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EFFECTS OF BOTANICAL PESTICIDES AND CLIMATE ON THE LIFECYCLE OF *SPODOPTERA FRUGIPERDA* (LEPIDOPTERA: NOCTUIDAE) ON MAIZE IN CÔTE D'IVOIRE

A thesis, in the Rural Polytechnic Institute of Training and Applied Research (IPR/IFRA) in partnership with the West African Science Service Centre on Climate Change and Adapted Land use (WASCAL), submitted in partial fulfilment of the requirements for the Doctor of Philosophy in Climate Change and Agriculture of the University of Sciences, Techniques and Technologies of Bamako (USTTB)

Presented and defended on: 06/ 05/ 2023

By Ms **Stéphanie Manuela Klamansoni Akissi KONAN**

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EFFECTS OF BOTANICAL PESTICIDES AND CLIMATE ON THE LIFECYCLE OF *SPODOPTERA FRUGIPERDA (*LEPIDOPTERA: NOCTUIDAE) ON MAIZE IN CÔTE D'IVOIRE

BY

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Msc. Biodiversity and Ecosystem Enhancement

(MATRICULE NUMBER: CI 0113255097)

A THESIS

IN THE RURAL POLYTECHNIC INSTITUTE OF TRAINING AND APPLIED RESEARCH IN PARTNERSHIP WITH THE WEST AFRICAN SCIENCE SERVICE CENTRE ON CLIMATE CHANGE AND ADAPTED LAND USE (WASCAL), SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN CLIMATE CHANGE AND AGRICULTURE OF THE UNIVERSITY OF SCIENCES, TECHNIQUES AND TECHNOLOGIES OF BAMAKO (USTTB), BAMAKO, MALI

MAY ,2023

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This work has not been presented elsewhere for the award of a degree, or any other purpose.

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I certify that this work has been carried out by M. Stéphanie Manuela Klamansoni Akissi Konan under my supervision and that to the best of my knowledge, it has not been submitted elsewhere for the award of a degree.

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Dedication

I firstly dedicate this thesis to the almighty God for his grace in my life.

I dedicate, with all my heart, this PhD thesis to:

- my father Kouadio KONAN for all his love and for teaching me patience and perseverance in work;
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List of abbreviations

BMBF:	German Federal Ministry for Education and Research
Bt:	*Bacillus Thuringiensis*
CABI:	Centre for Agriculture and Bioscience International
CFCs:	Chorofluorocarbons
CIMMYT:	International Maize and Rice Improvement Center
CNRA:	National Centre of Agronomic Research
DDVP:	Dimethyl 2,2-DichloroViny Phosphate
ENM:	Ecological Niche Modeling
GBIF:	Global Bioscience Information Facility
GCM:	Global Climate Model
IITA:	International Institute of Tropical Agriculture
IPCC:	Intergorvermental Panel on Climate Change
IPM:	Integrated Pest Management
IPR/IFRA:	Rural Polytechnic Institute of Training and Applied Research
LLM-IC:	Low & Lower-Middle Income Countries
MMT:	Million Metric Tons
MSV:	Maize Streak Virus
PROPACOM:	Agricultural Production and Marketing Support Project
RCP:	Representative Concentration Pathways
SfMNPV:	*Spodoptera frugiperda* nucleopolyhedrovirus
UMA-IC:	Upper-Middle & High Income
VIP:	Vegetative Insecticidal Proteins
WASCAL:	West African Science Service Centre on Climate Change and Adapted Land Use
ZALF:	Leibniz Centre for Agriculture Landscape Research

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Abstract

Spodoptera frugiperda (Lepidoptera: Noctuidae), a new invasive insect pest of maize, has successfully established itself in Africa, particularly in Côte d'Ivoire. The management of this pest is mainly based on synthetic insecticides. Hence the need to develop an alternative, affordable and sustainable control method. This thesis aims to reduce the use of synthetic insecticides against *S.* frugiperda and to model its potential distribution in Côte d'Ivoire. The study conducted in two climatic zones (Sub-Sudanian and Guinean) allowed the collection of biodemographic parameters and population dynamics in these zones following the rearing of *S. frugiperda* in semi-natural conditions both in dry and rainy seasons. Then, the efficacy of aqueous extracts from 4 local plants (*Ricinus communis*, *Azadirachta indica*, *Tephosia vogelii* and *Lippia multiflora*) was tested against *S. frugiperda*. Finally, the current and future distribution of the pest in Côte d'Ivoire was modeled by MaxEnt according to the MIROC and BCC-CSM models for low (RCP 4.5) and high (RCP 8.5) emissions. Results showed that *S. frugiperda* is a holometabolous pest with a developmental cycle of six larval stages with high survival rates. Biological and demographic parameters were more important in the rainy season. Seasonal variations of *S. frugiperda* population in a maize field showed that the percentage of damage varied with phenological stages and seasons. The highest number of moths in Sub-Sudanian zone (131.25± 35.76) and Guinean zone (47.75± 27.87) were obtained during the rainy season at the whorl stage and the lowest in Sub-Sudanian zone (30.33 ± 13.05) and Guinean zone (4.67±1.45) at the maturation stage. The results of the bioactivity of local plants showed that they had toxic and anti-appetent effects on *S. frugiperda*. The highest mortality rate was caused by *R. communis* (65%) while the lowest rate (40%) was recorded with *L. multiflora*. In addition, *A. indica* produced the highest anti-appetent rate (90.05%). Regarding the distribution of the pest, the results showed that only the western part of Côte d'Ivoire is unsuitable for its development. Among the climatic parameters, the temperature remains the main factor of the distribution of *S. frugiperda*. The pest will not be able to proliferate in 2050 and 2070 in Côte d'Ivoire due to unfavorable climatic conditions for its development.

Keywords: *S. frugiperda*, maize, distribution, climate change, biodemographic parameters, aqueous extract.

Résumé

Spodoptera frugiperda (Lepidoptera : Noctuidae), nouvel insecte ravageur invasif du maïs s'est établi avec succès en Afrique et, en particulier en Côte d'Ivoire. La gestion de ce ravageur est principalement basée sur des insecticides de synthèse. D'où la nécessité de développer une méthode de lutte alternative et durable. Cette thèse vise à réduire l'utilisation des insecticides de synthèse contre *S. frugiperda* et, à modéliser sa distribution potentielle en Côte d'Ivoire. L'étude conduite dans deux zones climatiques (Sub-soudanaise et Guinéen) a permis de récolter les paramètres biodémographiques et la dynamique des populations dans ces zones suite à l'élevage en conditions semi-naturelles tant en saison sèche qu'en saison des pluies. Ensuite, l'efficacité d'extraits aqueux issus de 4 plantes locales (*Ricinus communis, Azadirachta indica, Tephosia vogelii* et *Lippia multiflora*) a été testée contre *S. frugiperda* . Enfin, la distribution du ravageur en Côte d'Ivoire a été modélisée par MaxEnt selon les modèles MIROC et BCC-CSM pour les émissions faibles (RCP 4.5) et élevées (RCP 8.5). Les résultats ont montré que *S. frugiperda* est un ravageur ayant un cycle de six stades larvaires avec des taux de survie élevés. Les paramètres biologiques et démographiques ont été plus importants en saison des pluies. Les variations saisonnières de la population de *S. frugiperda* dans un champ de maïs ont montré que les dommages varient en fonction des stades phénologiques et des saisons. Les nombres les plus élevés d'imagos en zone Sub-soudanaise (131.25± 35.76) et zone Guinéen (47.75± 27.87) ont été obtenus pendant la saison des pluies au stade de verticille et le plus faible en zone Sub-soudanaise (30.33 ± 13.05) et zone Guinéen (4.67±1.45) au stade de maturation. Les résultats de la bioactivité des plantes locales ont montré que ces dernières avaient des effets toxiques et anti-appétents sur *S. frugiperda*. Le taux de mortalité le plus élevé a été causé par *R. communis* (65%) alors que le plus faible taux (40%) a été enregistré avec *L. multiflora*. De plus, *A. indica* a produit le taux anti-appétent le plus élevé (90.05%). En ce qui concerne la distribution du ravageur, les résultats ont montré que seule la partie occidentale de la Côte d'Ivoire est inadaptée à son développement. Parmi les paramètres climatiques, la température demeure le principal facteur déterminant de la distribution de *S. frugiperda*. Le ravageur ne pourra pas proliférer en 2050 et 2070 en Côte d'Ivoire pour des raisons climatiques défavorables à son développement.

Mots-clés : *S. frugiperda*, maïs, distribution, changement climatique, paramètres biodémographiques, extrait aqueux.

CHAPTER 1. INTRODUCTION

1.1 Problem statement

In Côte d'Ivoire, maize plays an important role for human nutrition and animal feed. It is the most widely grown cereal after rice. In 2021, the national production is estimated at 1,140 million tons, for a total area of 518,794 hectares, with a national consumption estimated at 458g/person/year (FAOSTAT, 2021). For human consumption, maize is consumed in several forms (roasted poured etc.). It can be processed into a variety of flour and semolina products. It is also used to make alcohol. However, maize cultivation in Côte d'Ivoire faces many difficulties such as low soil fertility, weeds, pathogens and pests leading to yield losses (Yoboue and Tano, 2021). Suspicions about the presence of an insect pest in maize field began in October 2016, when maize farmers benefiting from the Projet d'Appui à la Production Agricole et à la Commercialisation (PROPACOM) first reported an invasion of unidentified larva on their maize growing sites in Allékro, in the Sub-Prefecture of Bodokro in central Côte d'Ivoire (Malanno et al., 2019) Between July and October 2017, other maize growers, both in the central and northern regions of the country, also reported similar entomological problems. In response to the cries of distress from producers, teams of entomologists from the National Agricultural Research Centre (CNRA) carried out field surveys and identification missions (Malanno et al., 2019). The information gathered on the nature of the damage and the morphology of the larvae collected made it possible to identify the pest *Spodoptera frugiperda* (*S frugiperda*). The control methods used by the producers are essentially chemical and mechanical control. Chemical control is still the most used, but its abusive and uncontrolled use can be harmful to the environment and human health. Therefore, the country is experiencing climate change through changing in climate pattern mainly (Brou, 2019; Yao et al., 2021). It is necessary to look to an effective control method that are low cost, affordable to farmers in view to reduce the infestation and yield loss due to this pest and which can preserve human health and the environment. Côte d'Ivoire is a tropical country with a wide variety of plants. Among them, some are proved to have pesticidal effect which are easily to found. Reason why, botanical pesticides can be a good option for an alternative control methods. Also knowing, the current and future distribution under different climatic scenario will help decision making for better integrated pest management.

1.2 State of knowledge

Maize (*Zea mays*) is the third most important cereal in the world after wheat and rice (Adunola et al., 2021; Nafziger, 2011) . It constitute 38% of the food supply in America, 30% in Africa and 6,5% in Asia, and thus is major source for food security and economic development (Cairns et al., 2012). In sub-Sahara Africa, maize account for 40% of the cereal production of which 80% is used as food with a consumption up to 450g/ person/ day and provide 30% of the total calorie intake of people (Ekpa et al., 2019). In Cote d'Ivoire, maize is the second cereal crop cultivated after rice (*Oriza sativum*) (Akanvou et al., 2010; N'da et al., 2014). It is the main cereal used in the diet of the rural population due to its nutritional importance and medical purpose. Indeed, it is a natural antioxidant that helps prevent cardiovascular disease, reduce cholesterol and normalized blood pressure. It is also a good source of vitamins and many minerals (Huck, 2019; Rouf Shah et al., 2016). Maize is produced both by large and small-scale farmers (N'da et al., 2014). The world annual production of maize is estimated at 1,148 billion tons for an area of 190 million hectares (PwC, 2021). Despite that production, the maize farming system encounters a wide range of challenges that reduce the crop production and rarely meet the local demands. Some of the challenges include low soil fertility and losses associated to pathogens, weeds, diseases and pests (Khadioli et al., 2014). These losses are increased with global warming (Tonnang et al., 2017).

Global temperature predicted by Intergovernmental Panel on Climate Change (IPCC) will increase between 1.1 and 5.4°C by the year 2100. And it is likely to have a profound impact on many insects (Deutsch et al., 2018). Increased temperatures and droughts can affect by increasing the risk of invasive species, which affect all ecosystems. Hence, West Africa would be more vulnerable to climate change because additional warming will affect agricultural production by leading new invasive pests and increase their abundance and distribution (Deutsch et al., 2018). This is the case of *Spodoptera frugiperda* (J.E. smith) (Lepidoptera: Noctuidae), whose caterpillars are called fall armyworms (Fan et al., 2020). *S. frugiperda* native to America is an invasive polyphagous insect pest with a high migratory and dispersal capabilities(CABI, 2017; FAO, 2018). It does not diapause and can persist throughout the year (FAO and CABI, 2019). This pest causes considerable economic losses in several important crops (Susheela et al., 2021; Tepa-Yotto et al., 2021). A recent updated survey indicated a total of 353 *S. frugiperda* host plants belonging to 76 plant families, mainly

Poaceae (106), Asteraceae (31) and Fabaceae (31) (Montezano et al., 2018). However, maize is the most preferred host plant. *S. frugiperda* is composed of two morphologically identical strains that are defined by their host plant preferences. The two strain found in America are also present in Africa (Baudron et al., 2019). This polyphagous pest was detected in Africa with first report from West Africa including Benin, Nigeria, Ghana and Togo in 2016 (Goergen et al., 2016) and later July 2017 in Côte d'Ivoire (Malanno et al., 2019). Early September 2018, the whole Africa had more or less been invaded except Lesotho (Tepa-Yotto et al., 2021). Since its introduction, the potential economic impacts of *S. frugiperda* on agricultural productivity across Africa are substantial (Prasanna et al., 2018). A study conducted by predicted an overall reduction of about 10% in maize production by 2055 in Sub Saharan Africa, equivalent to losses up to $ 2 billion per year, due to climate change. Based on a note published by (FAO and CIMMYT, 2018), this pest threatens food security of more than 300 million people in Africa and can cause annual economic losses, up to 4.8 billion dollars just for the production of maize. In West Africa, this pest has significantly affected livelihoods of small-scale farmers. In view to reduce the losses Africa farmers relies on synthetic insecticides and cultural methods (Matova et al., 2020).

Synthetic insecticides used by farmers and producers to control *S. frugiperda* can cause many problems such as insect resistance, pesticide residues, destruction of non-target species, pollution of environment and human poisoning (Ahissou et al., 2021; Caniço et al., 2021; Khatri et al., 2020; Prasanna et al., 2018). It is necessary to look for an control methods that control without harming human health and the environment (Sisay et al., 2018). The use of botanical insecticides as alternatives to synthetic insecticides would have many advantages. Their low remanance makes them products with low ecological repercussion because they are biodegradable with a very short period of deficiency. They have more than one active ingredients, which work synergistically, making them difficult to develop resistance. Also most cases, they are readily available, cheap and easy to prepare (Ahissou et al., 2021; Prasanna et al., 2018; Siazemo and Simfukwe, 2020; Sisay et al., 2018). Following the introduction of *S.frugiperda* , studies using botanicals such as *Allium sativa*, *Melia azedarach* in Zambia (Siazemo and Simfukwe, 2020); *Nicotiana tabacum*, *Lippia javanica*, *Azadirachta indica* and *cymbopogon citratus* in Malawi (Phambala et al., 2020); *Jatropha curcas*, *Melia abyssinica*, *Phytolacca dodecandra*, *Shinus molle*, *Mellittia ferruginea*, *Azadirachta indica* and *Croton mascrostachyus* in Ethiopia (Sisay et al., 2019) and *Azadirachta indica* in

Democratic Republic of Congo (Vaidya, 2022) have been successful on this pest. These botanicals have shown mortality greater than 75% after 24 hour exposure and among them, *Azadirachta indica* was the widely used. (Ahissou et al., 2021).

In Côte d'Ivoire, the studies carried out on *S. frugiperda* by (Malanno et al., 2019) and (Hauverset et al., 2021) were focused on biology in the laboratory. However, the literature does not mention any study of the use of botanical insecticides as control methods on this pest and the future risk under changing climatic conditions. To overcome this limited knowledge, we propose to control *S. frugiperda* population and damages with botanicals and model its future distribution in Côte d'Ivoire under changing climatic condition. This work represents an important contribution to better-integrated pest management.

1.3 Research hypothesis

It is hypothesized that:

- The efficacy of botanical pesticides will depend on the stage of the *S. frugiperda* life cycle and concentration of the active ingredient.
- The efficacy of botanical pesticides will depend on the maize crop stage.
- Maxent can predict the distribution of *S. frugiperda* in Côte d'Ivoire.

1.4 Objectives

1.4.1 Overall objective

This study aims to reduce the use of synthetic insecticides on *S. frugiperda* on maize and the modelling of its potential future distribution in Côte d'Ivoire.

1.4.2 Specific objectives

It is targeted four specific objectives:

- Assess the biodemographic parameters of *S. frugiperda* in Côte d'Ivoire.
- Determine the population dynamics of *S frugiperda* and its damage on maize during different seasons in Côte d'Ivoire.
- Determine the bioactivity of four botanical plants on *S. frugiperda* in Côte d'Ivoire.
- Identify the current and future suitable habitat of *S. frugiperda* in Côte d'Ivoire.

CHAPTER 2. LITERATURE REVIEW

2.1 Climate change

2.1.1 Definition

Climate change is a long-term alteration in global weather patterns such as increases in temperature, precipitation and wind. It is linked to the consequence of rising level of heat trapping gases, known as greenhouse gases that retain the radiant energy provided to the earth by the sun in a process known as the greenhouse effect (IPCC, 2001; Sodangi and Izge, 2014). The common atmospheric gases are Carbon dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O). Among the greenhouse gases, CO_2 is the most important and abundant in the atmosphere. Its concentration has dramatically increased to 416 ppm, against 280 ppm before industrialization period and is likely to double in 2100 (Skendži´ et al., 2021). Greenhouse gases occur naturally, but anthropogenic activities have added more and more of these gases into the atmosphere (Sodangi and Izge, 2014).

2.1.2 Main drivers of climate change

2.1.2.1 Greenhouse gases

Greenhouse gases are gases that prevent infrared radiation to escape the atmosphere and contribute to the atmospheric temperature rise. According to (Isah, 2013) these gases include:

- **Carbone dioxide (CO_2):** is one of the important greenhouse gases. CO_2 is released into the atmosphere from both natural processes and anthropogenic activities. The natural process are eruptions of volcanoes, respiration of animals and the burning or decay of plants and other organic materials. While the anthropogenic activities are mainly, burning fossil fuels, deforestation, generate electricity and transportation.

- **Methane (CH_4):** is the second greenhouse gas produce through naturally process and human activities. It mainly provides from the digestion of ruminants (cows, goat, so on) and the decomposition of organic matter. CH_4 is less abundant in the atmosphere, but stronger greenhouse gas than CO_2 because it has the ability to absorb more heat.

