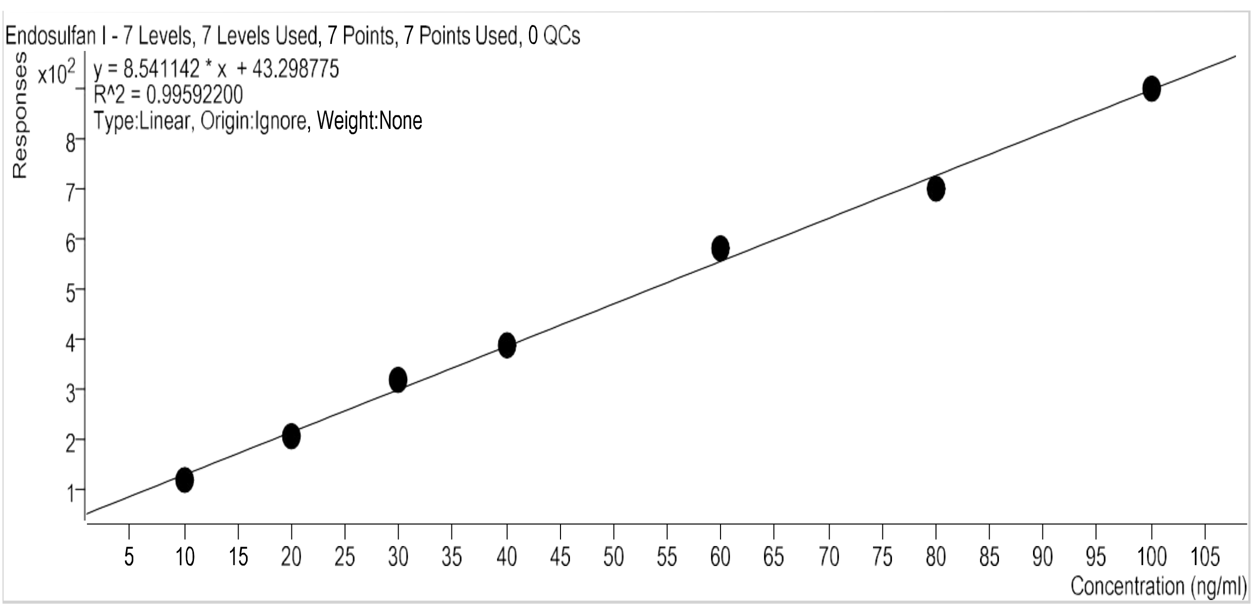

Figure 22: Calibration curve for Endosulfan I

Chlordane

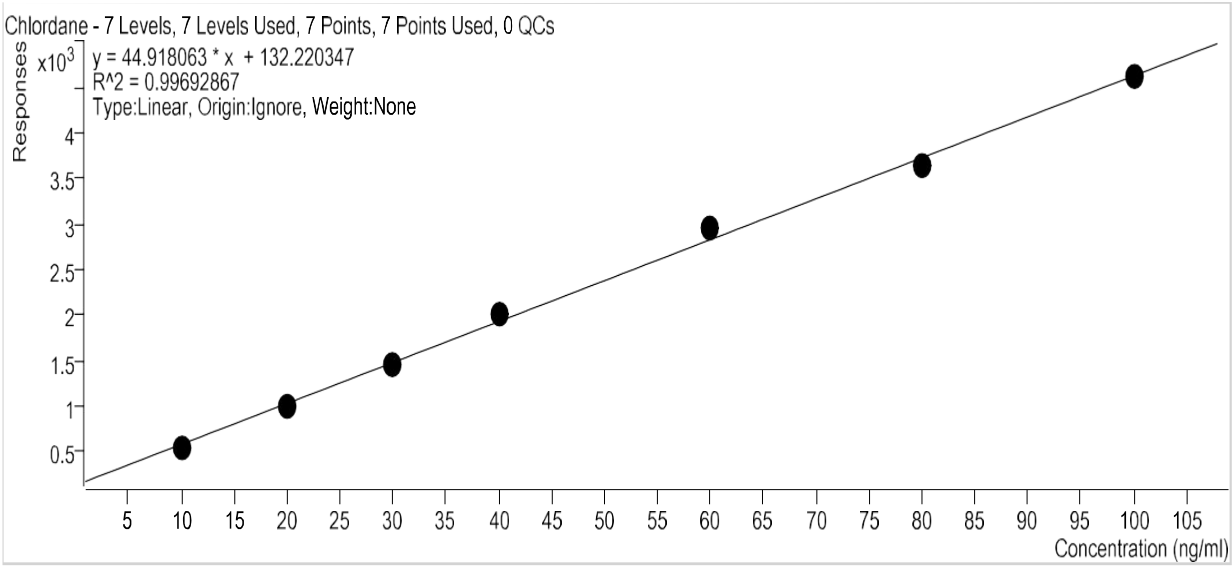

Figure 23: Calibration curve for Chlordane