- **Nitrous oxide (N_2O):** is a powerful greenhouse gas produce in agriculture sector specifically by the production and use of organic fertilizers and agriculture chemicals such as pesticides and herbicides. It also, produced when fossil fuels are burnt. N_20 is 298 times more potent than CO_2 in terms of is potential to intensify global warning.

- **Chorofluorocarbons (CFCs):** are man-made gases produced for industrial use like refrigerants and air conditioners. They are ones of the gases into atmosphere that depleted most ozone layer.

2.1.2.2 Aerosols in the atmosphere

Aerosols are airborne particulate matters that absorb and scatter solar and infrared radiation back into the earth by changing the microphysical and chemical properties of clouds. They are produced both naturally such as the particles and dust produce by volcano eruptions or anthropogenic like burning fossil fuels and farmland. Aerosols affect the transfer of heat energy radiated from earth to space. The effect of aerosols on climate change is still being debated, but scientists believe that light-colored aerosols have cooling effect, while dark aerosols like soot contribute to warming (Isah, 2013).

2.1.2.3 Land use change

Human beings cut down the tree for timber, clear land for farming or building, that have led to change in amount of sunlight reflected from the ground back into space (surface albedo). Deforestation changes evapotranspiration rates (the amount of water vapour put into the atmosphere through evaporation and transpiration from trees) and cause desertification that increase surface albido. The two major sources of land cover changes are clearing forest for agriculture and irrigated farming in arid and semi-arid lands. Irrigated agriculture increase solar absorption and the amount of moisture evaporated into atmosphere, whereas forest clearing decreases these two processes (Desanker, 2002; Isah, 2013; Sodangi and Izge, 2014).

2.1.3 Impact of Climate Change on agriculture

Agriculture is an economic activity that depends on climate to produce food and many other goods necessary to sustain human needs. However is extremely vulnerable to climate change (Isah, 2013). High temperature reduces yield of desirable crops, increase pest proliferation, and weed. Change in precipitation patterns increase the likelihood of long-run production declines and short-run crop failure.

Although there will be gains in some crops in some temperate regions of the world. The overall impact of climate change on agriculture is expected to be negative, as a one-third in the tropics and subtropics are already near their maximum heat tolerance (Nelson et al., 2009).

2.1.4 Impact of Climate Change on agricultural insect pests

Climate change is affected indirectly and directly agricultural insect pests. Indirect impacts are on the relation between pest, their environment and other insect species (natural enemies, competitors, and mutualists). Whereas, directly, climate change affect pest development, reproduction, dispersal and survival. Insects are poikilothermic organisms, which means that, the temperature of the body depends on the temperature of the environment that surround them. Thus, temperature is the most factor affecting insects. Therefore, other drivers could significantly affect insect pests (Anand et al., 2014).

- **Response of insect pest to increased temperature**

Insect physiology and metabolic rate are very sensitive to any change in temperature. An increase in temperature tends to accelerate insect development and movement that can modified population dynamic by influencing survival, fecundity, generation time and geographic range, by the way reduce the natural enemies (Anand et al., 2014) (Figure1) . Temperature also play an important role in insect behaviour because rising temperature should increase herbivory that reduce plant host availability (Skendžić et al., 2021). In addition, temperature affect growth rate of insect. (Deutsch et al., 2018) show that in tropical areas, insect population are expected to experience a decrease in growth rate as a result of climate warning due to the current temperature level, which is already close to the optimum for pest development and growth, while insects in temperate zones are expected to experience an increase in growth rate.

- **Response of insect pest to increased Carbone dioxide (CO_2) concentration**

Elevated concentration of atmospheric CO_2 can affect consumption rates, and performance of herbivorous insects. The effect of increasing CO_2 level on insect pests highly depends on their host plants. A common feature of plants grown under elevated CO_2 is a change in chemical composition of leaves, which could affect the nutrient quality of foliage and palatability to leaf-feeding insects. Some crops often accumulate sugars and starches in their leaves, which reduces palatability by altering the Carbon (C) to Nitrogen (N) ratio.

Nitrogen is the key element in the insect's body for its development. Therefore, increase CO_2 concentration leads to increase plant consumption rate in some pest groups (Figure 2). This can lead to increase level of plant damage, as insect pest must consume more plant tissue to obtain an equivalent level of food (Skendžić et al., 2021).

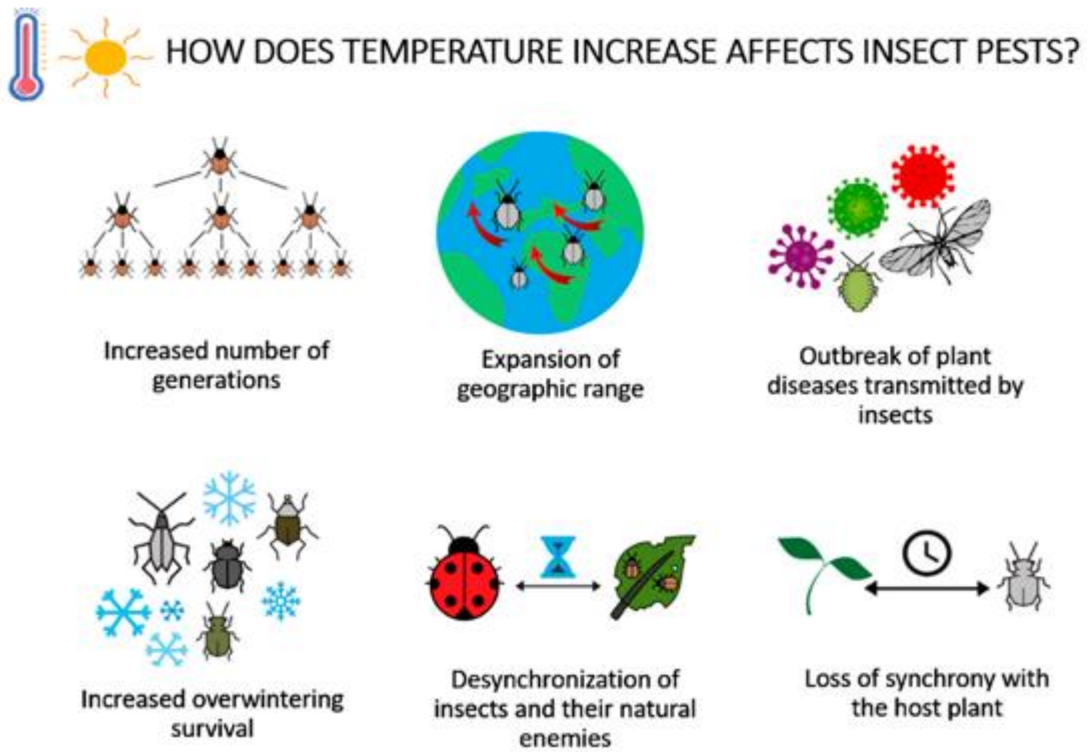

Figure 1: Effect of temperature increase on insect (Skendži´ et al., 2021)

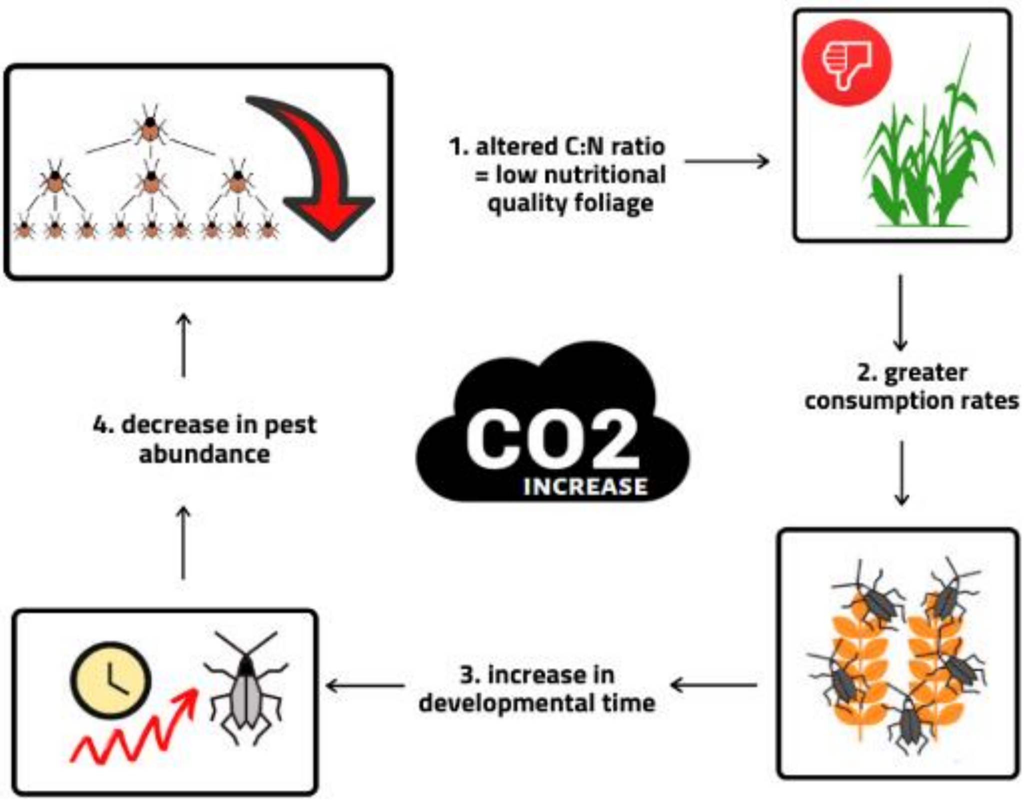

Figure 2:Impact of atmospheric CO_2 increase insect (Skendži´ et al., 2021)

- **Response of insect pest to changeable precipitation pattern**

Change in amount, intensity, and frequency of precipitation are important indicators of climate change. As observed in most event, the frequency of precipitation has decreased while the intensity of precipitation has increased. This type of rainfall pattern has favoured the occurrence of droughts and floods that threat insect survival and their diapause (Figure 3). Flood can wash insect egg away by heavy rains and flooding. Drought affected herbivorous insects through several mechanisms; dry weather may provide suitable environmental conditions for the growth and development of herbivorous insects; drought stressed plants are more attract by insects because of a decrease in the production of secondary metabolites that have a defence function (Skendžić et al., 2021).

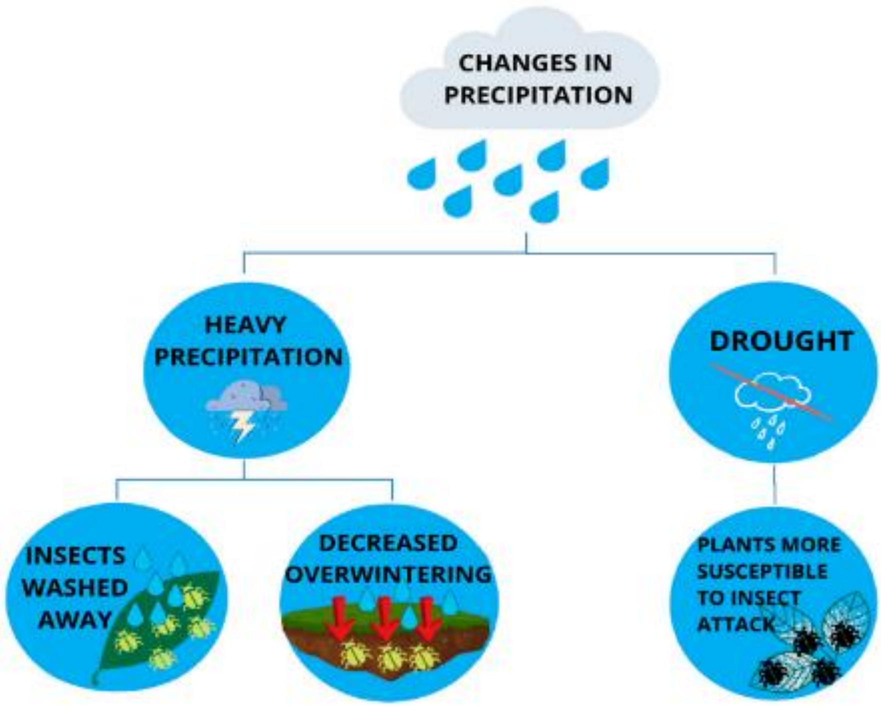

Figure 3: Impact heavy precipitation and drought on insect (Skendži´ et al., 2021)

- **Increase risk of invasive insect species**

Invasive species are defined as a species that are introduced either intentionally (food, livestock, pets) or intentionally due to anthropogenic activities outside their native habitat. They are often agricultural or stored product pests and can often be vectors of various diseases or parasites. The geographic range, population densities and voltinism predicted under the climate change scenario will increase leading potential severe consequences for sustainable agriculture production. Climate with landscape features sets the limits for dispersal and seasonal conditions for the development and survival of the invasive species in the new habitat. These habitat may have been previously unsuitable or have been blocked by geographic barrier such mountain or sea to the invasive species (Skendžić et al., 2021).

2.2 Spodoptera frugiperda

2.2.1 Origin and distribution

Spodoptera frugiperda is a native pest to tropical and subtropical regions of America from United States to Brazil and Argentina (Gichuhi et al., 2020; Prasanna et al., 2018; Tepa-Yotto et al., 2021). Because of the globalization of trade and its dispersal ability, *S. frugiperda* has extended to others continents in recent years(Sun et al., 2021). In Africa, according to (Goergen et al., 2016) it was first detected in January 2016 in western, central and Southern Africa (Nigeria, Benin, Togo and Sao Tome). Subsequently, at the beginning of 2017 and 2018, it quickly spread across the entire Sub-Saharan Africa with 44 countries (Nboyine et al., 2020). In July 2018, it was reported in India (Sharanabasappa, Kalleshwaraswamy, Asokan, et al., 2018). Then, by June 2019 it was reported in China (Sun et al., 2021) .

2.2.2 Systematic position

Domain : Eucaryota

Kingdom : Animalia

Phylum : Arthropo

Subphylum : Uniramia

Class : Insecta

Oder : Lepidoptera

Family : Noctuidae

Genre : *Spodoptera*

Specie : *Spodoptera frugiperda*

2.2.3 Description and biology

Female lay eggs masses, generally on the underside of the leaf. In few cases, particularly on the young crops, eggs can be laid on the stem. Eggs are usually covered with a protective, felt-like layer of scales (setae) rubbed off from the female abdomen. A white inverted ‘Y’ characterizes the mature larvae, which has four large spots that form a square on the upper surface of the last segment of its body (Figure 4) (CABI, 2017; FAO, 2018; Haranabasappa et al., 2018; Tendeng et al., 2019). Although pupation may occur in plant tissues such leaf bases or ears, final larvae usually move the soil where they normally pupate at the depth 2 to 8 cm. The larvae construct a loose oval cocoon by tying together particles of soil with silk or web together leaf debris and other material if the soil is too hard on the soil surface. The pupae is reddish brown in color. (FAO, 2018; Haranabasappa et al., 2018). The adult moths have a wingspan of 32 to 40 mm. In the male moth, the forewings is generally shaded gray and brown with triangular white spots at the tip and near the centre of the wing (Figure 4). Differently, the forewings of female are less distinctly marked with a uniform grayish brown colour, sometime mixed of fine motting gray and brown. In both sexes, the hind wing is iridescent silver-white with a narrow dark border (CABI, 2017; Haranabasappa et al., 2018; Prasanna et al., 2018; Tendeng et al., 2019).

Figure 4: Adult moth of *S. frugiperda* and Fifth instar larva of *Spodoptera frugiperda* with morphological characteristics (Goergen et al., 2016)

2.2.4 Host plants

The host plants of *S. frugiperda* are very wide. Recent surveys conducted by (Montezano et al., 2018) indicated a total of 353 host plant records belonging to 76 plant families, chiefly Poaceae (106), Asteracae (31) and Fabaceae (31). The most frequently consumed plants are maize, sweet maize, sorghum, Bermuda grass and grass weeds such as crabgrass. When the larvae are very numerous, they defoliate the preferred plants, acquire they typical 'armyworm' habit, and disperse in large numbers, consuming nearly all vegetative in their path. Field crops are frequently injured, including alfalfa, barley, Bermuda grass, buckwheat, cotton, clover, maize, oat, millet, peanut, rice, ryegrass, sorghum, sugar beet, sudan grass, soybean, sugarcane, timothy, tobacco and wheat. Among vegetables crops, only sweet maize is regularly damaged, but others are attacked occasionally. Other crop sometimes injured are apple, grape, orange, papaya, peach, strawberry, and a number of flowers. Weeds know to serve as host include bent grass, Johsongrass and sandspur (Prasanna et al., 2018).

2.2.5 Haplotypes

S. frugiperda consist of strains adapted to different host plants. One strain (the 'maize strain') feeds predominantly on maize, cotton and sorghum while the second (the 'rice strain') feeds primarily on rice and pasture grasses.

The two strains are morphologically identical but differ in pheromone compositions, mating behaviour, and host range, mating between the two strain result in viable offspring (Dassou et al., 2021; Prasanna et al., 2018)**.**

2.2.6 Damages

S. frugiperda can affect the crop at different stages of growth, from early vegetative to physiological maturity. When the plants are young and the leaf tissues are soft, first-instar larvae produce pinhole-type damage call 'window panes'. As the leaf tissues mature and become more fibrous and tough, window panes may be scattered and elongated rather than clustered. The width of the window panes reflects the width of the larva head capsule. Whorl-feeding damage results from damaged-leaves expanding out of the whorl, producing a horizontal series of holes across a 'pinch' in the leaf. Later larval instar chews larger holes, causing ragged whorl leaves, and produce sawdust-like larval droppings. Larvae move to the ear zone and start feeding after tassel emergence because they get exposed to natural enemies (Dassou et al., 2021; Domaine et al., 2019; Prasanna et al., 2018).

2.2.7 Management methods

2.2.7.1 Monitoring

Monitoring denote an effort to actively track the presence, population and movement of *S. frugiperda* within a specified geographic (Prasanna et al., 2018). It can be monitoring using different techniques such as regular field scouting, light traps and pheromone traps (Gebreziher, 2020). Scouting allows to rapidly and systematically determining overall crop health and estimating presence of *S. frugiperda* causing damage and potentially yield reduction. The scouting should begin at the early stage, during the first days after planting for looking at the presence/ absence egg masses, larvae and damage (Gebreziher, 2020; Prasanna et al., 2018). In addition, Pheromone traps can be erected near field to trap *Spodoptera frugiperda* adult male moths. A pheromone trap is a type of insect trap that uses pheromones to attract male insects. Hence, it will reduce the malting also the population (Prasanna et al., 2018).