DDE

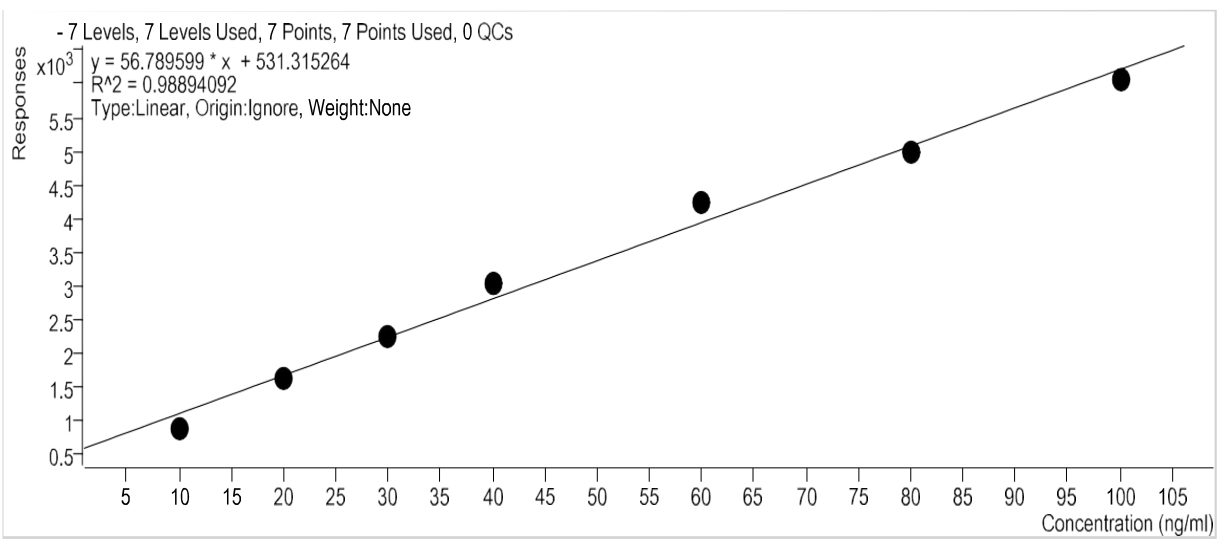

Figure 24: Calibration curve for DDE

Endosulfan II

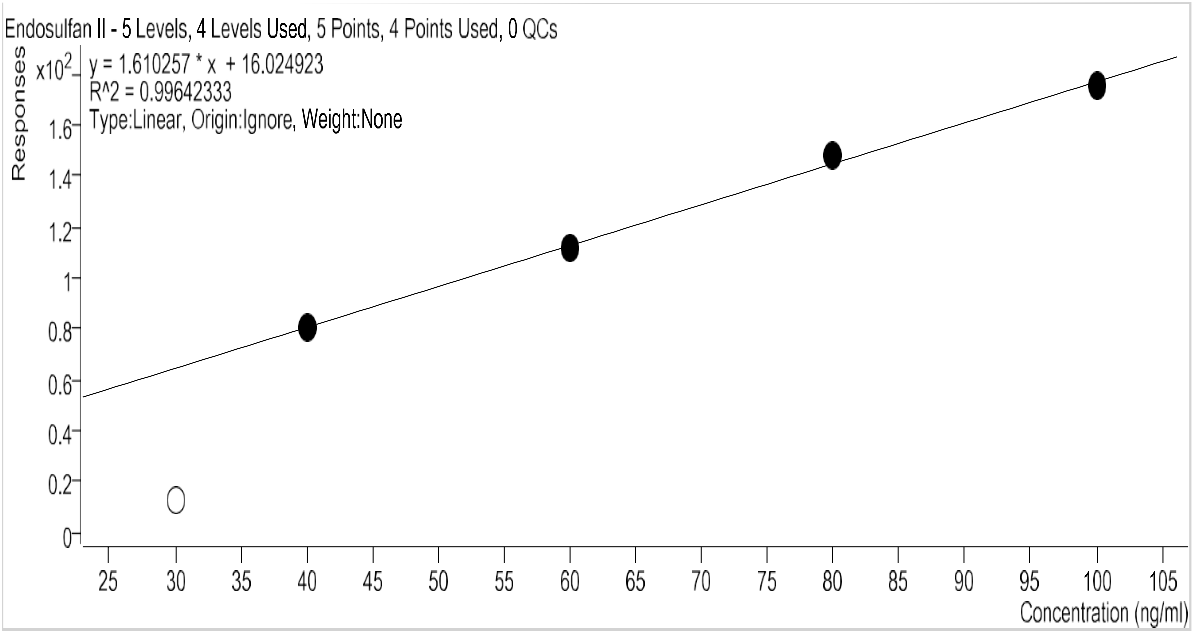

Figure 25: Calibration curve of Endosulfan II