2.2.7.2 Cultural methods

Cultural methods involve the application of appropriate agronomic practices. The use of high quality seeds and germination viability that are free of insect pests and diseases before planting is recommended. No tillage and burning crop residues as commonly practiced but retaining crop residues, that can encourage the development of beneficial insects. Apply fertilizer to have healthy crop that stand *S. frugiperda* attacked. Planting maize crop with other crops is recommended as it can increase the population of natural enemies like predators and parasitoids (Dassou et al., 2021; FAO and CABI, 2019). Besides, handpicking, destroying egg masses and larvae or putting sand mixed with lime or ash in the whorl of attacked maize to kill the larvae. These are some of cultural methods that can reduce the infestation (Assefa and Ayalew, 2019; Gebreziher, 2020)

2.2.7.3 Push-pull methods

Push-pull technology involves intercropping crops with a repellent plant (push plant), such as desmodium (Leguminacae) that repels *S. frugiperda* and an attractive plant (pull plant) such as Napier grass (Poacae) as a border crop around field. The push plant release volatile chemicals that have repellent characteristics to the female moths, while, chemicals release by pull plant are more attractive than maize to adult moths which facilitate its concentration in the pull plant (Assefa and Ayalew, 2019; Gebreziher, 2020; Prasanna et al., 2018). Push-pull technology is proven to be climate-smart, farmers friendly and affordable control methods (Gebreziher, 2020). A research conducted in Uganda has shown the effectiveness of push-pull technology with 36% infestation symptoms compared to 95% infestation by *S. frugiperda* in monocrop maize (Hailu et al., 2018) **.**

2.2.7.4 Biological control using agents

Biological control using agents is defined as the action of living organisms (parasites, predators, or pathogens) introduced by human intervention for regulating the population of another organism at densities less than those would occur in their absence (Prasanna et al., 2018). Thus, it can be a powerful tool and one of the most environmentally safe and sustainable plant protection (Assefa and Ayalew, 2019; Gebreziher, 2020). The biological control agents are parasitoids, predators and entomopathogens. Parasitoids are biological agents for which at least one of their life stages is intimately associated with specific life stages of the pest and with greater levels of specificity. The larvae of parasitoids always kill their host as the outcome of their development. Parasitoids species belonging to *Trichogramma* and *Telemonus*, both, parasitizing egg of insects have been widely use for the control of *S. frugiperda*. On the other hand, predators are never intimately associated with insect pests, and the pest serves as prey for the predator often with less specificity(Prasanna et al., 2018). Insects such as *Doru luteips*, *Lapidura riparia* and *Calosoma granulatum* have been reported the most important predators of *S. frugiperda* (Assefa and Ayalew, 2019; Gebreziher, 2020). Entomopathogens include bacteria, fungi, protozoans, nematodes, or viruses that infects and causes disease in insects. For instance, fungi such as *Metarhizium anisopliae* and *Beauveria bassiana*, viruses such as *Spodoptera frugiperda nucleopolyhedrovirus* (*SfMNPV*); bacteria such as *Bacillus thuringiensis* (*Bt*); nematodes specially *Heterorhabditis bacteriophora* cause significant mortality in *S. frugiperda*. (Hauverset et al., 2021; Prasanna et al., 2018; Tendeng et al., 2019).

2.2.7.5 Botanicals pesticides

Plant derived pesticides are commonly referred as botanicals pesticides (Prasanna et al., 2018). The use of botanical pesticides is recommended as a substitute to hazardous synthetic insecticides, such as pyretroids and organophosphate. The botanical pesticides are biodegradable, environment safe, less harmful to farmers and consumers, and often safe to natural enemies (CABI, 2017; FAO and CABI, 2019; Prasanna et al., 2018). A large diversity of plant is known to have insecticidal properties. Among many other botanicals, extract of plants such as *Azadirachta indica*, *Tephosia vogelii*, *Ricinus comminus* and *Piper hispidinervum* have been successfully use for control of *S. frugiperda.* indeed a study conducted by (Phambala et al., 2020) in Malawi have shown highest mortality with *Nicotiana tabacum* and *lippia javanica.*

2.2.7.6 Transgene-based resistance

Genetically modified (GM) crop varieties that express lepidopterian resistance is another strategy to effectively control *S. frugiperda* damage in maize. The first GM *Spodoptera frugiperda*-resistance maize varieties were developed using insecticide crystal protein genes (*cry*) isolated from *Bacillus Thuringiensis* (*Bt*). These traits are the same as those used by the conventional organic pesticide industry. The ingestion of the Cry protein is lethal to larvae of many lepidopteran species, including *S. frugiperda*. In addition, *Bacillus Thuringiensis* (*Bt*) produce another class of lepidopteran-specific proteins termed Vegetative Insecticidal Proteins (*VIP*). These *VIPs* are encoded by *vip genes*, the most notable of which is the *vip3A gene* used to confer *S. frugiperda* resistance. Numerous GM maize hybrids, including various combinations of *cry* and *vip genes*, are commercially available in Brazil and North America, where over 80% of the total maize production area is cultivated with *Bt* maize. In Africa, *Bt* maize is currently commercial available only in South Africa, where regulatory authorities overseen multiple approvals (FAO and CABI, 2019; Prasanna et al., 2018).

Africa-adapted maize inbred lines and commercial hydrides are currently being evaluated by CIMMYT against *S. frugiperda* population in Africa, to validate and identify new sources of resistance in African context. Conventional maize breeding for host resistance to *S. frugiperda* has also been initiated by the International Institute of Tropical Agriculture (IITA) in West Africa (Prasanna et al., 2018).

2.2.7.7 Chemical pesticides

Insecticides should be used indoors only as a last resort as they pose negative impact on the environment, human health and natural enemies. Control of *S. frugiperda* is usually achieved through the application of synthetic insecticides, however, it involve high cost, potential environmental contamination and development of resistance to chemicals, and often pest resurgence. Synthetics insecticides can be use at different stage. For instance Emamectin benzoate, Chrorantraniliprole can be applied at early larval stage while, chorantraniliprole as seed treatments.

2.2.7.8 Integrated management

The goal of the integrated management is to economically suppress pest populations using techniques that minimize harm to environment and humans (Prasanna et al., 2018). Thus, an effective integrated management strategy to control *S. frugiperda* will employ a variety of integrated approach including host plant resistance (native and transgenic), biological control, cultural control and safer pesticides to protect the crop from economic injury while minimizing negative impacts on people, animals and the environment.

Host plant resistance will be reinforced by biocontrol options as they are developed as well as cultural controls within the African context. As in all IPM programs, decisions on pesticide use will focus on the economic trigger elicited when these basic control options fail to limit the pest's damage and the economically viable interventions that pose the lowest risk to human and environmental health (FAO and CIMMYT, 2018; FAO and CABI, 2019)

2.3 Zea Mays

2.3.1 Origin and distribution

The origin of maize is central America, more precisely Mexico. The widespread distribution of maize, it is an indication of its great adaptability, which makes it one of the most popular crops in the world. The domestication of maize began 7000- 10,000 years ago. In 16 th century it was introduced into Asia from and later in Europa (Nafziger, 2011). Maize has been introduced in Africa more than 500 years ago possibly through the island of Sao Tomé, from where it spread to the West Africa coast, and by Arab traders crossing the Sahara. During its domestication, every region in which it has been cultivated over the centuries has produced a selection of maize cultivars (Babu-Apraku and Fakorede, 2017) **.** In Cote d'Ivoire, the most important cultivated areas are in the North and North-West (Tripathi et al., 2011).

2.3.2 Systematic position

Maize is a monocious plant belonging to the genus *Zea*, which is a representative of the tribe Myadae (Babu-Apraku and Fakorede, 2017; Nafziger, 2011). The systematic position of maize is as follow (Rouf Shah et al., 2016).

Kingdom	: Plantae
Subkingdom	: Tracheobionta
Superdivision	: Spermatophyta
Division	: Magnoliophyta
Class	: Liliopsida
Subclass	: Commelinidae
Order	: Cyperales
Family	: Poaceae
Subfamily	: Panicoideae
Tribe	: Andropogoneae
Genus	: *Zea*
Species	: *Zea mays*

2.3.3 Botanical description

Maize (*Zea mays*, Linne 1753) is a diploid (2n = 20) annual herbaceous plant, varying in height from 1 to 4 m. It produces large size (up to 10 cm wide and 1 m long), narrow and opposite leaves at the level of each node along the length of a solid stem. Depending on the variety, each plant carries between 15 and 20 leaves. The stem generally attains a thickness of three to four centimetres. The inter nodes, short and fairly thick at the base of the plant become longer and thicker higher up the stem and then taper.

The root system is fasciculated. It develops at the base of the stalk and form a network of roots of equal size. They allow the mechanical anchoring of the plant in the superficial layers of the ground. Maize is a monoecious plant; male and female flowers are born by the same plant but placed in different places. The male inflorescence, panicle (tassel) consists of a spikelet each grouping two flowers with three stamens. Ramified, it is located at the end of the stem. The female inflorescence, ear (cob) develops laterally from an axillary bud, inserted at the base of a leaf located in the middle of the plant. It has 12 to 20 rows of femal flowers topped by long styles, the silks. It surrounded by modified leaves, the spathes, which are dried out at maturity. The individual maize grain is a caryopsis. The seed contains a germ which includes the plumule and radical from which a new plant will develop and an endosperm which provide nutients for that germinating seedling until the seedling establishes sufficient leaf area to become autotroph (Babu-Apraku and Fakorede, 2017; Tripathi et al., 2011).

2.3.4 Growth and development

All maize varieties follow same general pattern of development. Maize growth are divided into two broad categories, defined by the formation of one or more essential organs (Figure 5) (Babu-Apraku and Fakorede, 2017).

Vegetative phase: the germination of the seed mobilizes the reserves contained in the albumen. The coleoptile pierces the ground and releases the first leaves. During this stage, the stem and leaves develop so that the young plant gradually becomes autotrophic. At the same time, the tracer roots develop in the surface layers of the soil take up water and nutrients needed for the growth (Tripathi et al., 2011).

Reproductive phase: is correspond to the formation and development of the reproductive organs. Maize is protandrous; the male and female organs do not mature at the same time. At the end of the vegetative stage, the panicle begins to develop and the anthere (male organ) mature 2 to 4 days before the silks (female organ) of the cob become receptive to pollen. The role of the silks is to capture the pollen grain emitted by the panicles so that the pollen can fertilize the ovules. The first silks to emerge correspond to the grains at the base of the spike.

Physiological maturation**:** The progression of the silks exit is then made from bottom to top until the end of the ear. The complete emergence takes place in 4 to 6 days. From this moment, and under good conditions, the complete fertilization of the ear is possible(Tripathi et al., 2011).

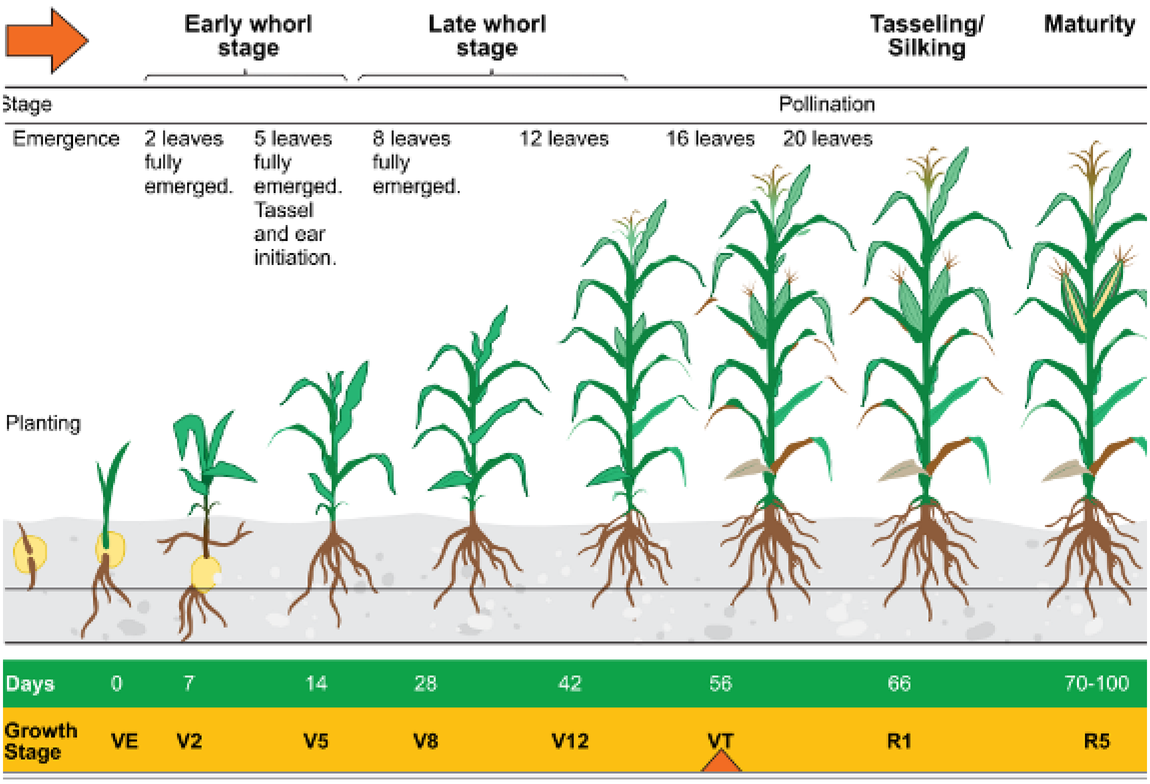

Figure 5: Maize growth stages (Prasanna et al., 2018)

2.3.5 Production of maize

2.3.5.1 Global production of maize

Maize or corn (*Zea mays* L.) is the mostly produced food worldwide, in term of consumption. More than 1 billion tons were produced worldwide, in 2021, the highest amount (51.6%) was produced in the Americas, followed by Asia and Europe, while Africa's harvest represented only 6.7% of the world production (Galani et al., 2022).

The maize production dynamics over the last quarter century build on earlier trends. Since 1961, the global maize area under maize production nearly doubled, up from 106 million hectares to the current 197 million hectares (+ 87%), with an acceleration of area expansion since the early 2000s ((Erenstein et al., 2022; PwC, 2021). Maize cultivation spans both emerging economies and the developed world, including 165 countries distributed across the Americas, Asia, Europe and Africa (Erenstein et al., 2022). The global maize area is primarily located in the Americas and Asia, with over a third each, followed by Africa with a fifth and Europe with a tenth (Figure 6 and Figure 7).

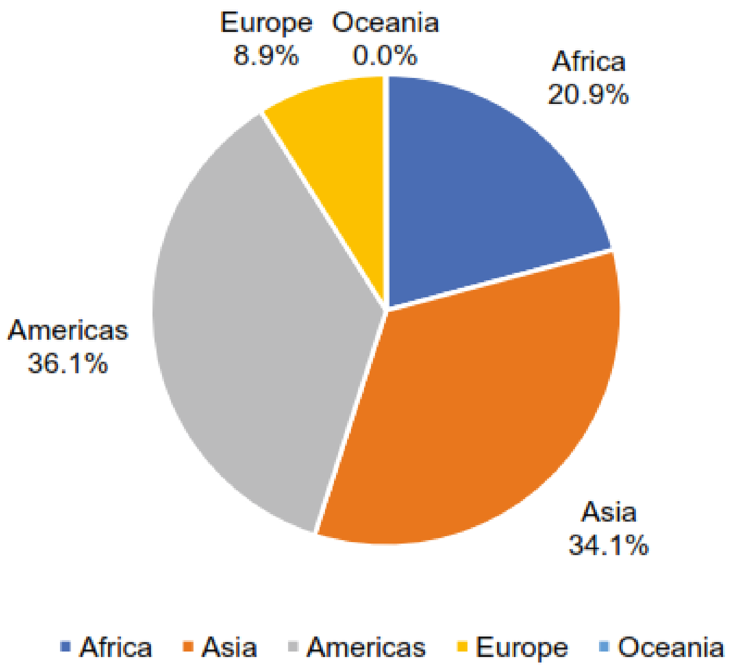

Figure 6: Area share of maize by country in 2021 (Erenstein et al., 2022)

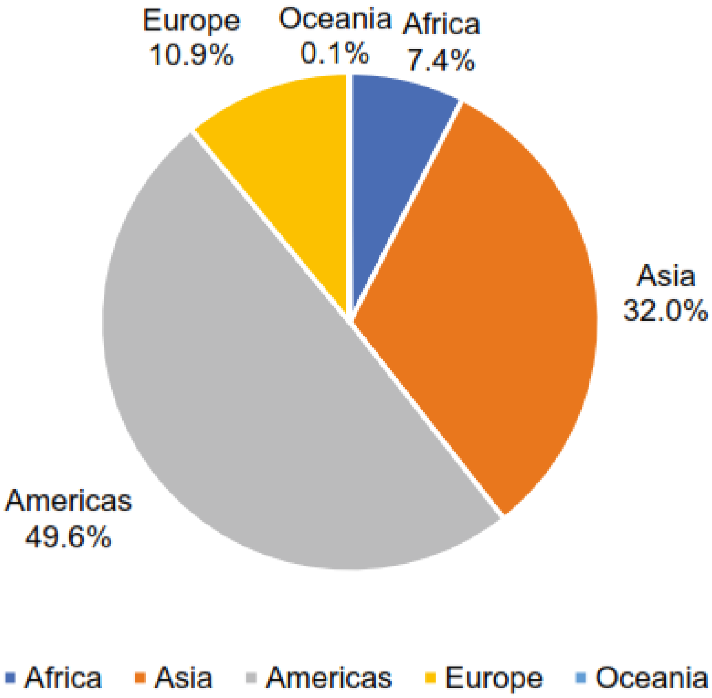

Figure 7: Production share of maize by country in 2021 (Erenstein et al., 2022).

World maize production is dominated by two main varieties, yellow and white. While yellow maize is by far the most popular variety of maize in the global market because of its use for animal feeds and ethanol production, white maize on the other hand is grown predominantly in Sub-Saharan Africa, Latin America and South Asia and is more commonly consumed as food (Ranum et al., 2014). During the period of 2019-2020, 1,140,784 billion tons were harvested from about 190 million hectares (PwC, 2021). Global maize production has surged in the past decades, enabled by a combination of maize yield increases and area expansion. The USA and China dominate maize production, with varying contributions from other geographies. The following figures 8 and 9 showed respectively the evolution of modal maize production from 2011 to 2021 and the world's top 10 maize producers.

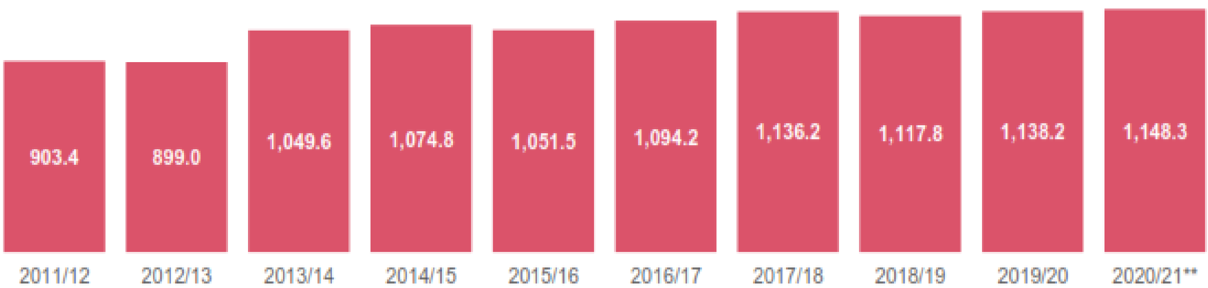

Figure 8 : Global maize production (MMT) from 2011 to 2021 (PwC, 2021)

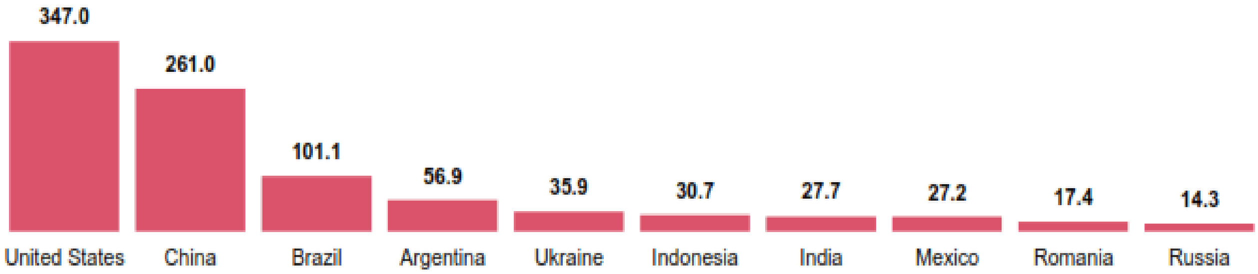

Figure 9: Top ten maize producers globally (MMT) in 2021 (PwC, 2021)

Maize is predominantly used as food, animal feeds and for industrial purposes such as in the production of maize-based ethanol and starch etc. About 60% of maize is used for animal feeds while 12% is used domestically as food. The USA is the biggest corn exporter, followed by Brazil, Argentina, Ukraine and Romania (Figure 10). The following table 1 mentionned maize production indicators according the regions.

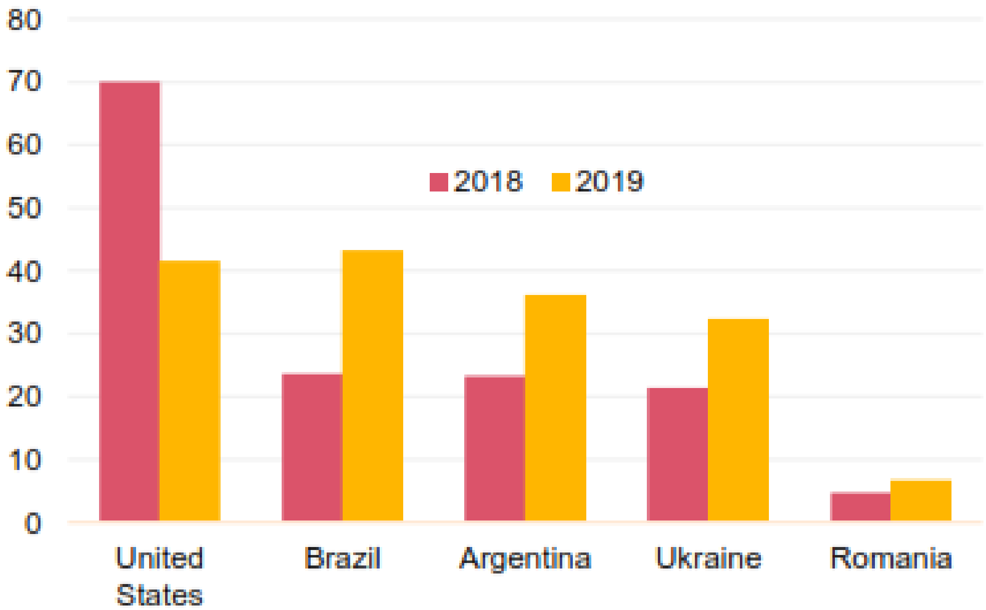

Figure 10: Top maize exporting countries (MMT) (PwC, 2021)

Table 1: Regional maize production indicators (Erenstein et al., 2021)

Region	Average 2017–19 (TE2019)			Average annual growth rate (TE1995-2019)		
	Area (M ha)	Production (M t)	Yield (t/ha)	Area (% pa)	Production (% pa)	Yield (% pa)
Africa	41.2	84.7	2.1	2.0	3.3	1.3
Eastern & Southern	19.3	46.5	2.4	1.4	3.2	1.8
West & Central	20.8	31.0	1.5	2.8	4.1	1.2
Northern	1.1	7.2	6.7	-0.7	1.6	2.2
Asia	67.3	363.6	5.4	2.2	4.0	1.8
South	12.4	41.3	3.3	1.7	4.9	3.1
East Asia	42.5	261.5	6.2	2.8	3.8	1.0
South-East Asia	11.2	51.7	4.6	1.3	4.8	3.4
West & Central	1.2	9.2	7.5	0.4	3.8	3.4
Americas	71.3	564.4	7.9	1.0	3.0	2.0
Northern	34.5	374.6	10.8	0.9	2.6	1.7
Central & South	36.8	189.8	5.2	1.1	4.3	3.1
Europe	17.6	124.0	7.1	1.4	3.2	1.8
Oceania	0.1	0.6	7.3	1.1	2.3	1.2
L/LM-IC [a]	63.0	169.3	2.7	2.2	4.6	2.3
UM/H-IC [b]	134.4	967.9	7.2	1.3	3.2	1.8
World	197.4	1,137.3	5.8	1.6	3.3	1.7

LLM-IC: Low & Lower-Middle-Income Countries

UMH-IC: Upper-Middle-& High-Income Countries

2.3.5.2 Maize production in Africa

The agriculture sector has remained the backbone of Africa's economic development for centuries without having taken on a real structural transformation (Nassirou, 2017). Africans consume maize as a starchy base in a wide variety of porridges, pastes, grits, beer, etc. Maize is consumed by about half of the population of Sub-Saharan African. Generally, Africa Accounts for about 7.4 % of global maize production (Erenstein et al., 2021). Maize is one of the major cereals produced in Africa, covering an average harvested area of 37 million hectares with average production quantity of about 70 million tons per year (Nassirou Ba, 2017). The highest amounts of maize consumed are found in Southern Africa at 85 kg/person/year as compared to 27 in East Africa and 25 in West and Central Africa (Nassirou Ba, 2017). East Africa is the hub of maize farming in the continent with an average annual production of 30 MMT which represent more than a third (37.6%) of Africa's aggregate production. East Africa is followed by West Africa and Southern Africa with average annual production of 19 MMT and 12 MMT respectively South Africa, Nigeria and Ethiopia are the largest maize producing countries in Africa, with a combined production of nearly 32 MMT in 2019, which represents 39% of Africa's maize production in that year (Ranum et al., 2014). The following figures 11 and 12 presented the countries which contributed at maize production in Africa.

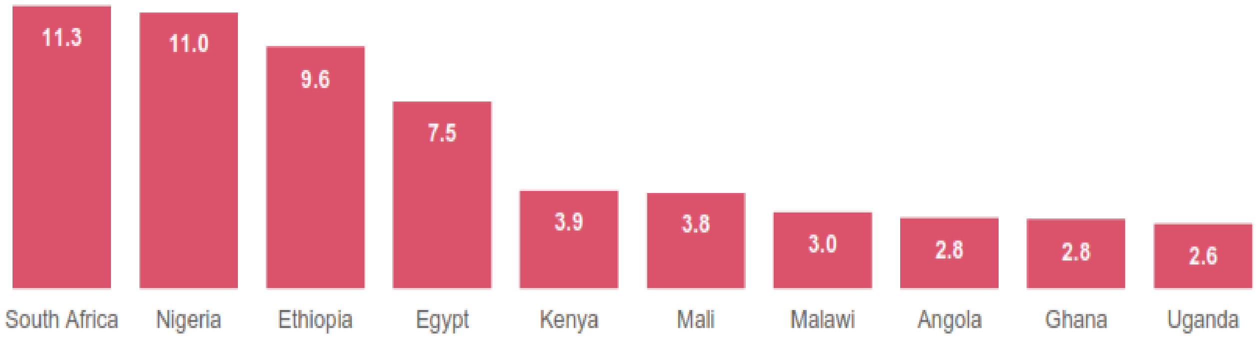

Figure 11: African top producers of maize in 2021 (PwC, 2021)

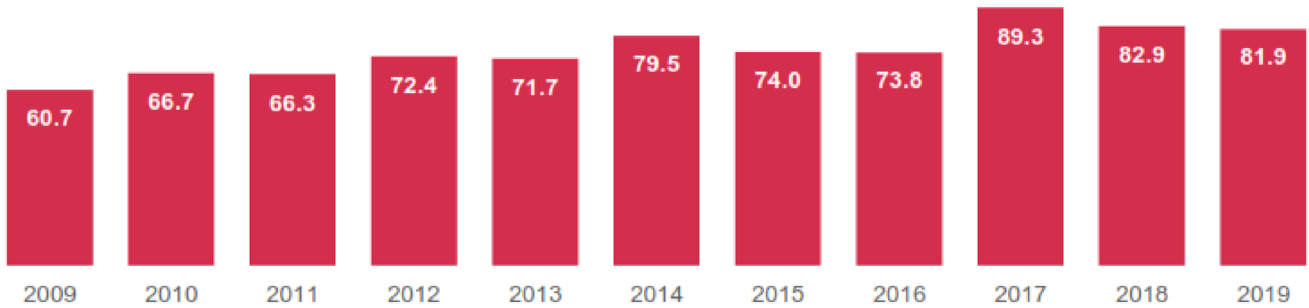

Figure 12: Africa's maize production from 2009 to 2019 (MMT) (PwC, 2021)

2.3.5.3 Maize production in Côte d'Ivoire

The agricultural sector is dominated by small-scale producers (about 1.8 million small farms support 11 million people, or 47% of the population). The farming systems are essentially extensive and rain-fed, using few agricultural inputs (fertilizers and improved seeds) with the exception of cash crops (cotton, oil palm, pineapple) and irrigated rice (Macauley H. et Ramadjita T., 2015). The yields of food crops are low and very vulnerable to climate change.

Maize occupies the second place after rice. Major producing areas are the North, the Centre and the West-Centre. The cereal sector in 2013-2014 in Cote D'Ivoire revealed that maize accounts for 29% of the cereal production and 39% of the area under cereal culture (Nassirou, 2017). The current demand for maize or the industry is 250,000 tons and will increase to 750,000 tons in 2030 (Akanvou et al., 2010). In Côte d'Ivoire, fourten maize varieties, two of which are local and twelve improved, produced by the National Centre of Agronomic Research (CNRA) are regenerated at Anguédédou experimental station. The maize collection consists of short-cycle, intermediate-cycle and long-cycle varieties. The variety of short cycle includes is characterized by a cycle of 54 at 56 days. As for the intermediate-cycle varieties, they are 4 to 5 days later than short-cycle varieties and the long cycle varieties (Table 2).

2.3.6 Maize consumption

Maize is the mostly produced food worldwide, and in term of consumption, the third most important cereal crop of the world after wheat and rice. More than 1 billion tons were produced worldwide in 2021, the highest amount (51.6%) was produced in the Americas, followed by Asia and Europe, while Africa's harvest represented only 6.7% of the world production (Galani et al., 2022).

Maize grain is the third most consumed cereal as human food after rice and wheat (direct pathway, processed or unprocessed). Global human food consumption of maize accounts to 18.5kg/capita/year 11% of the average annual cereal human consumption of 175kg globally.

Maize is consumed in 161 countries, with consumption levels exceeding 50kg/capita/year in 22 countries, primarily in eastern and southern Africa (9 countries) and Latin America. Aggregate maize use has grown markedly faster than per capita maize food consumption, in part reflecting higher population growth in Africa and Asia (Galani et al., 2022). The use of maize by country is shown in the table 3

Table 2: Maize varieties cultivate in Cote d'Ivoire (N'da et al., 2014)

Varieties of maize	Cycle (days)	Potential yiel (t/ha)	Average yield (t/ha)	Particulars characters	Grain characteristics
R 9131-SR	90	3	2		Yellow grain
CEEY-SR	75	1,2	1		Yellow grain
GMRP-18	100	5	2 – 4	Resistance to lodging, rust and streak resistance	Yellow grain, toothed, sweet taste sweet, easy to grind, rich in amino acids
V 8728-SR	105	4	3		Yellow grain
FERKE 7635	100 – 105	3	2		Yellow grain
FERKE 7622	115 – 120	3	2		Yellow grain
QCM.B	105	4	2,5		White grain
CEW-SR	75	1,2	1		White grain
EV99-MRP	90 – 95 (short)	5	2 - 4	Tolerance to dryness	White, semi-toothed rich in protein
V8766-SR-MRP	90 – 95 (short)	5	2 - 4	Tolerance to striation	Yellow, semi-toothed rich in protein
DMRESR-Y	90 – 95 (short)	5	2 - 4	Tolerance to striation	Yellow, toothed cornea
F8128	100 – 120 (long)	7	3 to 5	Tolerance to striation	Yellow, toothed cornea
Acr 97TZL Comp1-W	100 – 120 (long)	7	3 to 5	Tolerance to Striga	White, toothed / cornea
TS (violet de Katiola)	100 – 120 (long)	7	3 to 5		Purple and white toothed

Table 3: Regional maize foods supply(Galani et al., 2022)

Region	Maize and maize-based products in food supply (TE2018)			Maize share in total food supply (%/capita/day, TE2018)		
	Energy supply (kcal/capita/day)	Protein supply (g/capita/day)	Fat supply (g/capita/day)	Energy share (%)	Protein share (%)	Fat share (%)
Africa	398.7	10.2	4.2	15.3	15.0	7.8
Eastern & Southern	556.0	13.9	4.5	24.2	22.6	9.7
West & Central	286.9	7.6	4.0	11.1	12.2	7.3
Northern	318.3	c8.3	4.1	9.9	9.0	6.1
Asia	80.3	1.9	0.6	2.8	2.3	0.8
South	71.0	1.8	0.8	2.8	2.8	1.3
East Asia	64.0	1.2	0.3	2.1	1.3	0.3
South-East Asia	136.0	3.3	1.2	4.8	4.6	1.9
West & Central	104.4	2.4	0.8	3.4	2.8	0.8
Americas	301.3	7.2	2.5	9.1	7.6	2.0
Northern	96.0	1.8	0.3	2.6	1.6	0.2
Central & South	418.7	10.4	3.8	13.0	11.4	3.8
Europe	59.3	1.4	0.2	1.8	1.3	0.2
Oceania	38.3	0.8	0.1	1.2	0.8	0.1
L/LM-IC [a]	180.7	4.6	1.9	7.1	6.9	3.3
UM/H-IC [b]	138.2	3.2	1.0	4.3	3.4	0.9
World	155.7	3.8	1.4	5.3	4.6	1.6

LLM-IC : Low and Lower-Middle Income Countries

UMH-IC : Upper-Middle and High Income Countries

2.3.7 Main fungal and viral diseases

Helminthosporiosis, Rust, Cercosporiose and Curvulariosis are the main fungal diseases encountered on maize (Babu-Apraku and Fakorede, 2017)

Helminthosporiosis: caused by *Helminthosporium maydis* is a disease that attacks the leaves. At the beginning of the attack, it manifests itself with the appearance of large, oily green, fusiform spots. The spots develop in the direction the leaf veins. When the attack is early in favorable climatic conditions for the sensitive varieties, the spots lengthen and lead to the drying leaves. The spores of the fungus are disseminated by the wind. The high humidity of the air favors its expansion.

Rust: caused by the fungi *Puccinia polysora*. it is characterized by yellow spots that appear on both sides of the maize leaves. The spots turn into small brick-red pustules (raised spots) which cover practically all the surface of the leaves. The pustules give way to necrosis. The attacked leaves can dry out in case of strong infection. The fungus responsible for this disease is spread by wind. A high humidity favors the development of the disease.

Cercosporiosis is caused by the fungus *Cercosporazeae maydis*. The first symptoms are small, gray and wet spots surrounded by a thin yellowish layer. These symptoms can be observed on the leaves as well as the leaves sheaths. On the leaf sheaths, the spots are surrounded by a purple or violet layer. The symptoms can be confused with those caused by Helmintosporium. The development of this favored by humid and hot weather. The poor soil drainage contributes to the spread of Cercosporiosis.

Curvulariasis is caused by *Curvularia lunata* or *Curvularia pallescens*. The symptoms are brown and circular spots surrounded by a pale or yellowish layer. The ears and the stems of the maize can be infected. The fungus also occurs in the teguments and embryo of the seed.

The main viral disease of maize is Maize streak is caused by Maize Streak Virus (MSV). This virus is transmitted to maize plant by leafhoppers of the genus Cicadulina. Streaks can be recognized by the presence of fine yellowish or whitish striae along the veins. The striae are arranged parallel to the veins. Early infected plants are stunted and do not produce any ears (FAO, 2020).

2.3.8 Main insect pests

Insect pests are the most damaging to the maize crop. In addition to *S. frugiperda*, several others are found in maize crops and cause damage with yield losses up to 20%. All the different parts of the plant are attacked (Table 4).

2.3.9 Weeds

Maize Striga (*Striga Hermonthica*) is the most weed of cereals and particulary maize. It is an annual grass that can reach 60 cm in height. Its roots system is little developed and the stem is polygonal woody at the base. The leaves are tapered, about 90 mm long and 7 mm wide. The infloresecence is a spike to 5 to 25 cm long. The flowers are pink, light violet or reddish violet of about 3 cm in diameter and attached directly to the inflorescence. The fruit is a capsule of about 6 mm long. Striga propagated by seeds. When germinating maize release a substance that stimulate the germination of Striga. The Striga develops a kind of root called haustorium which attaches itself to the maize root, penetrates it and connects the conducting vessels of the two plants. Thus, Striga plant takes nutrients from the maize plant the necessary nutrients for its development that alters the photosynthetic activity of the maize causing yellowing (FAO, 2020).