DDT

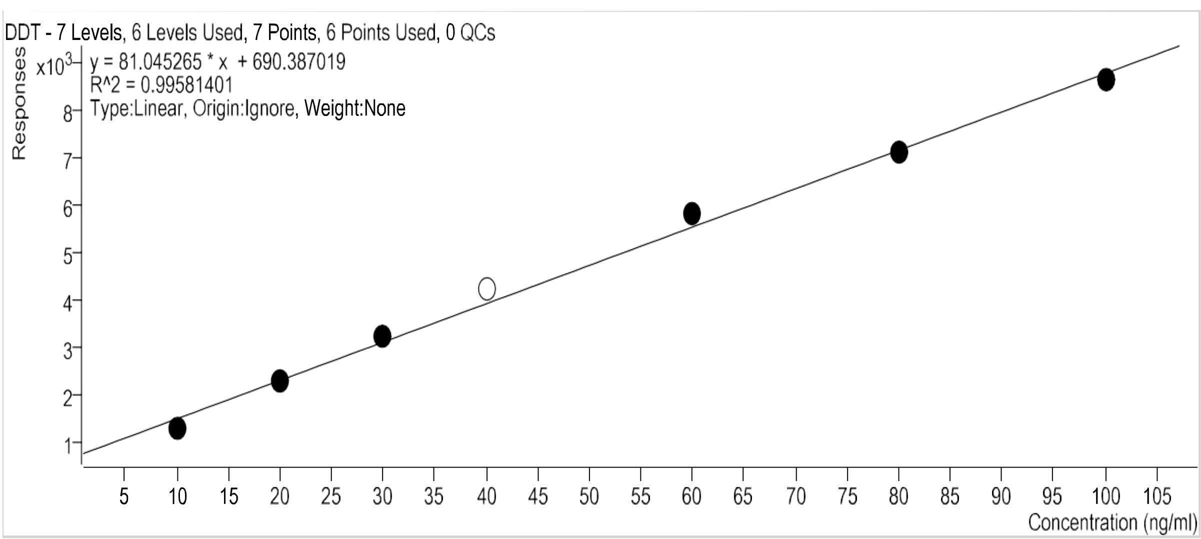

Figure 26: Calibration curve for DDT

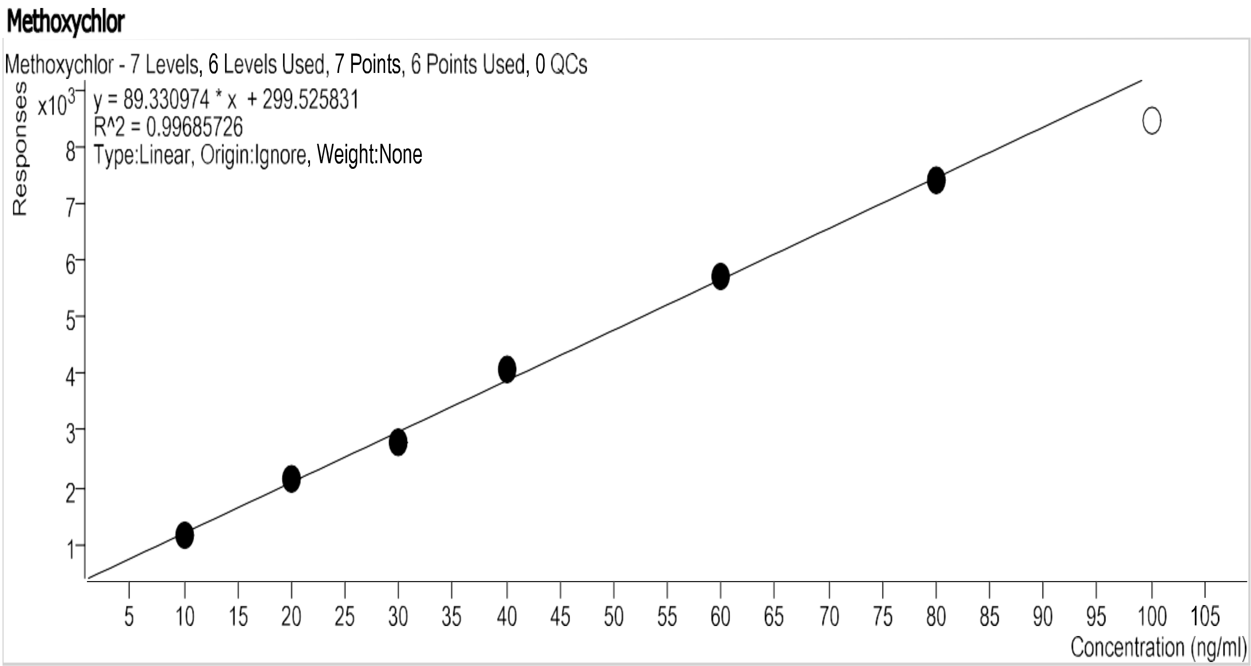

Figure 27: Calibration curve for methoxychlor

Fenthion