Table 4: Some main insect pests of maize (FAO, 2020)

Order	***Species***	**Damages**	**Consequences**
Defoliators			
Coleoptera	*Melolontha Melolontha*	Larvae attack young plant and destroy the root	Caused wilt to the young plants
	Sytophilus zeamays	Larvae develop inside the grains and devour it	The grains become floury
Orthoptera	*Brachypus membraceus*	Larvae and adults cut seedlings at ground level	Caused death of the plants
Lepidoptera	*Agrotis ipsillon*	Larvae feed on base plants by cutting them at the collar	
	Busseola fusca	Larvae penetrate stems and obstruct the hole with excrements	Caused the death when the heat of plant dried up
	Eldana saccharina		
	Sesamia calamitis		
	Mussidia nigrivenella	Larvae penetrate the grains and devours soft part of embryos	At shelling attacked grains appear as double-rooted tooth
Isoptera	*Odontotermes sp*	Adults consumed inside the stems and replaced it by clay soil	Caused the death of the plants
Sucking borers			
Hemiptera	*Rhopalosiphum maidis*	Larvae and adults suck sap of the plants and secret honeydew on which black fugus develops	Led to deformation chlorosis of the plants and thus, reduced photosynthesis

2.3.10 Importance of maize

2.3.10.1 Nutritional importance

Maize kernels can vary in color, depending on environmental, cultural, and genetic parameters; they can be white, yellow, orange, red, or black. Many of these kernel constituents, including starch, protein, and some micronutrients, are required for human health. Maize has become highly integrated into global agriculture, human diet and cultural traditions (Galani et al., 2022). Maize has great nutritional value as it contains 72% starch, 10% protein, 8.5% fibre, 4.8% oil, 3.0% sugar and 1.7% ash. It also contains vitamin C, vitamin E, vitamin K, vitamin B1 (thiamine), vitamin B2 (niacin), vitamin B3 (riboflavin), B(pantothenic acid) B6 (pyridoxine), folic acid, selenium, Potassium is a major nutrient present which has a good significance because an average human diet is deficient in it. In addition, maize contains about 45-50% of oil. That oil contains 14% saturated fatty acids, 30% monosaturated fatty acids and 56% polyunsaturated fatty acids. Moreover, the refined maize oil contains 54-60% linoleic acid, 25-31% oleic acid, 11-13% palmitic acid, 2-3% stearic acid and 1% blinolenic acid. Maize silk have various constituents essential for our diet such as maizenic acid, fixed oils, resin, sugar, mucilage, salt and fibers (Rouf Shah et al., 2016). In South Africa, the highest contribution of maize meals to nutrients in children were 102% for vitamin B6, 90% for magnesium, and 83% for vitamin B1(Galani et al., 2022). The following table presents the nutritional composition of the maize (Table 5).

Table 5: Composition per 100g of edible portion of maize (Rouf Shah et al., 2016)

Carbohydrate	71.88 g
Protein	8.84 g
Fat	4.57 g
Fiber	2.15 g
Ash	2.33 g
Moisture	10.23 g
Phosphorus	348 mg
Sodium	15.9 mg
Sulfurr	114 mg
Riboflavin	0.10 mg
Amino acids	1.78 mg
Minerals	1.5 g
Calcium	10 mg
Iron	2.3 mg
Potassium	286 mg
Thiamine	0.42 mg
Vitamin C	0.12 mg
Magnesium	139 mg
Copper	0.14 mg

2.3.10.2 Pharmaceutic importance

Maize has various health benefits. The B-complex vitamins in maize are good for skin, hair, heart, brain and proper digestion. It also prevents the symptoms of rheumatism because it improves the join motility. The presence of vitamins A, C and K together with beta-carotene and selenium help to improve the functioning of thyroid gland and immune system. Maize silk has many benefits. It used in some countries of the world such as India, China, Spain to treat kidney stones, uninary tract infections, jaunidice and fluid retention. It also has a potential to improve blood pressure, support liver functioning and produce bile. It acts as a good emollient for wound, swelling and ulcer. Decoction of silk, roots and leaves are used for bladder problems, nausea and vomiting. While decoction of cob is used foe stomach complaints. Maize starch is famous in Pharmaceutical industries as diluents (Huck, 2019; Rouf Shah et al., 2016).

2.3.10.3 Economic importance

Maize is very importance because of good source of minerals, vitamins fiber and oil present in maize. This oil is used for cooking and soap making companies. Maize starch is famous in pharmaceutical Industries as diluent and also used in cosmetics. Its seeds used to make alcohol while stem used for paper manufacturing. Small scale farmers are engaged with maize forming because of its highly nutritional values and affordable source of vitamins and minerals for peoples living in rural areas (Rouf Shah et al., 2016).

2.4 Plants with pesticidale effects

2.4.1 *Ricinus communis* (Euphorbiaceae)

Ricinus communis is native to tropical Africa found throughout the world where the climate permits. It grows in many places near villages and in urban areas, at the level of dumps. The castor is an herbaceous plant or aborescence. Its leaves, green or red depending on the variety of the plant, are serrated and palmately lobed. The fruits are tricolored capsules with a pointed tip. This euphorbia is known for its medicinal and therapeutic virtues, which are very interesting due to the pharmacological activities of the phytochemicals present in the plant extracts (flavonoids, alkaloids and tannins)(Dumeignil, 2012). The whole plant seems to be toxic due to the presence of a glycoprotein lectin: ricin. Its insecticidal effects have also been proven on the larvae of some mosquito species such as *Culex pipiens*, *Aedes caspius*, *Culicta longiareolata* and *Anopheles maculipennis* ((Aouinty et al., 2006) Figure 13 A).

2.4.2 *Lippia multiflora* (Verbenaceae)

Savannah tea (*Lippia multiflora*) is a very common plant in Central Africa as well as in Ghana, Nigeria, in the V Baoule area in Cote d'Ivoire. It is a heliophilous plant wildly found in savanna. The plant is presented in the form of a spider plant of 2 to 4 m in height. The leaves of this plant, whorled by 3 or 4, are mainly used as aromatic tea. *Lippia multiflora* is used in traditional medicine in Africa (malaria in Mali; tetra in Congo). This plant is also used for the treatment of viral diseases as well as arterial hypertension. Numerous studies indicate that aqueous extracts or essential oils have phamacological cosmetic and pesticidal virtues (Dumez, 2016) (Figure 13 B) .

2.4.3 *Azadirachta indica* (Meliaceae)

Neem is an evergreen, imperipenous tree (5 to 8 pairs of leaflets with a very uneven base) that can reach a height of 10 m (Gauvin et al., 2003). Native to Southeast Asia, it has been used for thousands of years, especially in India, for its extraordinary insecticidal, medicinal and cosmetic properties. According to (Sanou, 2018) neem is a wonderful 100% natural insecticide, harmless to humans and animals, active against more than 200 insects, mites, nematodes, fungi and bacteria. This plant owes its insecticidal and anti-appetent activity mainly to limonoid compounds (azadirachtin, salanine, nimbine and their analogues) (Sanou, 2018) (Figure 13 C**)**.

2.4.4 Tephosia vogelii (Fabaceae)

Tephrosia vogelii is a 1-4 m high shrub with dense foliage. The leaves are spiral, imparipinnate with 6 to 15 pairs of leaflets and a terminal leaflet. The inflorescence is terminal or axillary, with pseudo-roots 8 to 25 cm long. The flowers are bisexual with a dense, broad, white or purple terminal head. The pods can be up to 15 cm long. The species grows at altitudes of up to 2100 m. Rotenone is the chemical responsible for the pesticidal properties of *Tephosia*. *vogelii*. Indeed, it has a repulsive toxic action on *Callosobruchus maculatus* (Stevenson et al., 2017) (Figure 13 D**)**.

Figure 13 :Biopesticides plants

(**A** :*Ricinus communis* L., **B** : *Lippia multiflora* M. ; **C**: *Azadirachta indica* J. ; **D**: *Tephosia vogelii* H.)

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Study area

The Republic of Côte d'Ivoire is located in West Africa, between 4°30' and 10°30' North Latitude and 2°30' and 8°30' West Longitude. North latitude and 2°30' and 8°30' West longitude. It is bordered to the south by the Gulf of Guinea, to the west by Liberia and Guinea, to the north by Burkina Faso and Mali and to the east by Ghana. It covers an area of 322462 km^2. Its population is estimated at 27.48 million (World Bank, 2008).

The study was carried out in two climatic zones of Côte d'Ivoire: the Sub-Sudanian zone (Ferkéssédougou) and Guinean zone (Alépé) (Figure 14). Côte d'Ivoire, a forest and savannah country, has experienced significant variability in its bioclimatic conditions for over 40 years (Bigot, 2015) Correlatively to this climatic variability, a change in the dynamics of the vegetation cover can be observed.

A difference in annual rainfall amounts across the 1970s was observed by (Brou, 2019) he decades before 1970 (1950-1959 and 1960-1969) were very rainy periods (Figure 15). Côte d'Ivoire is bounded by the 2400 mm isohyet curves (lines passing through points on the Earth where the volume of rainfall is the same during a given period) on the latitude of Tabou and 1400 mm in the Centre at Bouaké and the North-East. Before 1970, only a few stations in the Centre (Dimbokro, Bouaké and Katiola), with an extension to the East, recorded rainfall of less than 1200 mm. However, the other regions, including the mountainous western region, received rainfall between 1400 and 2000 mm. This is in stark contrast to what is observed from the 1970s onwards where most rainfall levels were lower than in the past. Indeed, initially confined to the north-eastern quarter, the area of rainfall below 1200 mm reached during the decades after 1970 (1970-1979 and 1980-1989) the Centre-South (at the latitude of Tiassalé) and the Centre-West (including the stations of Bouaflé, Daloa and Seguela). It is in the north-eastern corner, around Dabakala and Bouna, that the situation is most worrying. In these stations, annual rainfall remains below 1000 mm after 1970. The prevailing atmospheric conditions are therefore increasingly similar to those of dry tropical climates (Brou, 2019) few regions escape this situation of a general decline in annual rainfall. This is the case of the Tabou region, the most watered area of the territory, where annual rainfall remains above 2,400 mm. The decade 1990-1999 is marked by the persistence of the situations observed during the dry period of the 1970s and 1980s. The rainfall pattern remained almost identical. The major change is the shrinking of the zone of rainfall below 1000 mm. This zone is now limited to the North and North-East and to a few stations in the Centre at Bouaké and Dabakala.

The choose of Ferkessedougou as study site in Sub-sudanian zone was due to the fact that, is the main zone of cereal production particularly maize. The National center of agronomic research (CNRA) of Ferkessedougou work with the rural population for whose maize cultivation represent one of their main activities. The study site of Alepe in Guinean zone was chosen because, in the south of the country, it is the one supplying Abidjan, the economic capital in maize used as roasted maize.

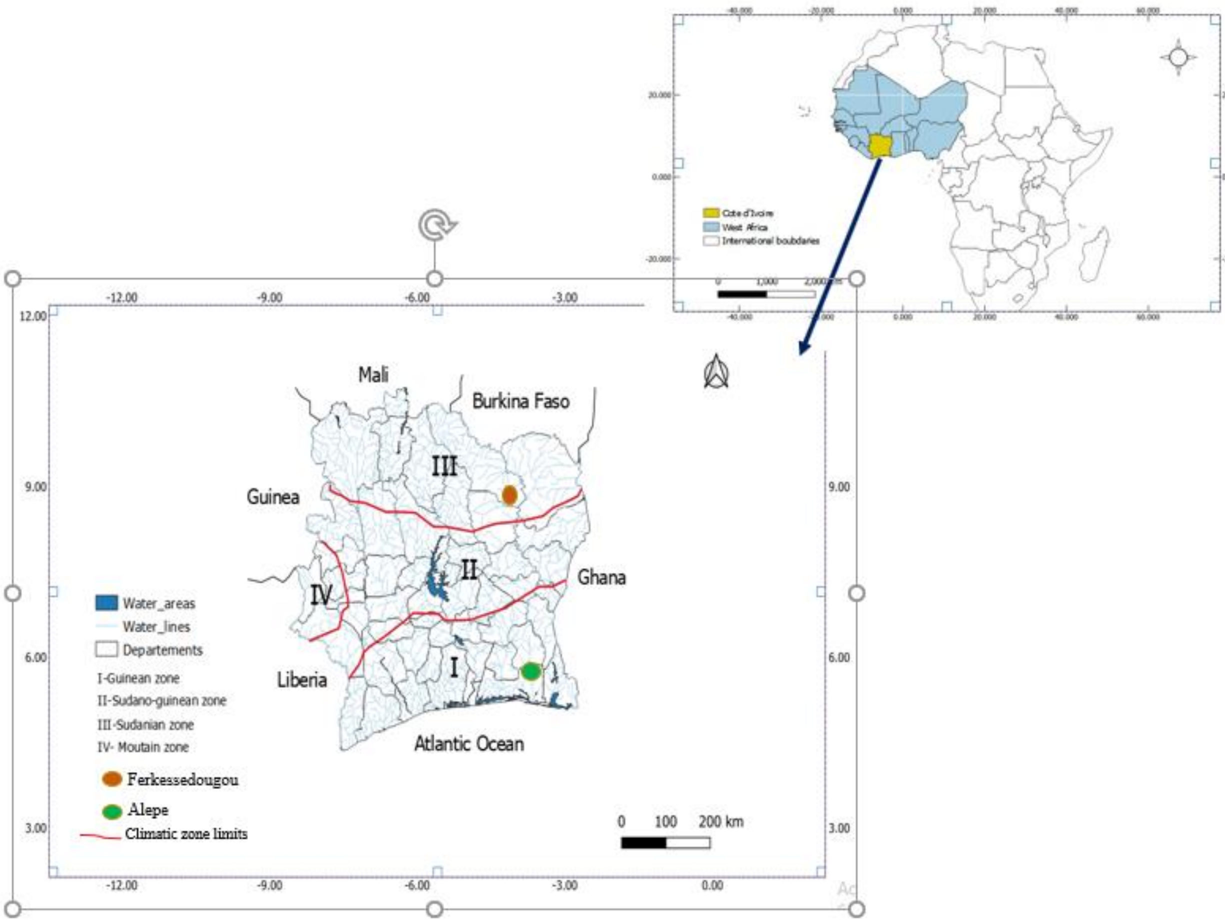

Figure 14: Climatic zones in Cote d'Ivoire

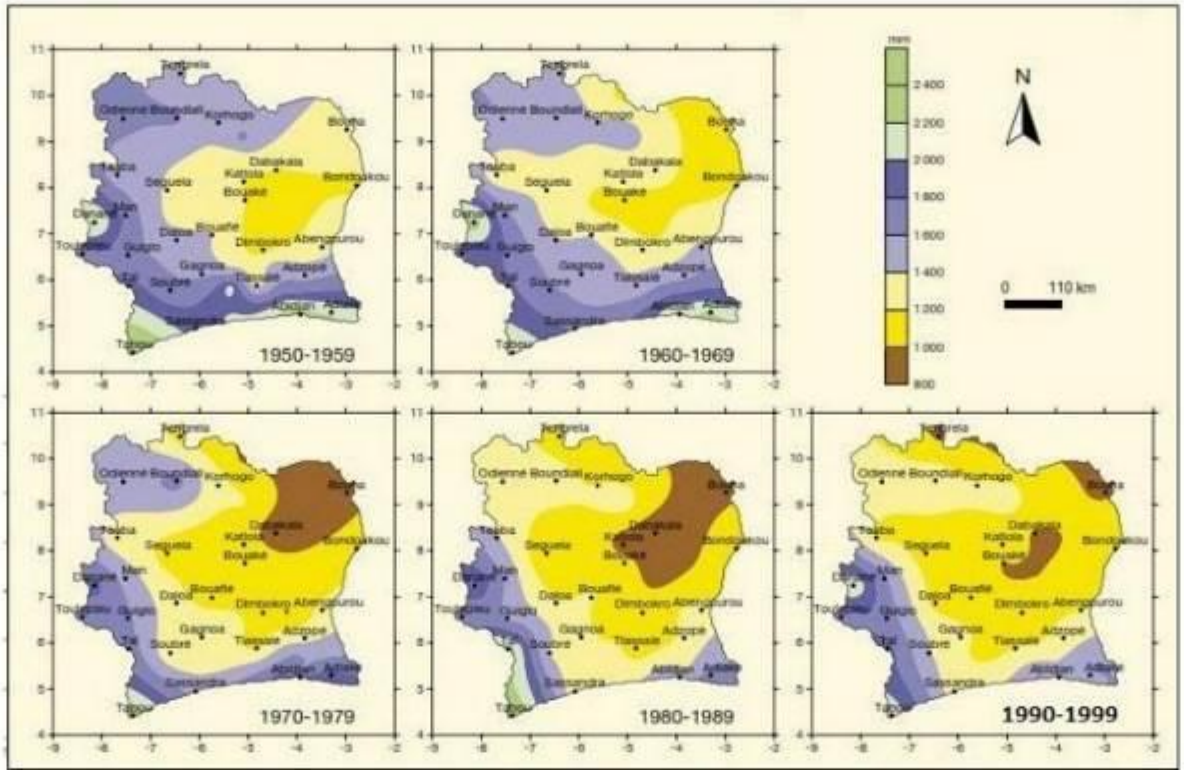

Figure 15: Interannual average rainfall from 1950 to 1999 in Cote d'Ivoire (Brou, 2019)

3.1.1 Characteristics of the sub-sudanian zone (Ferkessedougou)

The department of Ferkessedougou, with a total area of 3220 km^2, is located between latitudes 9°20' and 10°' North and longitudes 4'50' and 5'40 West. It is bordered to the north by Mali, Burkina Faso and Ouangolodougou, to the south by Katiola, to the east by Bouna and to the west by Korhogo (Figure 14).

The vegetation Sub-sudanian with more or less woody savannah and gallery forests. The floristic distribution is linked to climatic (rainfall) and edaphic (soil types) factors. The flora is characterized by the dominance of species from the families of leguminous plants and grasses, the most abundant are Cyperaceae, Rubiaceae and Compositae (Hauverset et al., 2021). Ferkessedougou has a diversity of shallow soils on granite or gneiss, the main units of which are ferralitic, hydromorphic lowland and sandy soils. These ferralitic soils are the most representative with a shallow topsoil (40-60 cm) limited by indurations. The physical properties of these soils, according to are generally poor and present development constraints (shallow indurated soils) (Bigot, 2015).The climate is hot and dry, with the harmattan, a powerful wind from the Sahara, which considerably lowers the temperature in December and January. The long dry season

(October-May) precedes the rainy season marked by two rainfall maxima, one in June and the other in September.

The climate of the Ferkessedougou region is of the sub-humid tropical or sub-Sudanese type (Pene, 1999). It characterized by two main seasons (Soro et al., 2013). a long rainy season, from April to October, with average monthly rainfall ranging from 129.3 to 250.4mm and a long dry season, from November to March, with average rainfall ranging from 1.9 to 82.5 mm. The Average monthly temperature ranges from 25 ◦C in August to 29 ◦C in March (Yao et al., 2021)

3.1.2 Characteristics of Guinean zone (Alepe)

Alepé is located 45 km of Abidjan. It is bordered to the north by the Departement Adzope and Yakasse Attobrou to the east by the department of Aboisso and to the west by Abidjan and Agboville. It covers an area of 2700 km^2 and has geographical coordinates 5°29' and 46°' North and longitudes 3°39' and 49°' West. It is part of the Me region and belongs to the Guinean domain (Figure 14).