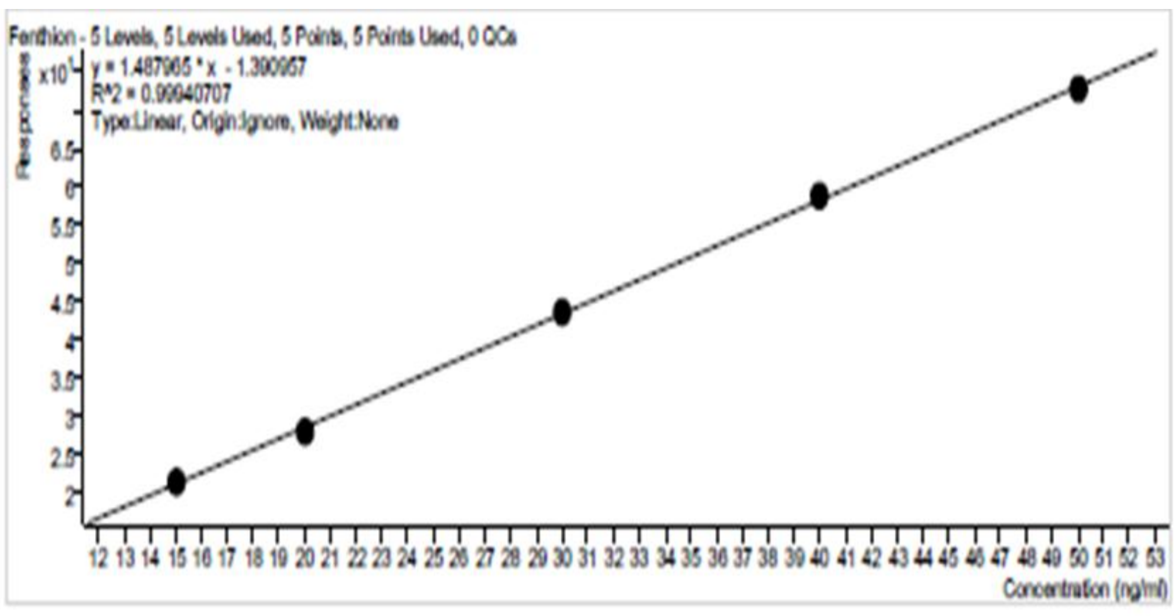

Figure 28: Calibration curve for fenthion

Fenitrothion

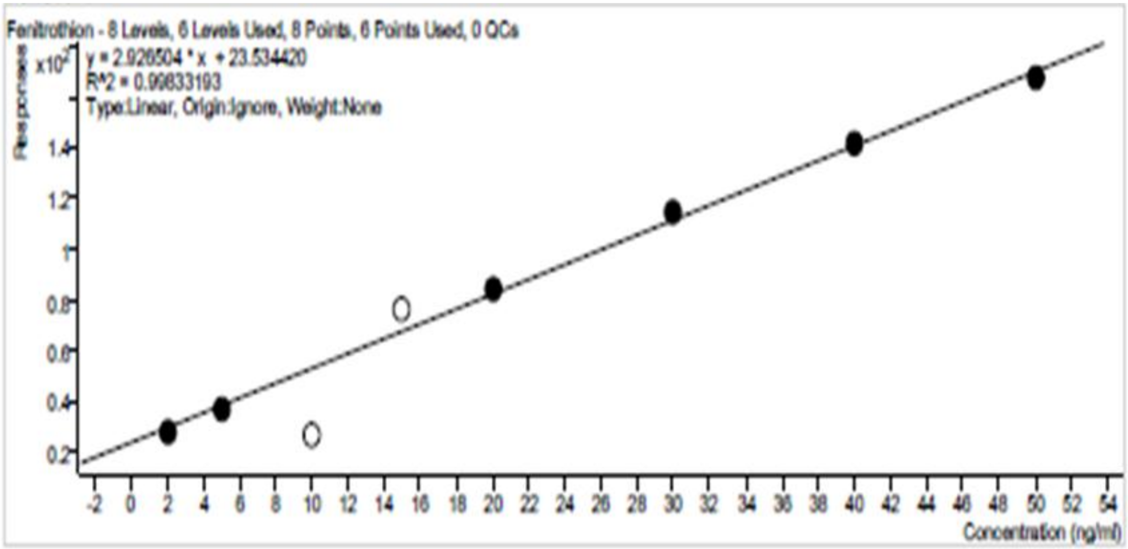

Figure 29: Calibration curve for fenitrothion