The natural vegetation belongs to the *Turraeanthus africanus* and *Heisteria parvifolia* shady sector. But today, the primary forest has practically given way to agricultural exploitation dominated by palm and rubber tree (Hauverset et al., 2021). Derived from tertiary sands, the soil is ferralitic, highly desaturated, deep, loose and lumpy with fine elements. The clay content varies from 10 to 45%. The crumbly, sandy-textured, brown-grey surface layer corresponds to the main root zone. The yellow-ochre sub-soil has a sandy-clay texture. Despite their low mineral content, especially potassium, this soil is excellent support for crops(Hauverset et al., 2021). Like the entire southern region, Alepé has four seasons: a long rainy season (April-July), a short rainy season (October-December), a long dry season (January-March) and a short dry season (August-September) (Ossey, 2017). The annual average temperature is 27±1.4 °C and rainfall of 1500 mm (Ekien et al., 2016).

3.1.3 Climate Parameters in Sub-Sudanian and Guinean Zone

3.1.3.1 Experimental climate conditions in Sub-sudanian zone

- **Rainfall**

Ferkéssédougou is characterized by a Sudanese climate with two seasons: a dry season and a wet season with low rainfall. The dry season extends from November to mid-April. It lasts six months. The rainy season runs from mid-April to October. It also lasts six months and the heaviest rainfall occurs from July to September with a maximum in July. The average monthly rainfall values recorded over the period from January 2020 to December 2021. The recorded rainfall amounts were 965.97 mm in 2020, and 1022.32 mm in 2021 (Figure 16).

- **Temperature and relative humidity**

Annual mean temperatures in Ferkéssédougou ranged from 24.5°C to 30°C for the year 2020 and from 24.4°C to 29.8°C for the year 2021. The umbrothermal diagrams constructed indicate that the warmest months were from December to February due to the presence of harmattan (a dry and hot wind) with a total absence of rainfall. In contrast, July and August were the coolest months for the two study years. The average values of relative humidity (RH) during the study period were between 17.7 and 85.2% for the year 2020 and between 29.5% and 88.2 for the year 2021 (Figure 16 and 17).

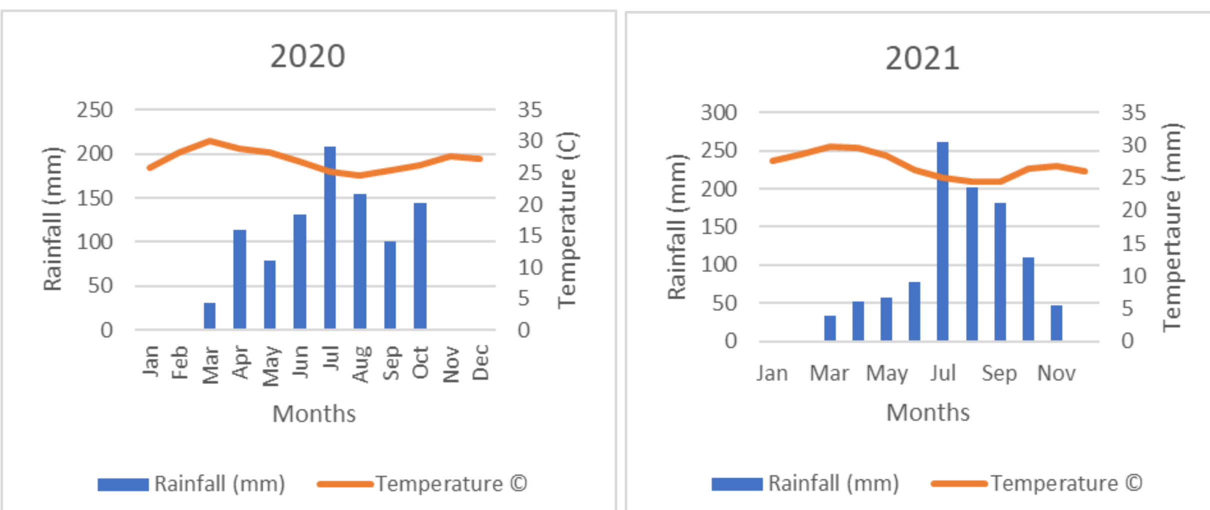

Figure 16: Umbrothermal diagrams of Ferkessedougou in Sub-sudanian zone in 2020 and 2021

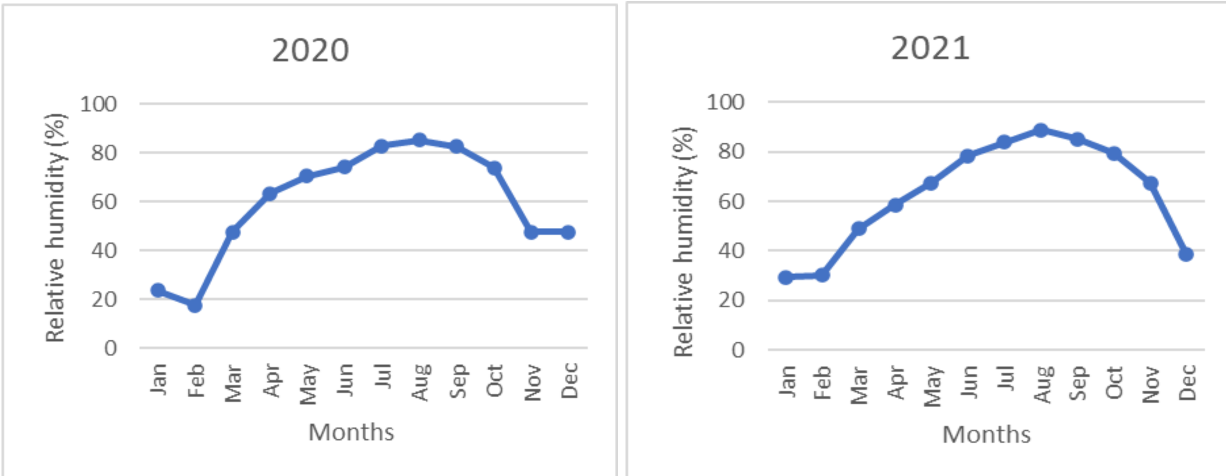

Figure 17: Relative humidity of Ferkessedougou in Sub-sudanian zone in 2020 and 2021

3.1.3.2 Climatic condition in Guinean zone

- **Rainfall**

The climate Guinean zone is characterised by four seasons:
- a long dry season, from December to March;
- a long rainy season, from April to mid-July;
- a short dry season, from mid-July to mid-September;
- a short rainy season, from mid-September to November.

The average monthly rainfall values recorded over the period from January 2020 to December 2021 showed a variation. The recorded rainfall amounts were 1816.1 mm in 2020, and 1537.26 mm in 2021 (Figure 18).

- **Temperature and relative humidity**

The thermal regime in Alepé shows little variation from one month to the next from 2020 to year 2021. Annual mean temperatures ranged from 25.2°C to 29.03°C for the year 2020 and from 25.8°C to 28.9°C for the year 2021. The umbrothermal diagrams constructed indicate that the warmest months were February, March and April. In contrast, August and September were the coolest months for the two study years (Figure 18). The average values of relative humidity (RH) during the study period were between 77.2 and 89.1% for the year 2020 and between 28.7% and 91 for the year 2021 (Figure 19).

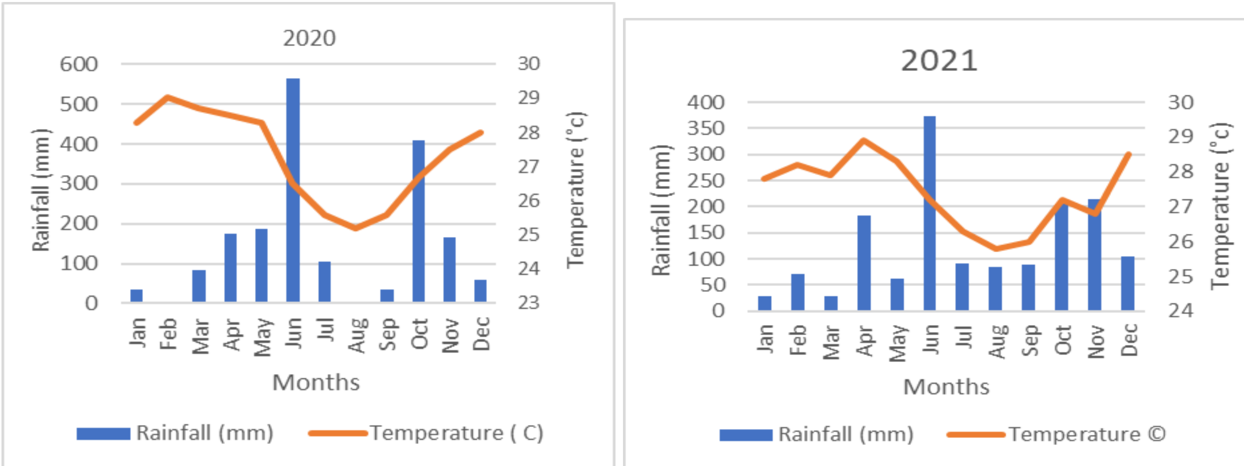

Figure 18: Umbrothermal diagrams of Alepe in Guinean zone in 2020 and 2021

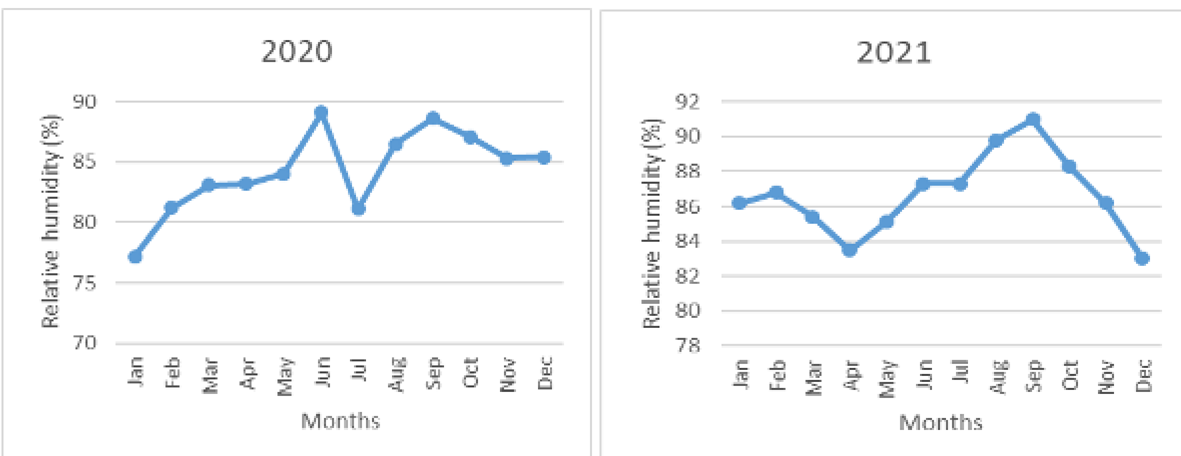

Figure 19: Relative humidity of Alepe in Guinean zone in 2020 and 2021

3.2 Material

It is composed of biological and technical materials.

3.2.1 Biological material

This concerned both plant material and animal material.

The plant material consisted of maize plants *Zea Mays* of the improved variety EV 87/28-SR. The variety used was EV 87/28-SR which was provided by National Centre of Agronomic Research

(CNRA) Cote d'Ivoire. The colour of the grain was yellow and its growth cycle was 105 days and does not have any resistance characteristic. The yield of this variety is 4 tons/ha.

The choice of this maize variety is justified by the fact that it is the best adapted to the climatic conditions of Côte d'Ivoire, it has cycle relatively short with a high yield and its widely use by famers. The four local plants (*Azadirachta indica* leaves, *Lippia multiflora* leaves, *Tephosia vogelii* leaves and *Ricinus communis* leaves) were chosen for the preparation of the aqueous extracts because of their insecticidal effect already tested by many authors and their wide availability in both study areas.

The animal material consisted of eggs, larvae, nymphs and adults of *S. frugiperda* from either laboratory or farms.

3.2.2 Technical material

The technical equipment consists of equipment for setting up and maintaining the experimental plots, capturing, rearing, observing and preserving the insects and preparing the extracts.

- **Equipment for plot setting**

The equipment used for planting and maintaining the plots consisted of dabas, machetes. A double decameter was used to measure the plots and the distance between the stakes.

- **Capture equipment**

The equipment used to collect adult moths consisted of catcher bucket (yellow trap), strip of Dimethyl 2,2-DichloroVinyl Phosphate (DDVP), *S. frugiperda* female sex pheromone prepared by Russell IPM, UK with catch number 72/1936, labelled with the trade name *Spodoptera frugiperda* PH-869-1PR, pillboxes (15 cm high x 25 cm diameter) and entomological forceps (Figure 20).

- **Rearing equipment**

The rearing equipment consisted of entomological forceps to facilitate the handling of the larvae, which tend to make a fairly adhesive silk thread on the maize leaves. Plastic vials (7.5 cm high × 2.5 cm in diameter), pillboxes (15 cm by 25 cm high by diameter) and cotton containers were used to rearing the larvae. The rearing cages (61 × 41 × 50 cm^3 in length, width and height) were used for adult mating. Honey mixed with distilled water was used for feeding the adults (Figure 21).

Figure 20: Capture equipment

A: Yellow catcher trap; **B**: DDVP strip; **C,D**: Sex pheromone

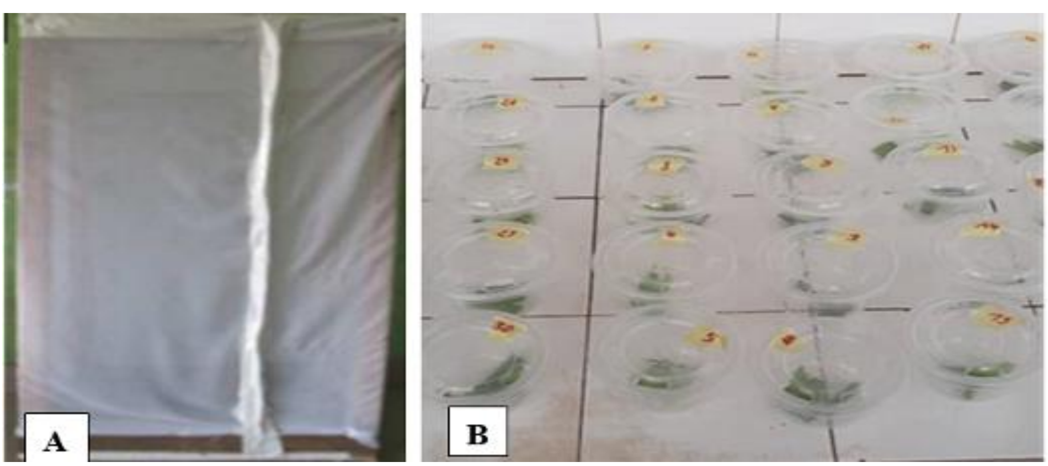

Figure 21: Rearing equipments

(**A**: Rearing cage;   **B**: Pillboxes)

- **Observation equipments**

A digital camera (16.00 Mega Pixels) was used to photograph equipment and damage. An Optika binocular magnifying glass with a Mikrocamlab 7 version 4.0 camera that could be connected to a computer and hand-magnifying glass was used to magnify eggs and larva (Figure 22)**.**

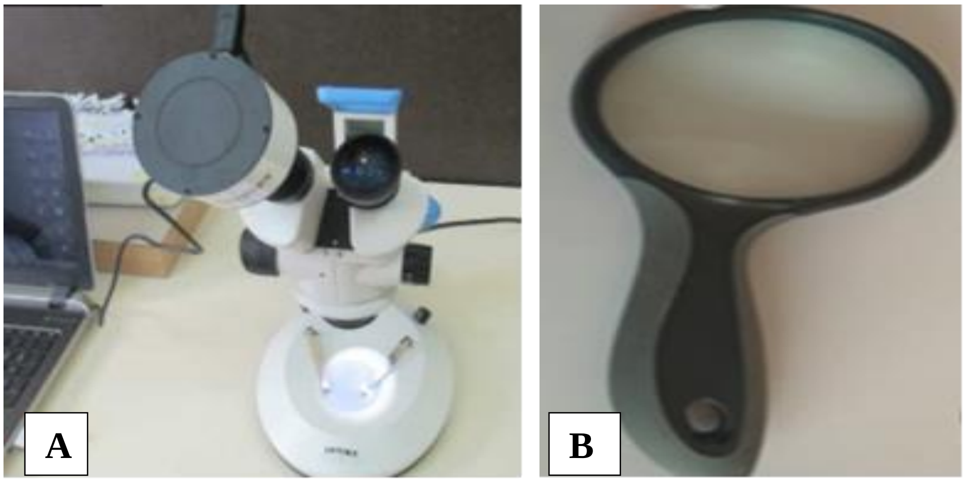

Figure 22: Observation equipments

A: binocular magnifying glass;   **B**: hand-magnifying glass

- **Material for the preparation of aqueous extracts of botanicals**

The equipment consisted of an electronic balance with a precision of 1 gram which was used for weighing the powder of the leaves, a blender which was used to reduce the leaves to powder and also to mix the weighed powder with distilled water. For the different filtrations of the mixture (powder + distilled water), poplin, whatman paper, cotton wool and a funnel were used. Melam plates were used to collect the filtrate obtained after filtration. An oven was used to evaporate the filtrat (Figure 23).

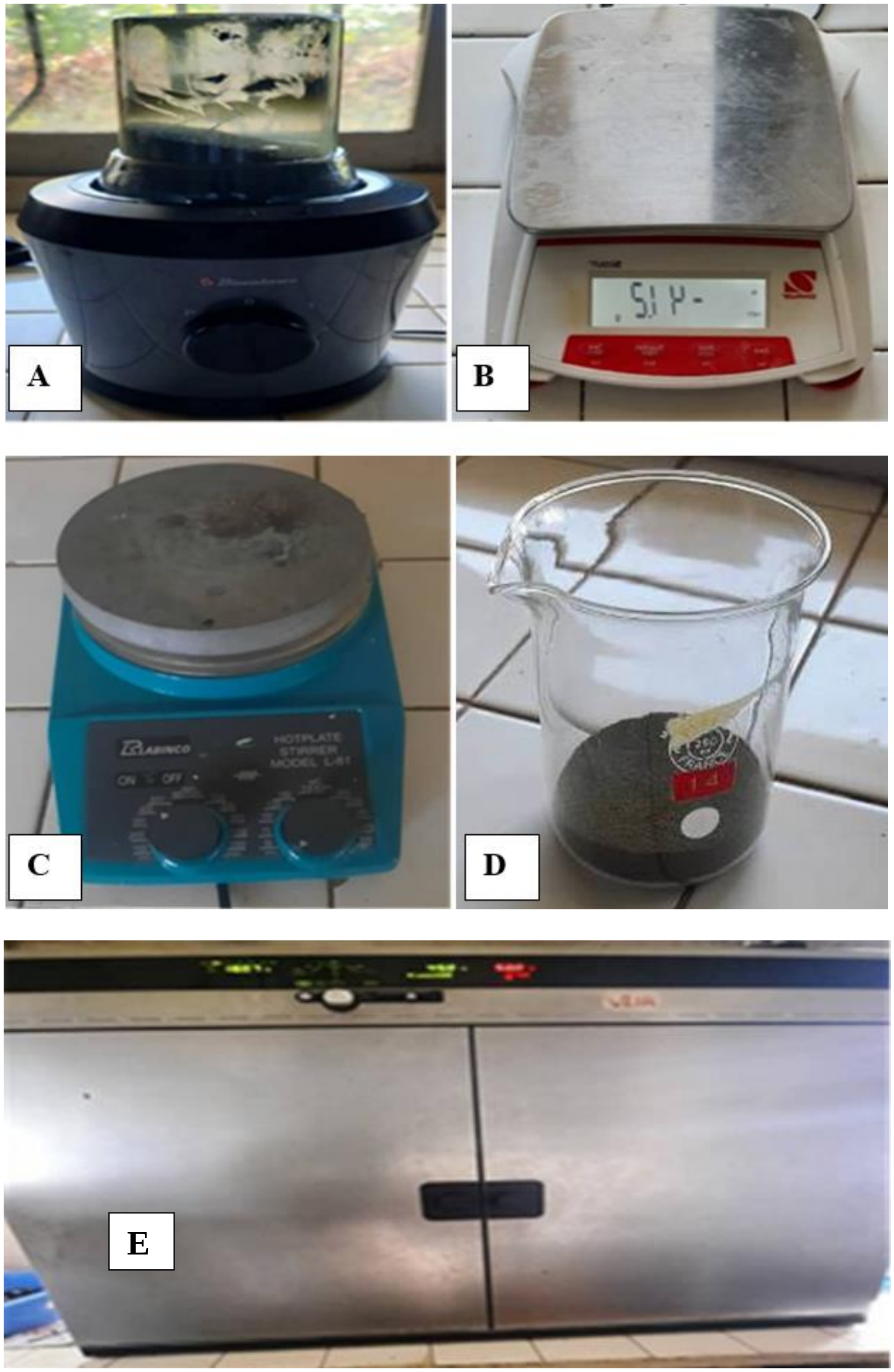

Figure 23: Aqueous extract preparation equipment

(**A**: Blender; **B**: Scale; **C:** Votex; **D**: Glass vial; **E**: Oven)

3.3 Methods

3.3.1 Setting of maize cultivation

Clearing and scrubbing were carried out in a succinct manner. They consisted of cutting the grass while leaving the stumps in place, allowing in this case a shifting cultivation to ensure a quick regrowth or recruitment when the plot is abandoned. Ploughing was done manually with a hoe. The hoe was driven into the soil and the clod was turned over so that the bottom of the ploughing was on the surface. Staking, with the purpose of leading ridge formation, consisted of placing a stake on either side of the field, connected to a nylon measuring rope (template). Once connected, the rest of the stakes were added between the two fixed stakes, respecting the corresponding row spacing (40 cm). The ridges, consisted of small mounds of about 15 cm with a flattened top were made manually with a hoe and were separated by furrows. The distance between the ridges was 80 cm and 40 cm between the bunches with two plants per seeding hole. Sowing was done manually (in aligned bunches). The number of seeds per cluster was three. Approximately 15 days after germination, excess plants were removed to achieve the desired density. Also weeds, especially during the vegetative phase of the crop, were pulled out manually (weeding). Chemical fertilisers (NPK compoud: 10-22-22) and urea, were applied to the soil to promote good plant growth applied at a rate of (60-60-60 kg/ha) 10 days after sowing and top dressed with 30 kg of Urea 6 weeks after sowing. During dry season, watering was done manually with a 20 m connection to a modern borehole. The frequency was every three days until the plants were two weeks old and two days during the rest of the vegetative cycle.

3.3.2 Assessing the biodemographic parameters of *S. frugiperda*

3.3.2.1 Setting up the experimental plot and collection

The study was carried out on a plot of 300 m² (30 m×10 m). Two weeks, after the sowing, the maize field was visited regularly. Then, the larvae were collected from the fields and transferred into transparent plastic pots (15 cm high × 25 cm diameter). The larvae were fed with maize leaves collected from the field. The pupae obtained during the larval development process were transferred to plastic pots (15 cm high × 25 cm diameter) on a cotton substrate until the emergence of the adults.

3.3.2.2 Rearing methods

Rearing was done in a semi natural environment that consisted of putting the rearing cages and glass vials contening the larva under shade on support near the field. On the day of emergence, females and male were paired and putting in rearing cages. During the oviposition period, the cages were checked daily for egg masses laid. All eggs were checked daily, the duration of egg development and the total number of hatched eggs were recorded. Newly emerged larvae (24 hours old) were individually transferred into glass vials (7.5 cm high x 2.5 cm diameter) with a fine brush and fed with fresh leaves. The larvae were inspected daily to record mortality and development time to pupation. Developed pupae were then removed from the artificial diet and transferred to an empty glass vial (measuring 7.5 cm high x 2.5 cm diameter), sealed with cotton wool, where they were observed until emergence. Those that did not emerge were observed for a longer period of time (over a month) and recorded as dead. On the day of emergence, thirty females and males were paired and placed individually in clear plastic pots (9 cm diameter x 16 cm height).

3.3.2.3 Determination of some biological and demographic parameters

- **Biologicals parameters**

- **Average pre-oviposition period**

The average pre-oviposition period corresponds to the time between the emergence of the females and their first oviposition. During the experiment, the date of the imaginal moult was noted Jo. The experiment continued until the first oviposition was observed. The day of first oviposition (Dpp) was recorded and the average pre-oviposition period was determined using the following formula (Ossey, 2017a)

$$\mathbf{Po\ (days)} = \frac{\sum 0ifi}{\sum fi}$$

Po=Average pre-oviposition period; 0i = Dpp - Jo; fi: number of females

- **Average number of eggs laid per female and average laying time**

As soon as the first egg was observed, the number of eggs laid by the female was noted each day. The experiment continued until the female died. The number of eggs laid per female was summed.

The day of the last oviposition (Dp) was recorded and the average oviposition period was determined by the formula of (Ekien et al., 2016):

$$\mathbf{Dp\ (days)} = \frac{\sum pifi}{\sum fi}$$

Dp = average laying time; pi = Jdp - Jpp; fi: number of females

- **Average lifespan of adults**

The life span is the time between the date of emergence (Jo) of the imago and the date of its death (Jm). The average life span of females and males was calculated using the formula of (Ekien et al., 2016):

$$\mathbf{Dv\ (days)} = \frac{\sum divi}{\sum vi}$$

Dv: average life span; di = Jm - Jo; vi: number of males or females.

- **Incubation period and egg fertility rate**

The date of egg laying was recorded as Dp. For each of the 30 females (Ekien et al., 2016; Ossey, 2017a) , the number of eggs was recorded and the fertility rate was calculated using the formula of (Ossey, 2017a):

$$\mathbf{Tf\ (\%)} = \frac{\sum tivi}{\sum fi} \mathbf{x\ 100}$$

Tf : Average fertility rate; Ti = $\frac{\text{Number of eggs hatched}}{\text{Number of eggs laid}}$; fi = number of females

- **Demographic parameters**

- **Net reproductive rate ((R_o)**

This is the average number of female offspring produced by a female during her lifetime.

- **Intrinsic rate of natural population increase (r_m)**

This is the instantaneous growth expressed when the population grows in an unlimited environment where the effects of density increase cannot be felt and under certain conditions (relative humidity, temperature, etc.). This rate was determined by the formula of (Giga and Smith, 1983):

$$\mathbf{rm} = \frac{\mathbf{ln(NS)}}{\mathbf{T + 1/2L}}$$

In this formula, **L** = *female life span*; **N** = *average number of eggs laid per female*; **S** = larval *survival rate*; **T** = *development time;* ***ln*** = *natural logarithm*

- **Generation time**

The generation time (**Tg**) was determined according to the formula used by (Giga and Smith, 1983):

Tg = (development time) + average age of a female at the time of laying of all her eggs

- **Population doubling time**

The population doubling time (**Dt**) is the time required for the population to double in size. It was calculated according to the formula (Murúa and Virla, 2022):

$$\mathbf{Dt.} = \frac{\mathbf{ln2}}{\mathbf{rm}}$$

3.3.2.4 Statistical analysis

The data collected was entered into the Excel 2016 spreadsheet which was then used to calculate the averages and construct the various graphs. The data were then subjected to a descriptive analysis (Student's t test) using the STATISTICA 7.1 software at the 5% probability threshold.

3.3.3 Assessing the seasonal variation of *S. frudiperda*

3.3.3.1 Experimental plot pheromone traps setting

Three area of 300 m^2 (30m x 10m), were delimited in each study areas. The areas were about 8 km apart.

3.3.3.2 Seasonal variation of adult molts

The study of adults dynamic was done by using pheromone trap. It was composed of catcher bucket, strip and fall armyworm female sex pheromone prepared by Russell IPM, UK with catch number 72/1936, labelled with the trade name *Spodoptera frugiperda* PH-869-1PR. The pheromone was hanged in cage at the top of catcher bucket and one strip of Dimethyl 2,2-DichloroVinyl Phosphate (DDVP) was placed at the bottom in the bucket as killing agent to knocked male molts and other insects entering through vents on the sides of the bucket.

Traps were mounted at field level (Figure 24), after emergence of plant maize. One trap hanged on a pole was put in the centre of each delimited areas at height of 1.5 m over maize plants as they grow (Figure 24). The pheromones were replaced every 3 weeks while the strips 2 months. Each week, the traps were emptied and the adult males were counted. Data were collected during vegetative, reproductive and maturation of maize.

Figure 24: Setting of trap at field level

(**A**: Mounting of sex pheromone trap; **B**: Trap at 1.5m over maize plants)

3.3.3.3 Larva infestation and damage

After emergence of maize, each farm was sampled weekly on the same day of the emptied moths trap to count the number of larva and score the damage. In each field, as preconized by (Prasanna et al., 2018), 20 plants were selected randomly in 'w' pattern for a total of 100 plants. The number of larvae presents in each plant was recorded as well as damage scores. The damage was assessed by visually estimating the area of damaged leaves on the maize plants by assigning an index from 0 to 5 from the rating scale proposed by (Caniço et al., 2020):

0 = no visual damage;

1 = up to 10% of foliar damage;

2 = foliar damage between 10 to 25%;

3 = foliar damage between 25 to 50%;

4 = foliar damage between 50 to 75%;

5 = foliar damage between up to 75%.

The percentage of damaged leaves was calculated as the ratio of the number of damaged leaves to the total number of leaves multiplied by one hundred.

3.3.3.4 Statistical analysis

The data collected was entered into the Excel 2016 spreadsheet which was then used to calculate the averages and construct the various graphs. The data were then subjected to a descriptive analysis (ANOVA test) using the STATISTICA 7.1 software at the 5% probability threshold.

3.3.4 Control of *S. frugiperda* using aqueous extract of botanicals

3.3.4.1 Extract plant preparation

The extract preparation was done according to (Ossey, 2017a). the leaves of *Ricinus communis*, *Azadirachta indica, Lippia multiflora* and *Tephosia vogelii* were harvested and dried in the shade (away from the sun) at ambient temperature for three to four weeks. The leaves were then crushed using a blender until they will be reduced to powder. A quantity of 100 g of powder obtained per organ type of each plant species were diluted in 200 ml of distilled water. The whole (powder plus distilled water) was then homogenized in the blender for ten minutes. The resulting mixture was filtered through the poplin. Two more filtrations were made with Whatman paper (3 MM) and a funnel, respectively containing inside hydrophilic cotton. The product obtained from these three filtrations was put in melam plates, then concentrated by evaporation in an oven set at 50 °C for 48 hours, until a dry residue is obtained (Figure 25). The dry residue obtained per organ type of each plant species was allowed to prepare five concentrations of aqueous extracts: 10 g/l; 30 g/l; 50 g/l; 70 g/l and 90 g/l. Thereafter the extracts were used in bioassays.

3.3.4.2 Bioassays methods

- **Feeding bioassays**

The feeding biossays was done according to (Ossey, 2017a). The healthy, fresh maize leaves were cut into 50 mm diameter slices. One of the slices, considered as a control did not receive any treatment. The other slices were each treated with the concentration of the different aqueous plant extracts. Both sides of each leaf were treated for 10 seconds. After air-drying for 30 min, the leaf slices were placed on filter paper in a glass jar. Then, a 2nd instar larval was carefully placed in the jar, which was then covered with muslin for aeration and to prevent the larval from escaping. 24 hours later, the leaf slice was retrieved and the area consumed by the larval was measured using graph paper and expressed in mm^2.

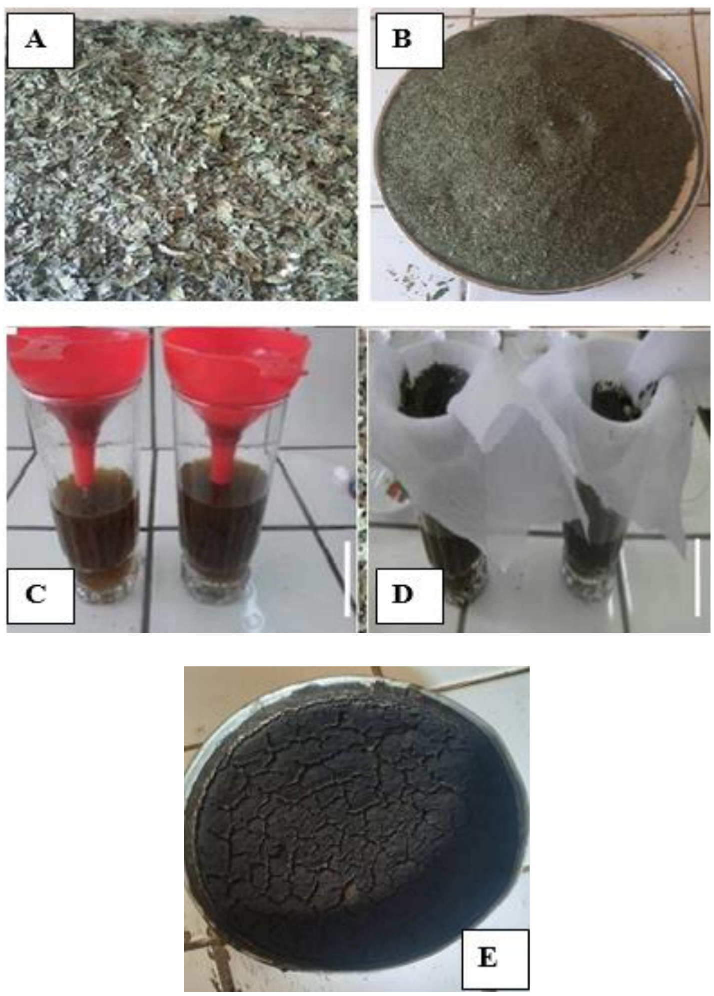

Figure 25: Aqueous extract preparation

A: Leaves dry matter; **B**: Leaves powder; **C**: Filtration through funnel.

D: Filtration through Whatman paper and poplin, E: Aqueous extract

The anti-feeding effect was calculated by the formula proposed by Cui et al. (2013):

Anti-appetence rate (%) = [(Ct- Ce)/Ct] × 100

Ct = Leaf area consumed in the control and Ce = Leaf area consumed with the extract.

For the control and different aqueous plant extracts, 30 replicates were made.

- **Contact toxicity**

The contact toxicity was done according to (Phambala et al., 2020). 10 µL of each extract was applied topically on 2nd instar larvae by using 20 µLpipette. Then, the10 larvae were placed in glass vial 7.5cm high x 2.5cm diameter) with 3 replicates containing fresh leaves and covered with foil paper. The distilled water was used as control. the rate means of mortality for each concentration evaluated were calculated and corrected 24 h later.

$$\mathrm{M} = \frac{\text{Number of dead larvae}}{\text{Total number of larvae}} X\ 100$$

$$M_c = \frac{M_0 - M_T}{100 - M_T} X\ 100$$

M: Mortality rate, M_c: Mortality rate corrected, M_0: Mortality rate for each treatment and

M_T: Mortality rate of the control.

Lethal concentration 50 or LC50 is the concentration that causes 50% of group of test animal death was determined for each plant extract.

3.3.4.3 Evaluation of the most efficient extracts on growing maize in field

- **Experimental design**

The experimental dispositive was a Fisher block with 3 repetitions and 3 treatments. An area of 720m² (60m x 12m) was delimited and divided into 3 blocks 2m apart. Each block was 23m long by 8m wide and was divided into 4 elementary plots (23m x 2m wide) (Figure 26).

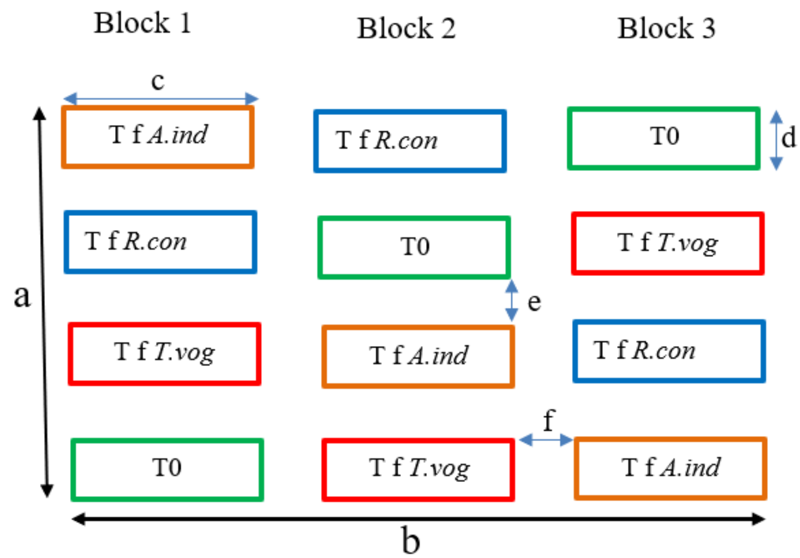

Figure 26: Experimental design for the field evaluation of the efficacy of extracts

A = 60 m; b = 12m; c = 23 m; d= 2m; e = f= 2m (m: meters)

T0: Control plots,

Tf *A. ind*: Plots treated with aqueous extract *Azadirachta indica*,

T f *R.con*: Plots treated with the aqueous extracts of *Ricinus communis*,

T f *T.vog*: Plots treated with the aqueous extracts of *Tephosia vogelii*

- **Application of the treatments (aqueous extracts)**

Differents back sprayers were used for the application of the treatments. The sprayers labelled Tf *A. Ind*, Tf *R.con*, Tf *Tvog* were used for the application of the leaves of *A.indica*, *R. communis* and *T. vogelii* aqueous extracts respectively. For homogeneous treatment, the jets were directed to cover the lower and upper surfaces of the leaves of each plant. The treatments were carried out at seven-day intervals, started two weeks after sowing. The treatments were done early in the morning from 6 am to 9 am.