Hexachlorobenzene

Hexachlorobenzene-8 Levels, 6 Levels used, 8 Points, 6 points used, 0 QCs

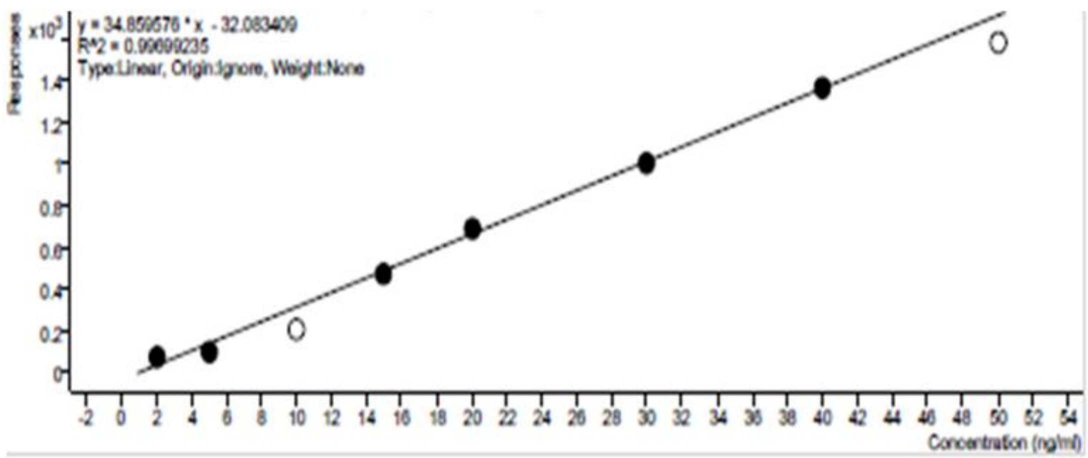

Figure 30: Calibration curve for hexachlorobenzene