- **Infestation and damage assessment**

In each plot, as preconized by (Prasanna et al., 2018), 20 plants were selected randomly in ‘w’ pattern for a total of 100 plants. Once a week on all the plants in each elementary plot. The percentage of damaged leaves was calculated as the ratio of the number of damaged leaves to the total number of leaves multiplied by one hundred (Adagba et al., 2015).

3.3.4.4 Statistical analysis

The data were processed using Statistica software, version 7.1. Analysis of variance (ANOVA) and Kruskal Wallis H-test at the 5% threshold were used to process and compare attack rates; mortality rate; and feeding rate.

3.3.4.5 Phytochemical screening of botanicals

- **Qualitative screening**

➢ **Polyphenol tests**

Polyphenols were detected using the method described by (Jaramillo-Barrios et al., 2019; Souley Kallo et al., 2018). Thus, in 2 mL of plant extract was added a drop of alcoholic solution of 2% ferric chloride. The appearance of a more or less dark blue-black or green coloration indicates the presence of phenolic compounds.

➢ **Flavonoid test**

Flavonoids were detected by the Shibata test (Jaramillo-Barrios et al., 2019). Thus, 2 mL of plant extract was evaporated to dryness. After cooling, the residue was taken up in 5 mL of hydrochloric alcohol diluted 2 times in a test tube. Two to three magnesium chips were added (heat release). The addition of 3 drops of isoamyl alcohol intensifies the pink-orange or purplish coloration, indicating the presence of flavonoids.

➢ **Catechic tannins test**

5ml of extracts were evaporated and then to the dry residue, 15ml of STIASNY reagents (10ml of 40% formalin plus 5ml of concentrated Hcl) were added. The mixture was kept in a water bath at 80°C for 30 minutes and then cooled under a stream of water. The observation of large precipitates in vials characterizes catechic tannins.

- **Gallic tannin tests**

The solution containing the vials was filtered and the filtrate collected was saturated with sodium acetate. 3 drops of 2% ferric chloride were then added to the mixture. The appearance of an intense blue-black colour indicates the presence of gallic tannins.

- **Tests for saponins**

10ml of plant extracts were placed in a test tube, shaken for a few minutes and the height of the foam measured. A foam height greater than 1cm indicates the presence of saponins. Saponins can also be detected by the persistence of the foam**.**

- **Tests for polyterpenes and sterols**

The Liebermann reagent was used for this test. A 5ml volume of plant extract was dried under rotary evaporator. The residue was dissolved in 1ml of acetic anhydride and collected in a test tube. Then 0.5ml of concentrated sulphuric acid was run down the tube. The appearance at interphase of a purple or violet ring, which quickly turns blue and then green, indicates the presence of polyterpenes and sterols.

- **Alkaloid test**

6 mL of plant extract was taken. The residue was taken up in 6 mL of 60° alcohol and the resulting alcoholic solution was divided into two test tubes. First, 2 drops of DRAGENDORFF reagent (aqueous solution of potassium iodobismuth) were added to the first tube. The appearance of a precipitate or an orange coloration indicates the presence of alkaloids. Then, in the second tube, 2 drops of BOUCHARDAT's reagent (aqueous iodine solution) were added. The appearance of a reddish-brown coloration indicates the presence of alkaloids. Finally, in the third, a yellowish-white coloration after addition of 2 to 3 drops of MAYER's reagent indicates the presence of alkaloids. The procedures have been described in previous works (Jaramillo-Barrios et al., 2019; Toyin and Fakai, 2012).

- **Quinone test**

To five (5) mL of extract, 5 mL of HCl diluted to 1/5 is added, and the whole is heated in a boiling water bath for 30 minutes, then extracted with 20 mL of chloroform after cooling. To the organic phase, 0.5 mL of ammonia diluted to 50% (v/v) is added. The appearance of a red to purple hue indicates a positive reaction.

- **Leucoanthocyanin test**

HCl 12.07 N, volume 0.5 mL is poured into a tube containing 2 mL of extract, then the solution is heated in a water bath at 100°C for 30 min. The appearance of a red coloration after cooling indicates the presence of leucoanthocyanins.

- **Cardiotonic glycoside test**

To 4 mL of extract is added 5 mL of glacial acetic acid. To this mixture is added 2 mL of a concentrated acetic anhydride/sulphuric acid mixture in the proportions 50:1 (v/v). After a few minutes, a pink to green and blue coloration develops, indicating a positive reaction.

- **Quantitative phytochemical screening**

The phytochemicals present in all plants were subjected to quantitative screening

- **Spectrophotometric determination of total polyphenols**

Wood's method was used for the determination of total polyphenols. A volume of 2.5 ml of diluted Foling-Ciocalteu reagent (1/10) was added to 30 µL of extract. The mixture was kept for 2 minutes in the dark at room temperature, then 2 ml spectrophotometric calcium carbonate solution (75 g.L-1) was added. The mixture was then placed in a water bath at 50°C for 15 minutes and then rapidly cooled. The absorbance was measured at 760 nm, with distilled water as a blank. A calibration line was performed with gallic acid at different concentrations. The analyses were carried out in triplicate and the concentration of polyphenols was expressed in milligrams per litre of gallic acid equivalent extract (mg. L-1, Eq AG).

- **Spectrophotometric determination of total flavonoids**

The method of (Marinova et al., 2005) was used for the determination of total flavonoids. In a 25 mL flask, 0.75 mL of 5% (w/v) sodium nitrite ($NaNO_2$) was added to 2.5 mL of extract. To the mixture was added 0.75 mL of 10% (w/v) aluminium chloride ($AlCl_3$) and incubated for 6 minutes in the dark. After incubation, 5 mL of sodium hydroxide (1N NaOH) was added and the volume was made up to 25 mL. The mixture was shaken vigorously before being determined by UV visible spectrophotometer. The reading was taken at 510 nm. The tests were carried out in triplicate. The flavonoid content was expressed in milligrams per litre of quercetin equivalent extract (µg quercetin equivalent/g).

- **Determination of condensed tannins**

The condensed tannin content of the extracts was measured by the vanillin colorimetric method in acid medium following the method of (Broadhurst & Jones, 1978)modified by The method is based on the ability of vanillin to react with the terminal flavonoid group of condensed tannins to form red colored complexes (anthocyanidols).

To a test tube containing 50 µL of extract solution, 3 mL of a 4% methanolic vanillin solution was added. Then 1.5 mL of 37% concentrated hydrochloric acid (HCl) was added. The mixture was incubated in the dark for 15 min at laboratory temperature (25 - 30 °C). The absorbance was then read on a UV/visible spectrophotometer at 500 nm against a MeOH blank. Catechin was used as standard. The condensed tannin contents of the extracts were determined according to the catechin calibration curve established from different concentrations (0; 1.95; 3.91; 7.81; 15.625; 31.25; 62.5; 125; 250; 500 and 1000 µg/mL). The contents are expressed in milligrams of catechin equivalent per gram of extract (µg CE/g). They were calculated from the relationship below (Souley Kallo et al., 2018):

$$\boxed{Q_{tan}(\mu g\ EC/g) = \frac{Conc_{spect} \times FD}{Conc_{ext}}}$$

$Conc_{spect}$: Concentration read by the spectrophotometer

$Conc_{ext.}$: Extract concentration; FD : dividing factor

- **Determination of total tannins**

The determination of total tannins was performed by the colorimetric method with Folin Ciocalteu reagent as described by (Chandran and Kavitha, 2016)

100 µL of extract solution was added to a test tube containing 7.5 ml of distilled water and 0.5 ml of Folin Ciocalteu reagent. Then 1 ml of 35% Na2CO3 was added. The volume is made up to 10 ml by adding 900 µL of distilled water. The reaction mixture is stirred and left to react for 30 min

at laboratory temperature (25 - 30 °C). The absorbances were read with a UV/visible spectrophotometer at 700 nm against distilled water used as a blank.

A calibration line was drawn from a concentration range of tannic acid (0; 1.95; 3.9; 7.81; 15.62; 31.25; 62.5; 125; 250; 500 and 1000 µg/mL) used as standard. The contents are expressed in micrograms of tannic acid equivalent per gram of extract (µg TEA/g). They were calculated from the relationship below:

$$\boxed{Q_{tan}(\mu g\ EAT/g) = \frac{Conc_{spect} \times FD}{Conc_{ext}}}$$

$Conc_{spect}$: Concentration read by the spectrophotometer

$Conc_{ext}$: Extract concentration; FD : dividing factor

3.3.5 Assessing current and future distribution of *S. frugiperda*

3.3.5.1 Occurrence records

Geographic coordinates (longitude and latitude) of the native range of S. fr*ugiperda* were downloaded from the Global Biodiversity Information Facility (GBIF, https://www.gbif.org) and Centre for Agriculture and Bioscience international (CABI, https://www.cabi.org). Duplicate records and records outside the geographic range were discarded. A total of 2296 occurrence points obtain in the native range were used for modelling (Figure 27). A buffer of 200 km was delimited around occurrence points for setting the calibration area (M) using the Ellipsenm R package (Cobos et al., 2019). The M area represents the area that has been accessible or explored by the specie based on the biogeographic history and biological capacity (Simoes et al., 2020) (Figure 27). To evaluate the model, 70% of the occurrence records were used for calibration and the remain 30% for testing the model.

3.3.5.2 Environmental data

The current and future climate data (bioclimatic variables) were downloaded from Global Climate Data (WorldClim) using the raster R package. The current climate data were downloaded for the period 1970-2000 at 2.5 arc/minutes (longitude latitude) degree spatial resolution from interpolated monthly climate data for global land area considering the historical series 1950-2000. At the same spatial resolution, the projected bioclimatic variables were downscaled for three time periods (2041-2060, 2061-2080 and 2081-2100) extracted from two Global Climate Models (GCMs). Two different Representative Concentration Pathways (RCPs) were considered: the low emission (4.5) and high emission (8.5). A total of 19 bioclimatic variables were obtained for each time period, GCMs and RCPs. Four sets of bioclimatic variables were selected set 1 (Bio1, Bio2, Bio5, Bio12, Bio15); set 2 (Bio1, Bio3, Bio5, Bio12, Bio17); set 3 (Bio5, Bio8, Bio11, Bio15, Bio16) and set 4 (Bio2, Bio7, Bio15, Bio16, Bio17). based on previous works conducted with the fall armyworm. To avoid multicollinearity, correlated bioclimatic variables (i.e., $r \geq 0.8$) were not considered in the same set. The M area created previously was masked to the bioclimatic variables to create the environmental layers that represent the calibration area of the specie in this study (Figure 27).

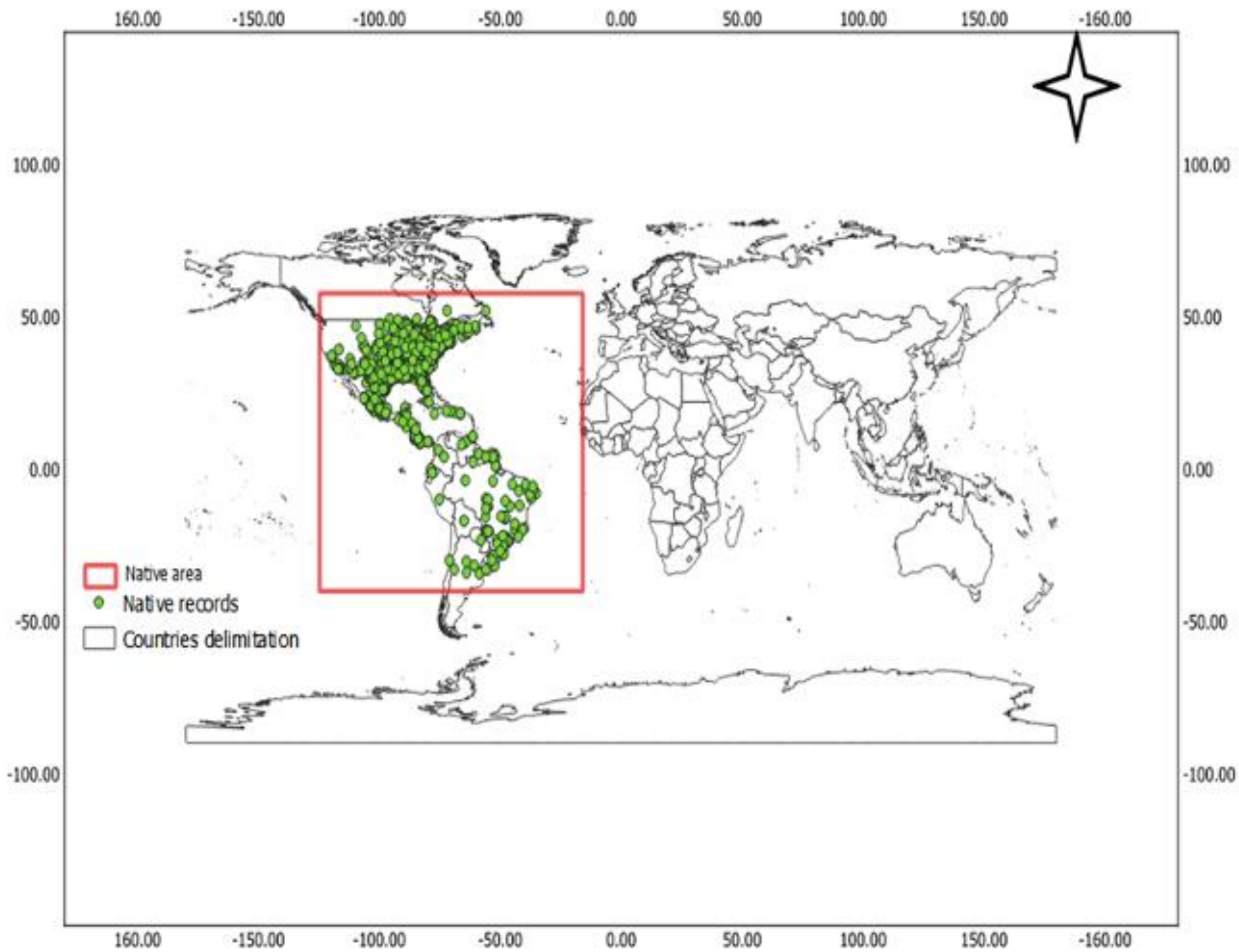

Figure 27: Native area showing native records

3.3.5.3 Modelling the distribution of the specie

MaxEnt, one of the loudest modelling approach to model suitable habitat for species (Phillips et al., 2006), was used for modelling the distribution of *S. frugiperda* . Setting MaxEnt model was run using R package Kuenm. This package implements three crucial phases of ENM: calibration, final model creation and evaluation, and extrapolation risk analysis (Figure 28).

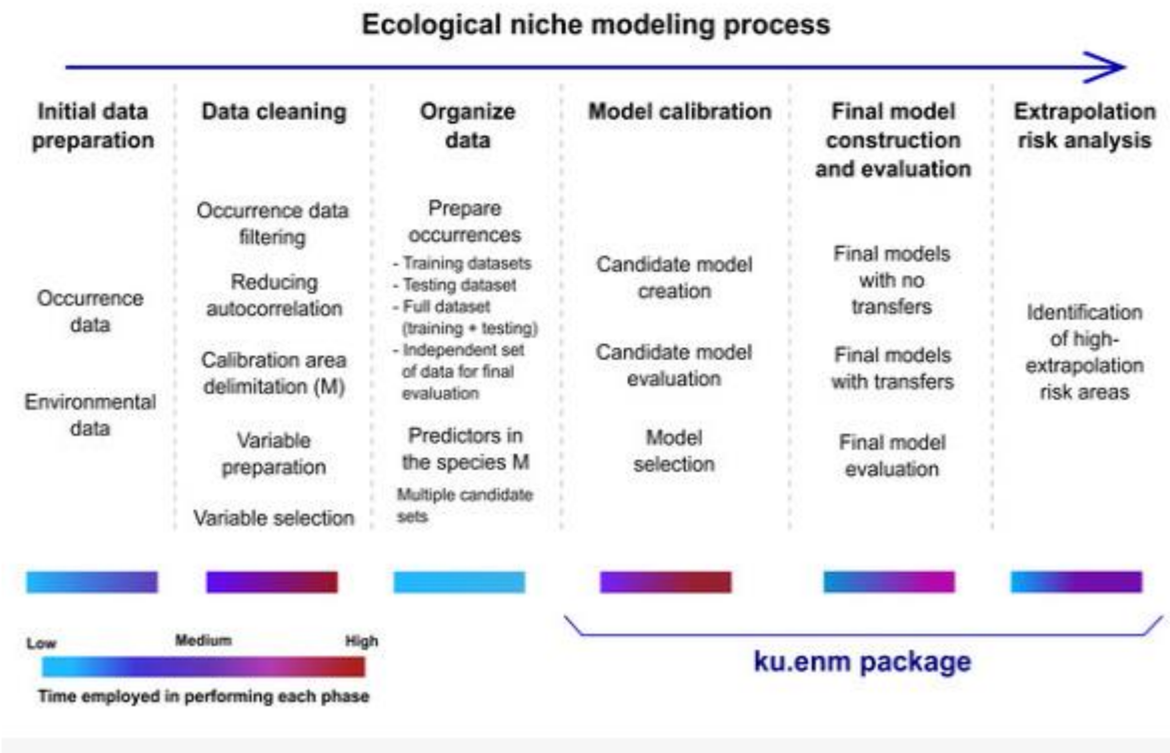

Figure 28: Ecological niche modeling process using kuenm package (Cobos et al., 2019)

- **Model calibration**

In the process, MaxEnt was kept as default, 10,000 background points were used along 500 iterations and a convergence threshold of 5. These candidate models are created with several combination of regularization multipliers, set of environmental variables and features classes (Ruane and McDermid, 2017). For each combination, it create one MaxEnt model with the full set of occurrences and another with training occurrence records only (Cobos et al., 2019). Then, model selection was performed based on the corrected Akaike information criteria (AICc).

- **Final model evaluation and extrapolation risk**

MaxEnt was run using 10 replicate bootstraps with logistic output format. To assess extrapolation risk, Mop analysis was performed. MOP calculation allow comparisons of the environmental conditions between the calibration area and the projected scenario to which models were transferred.

CHAPTER 4. RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Effect of season on biodemographical parameters of *S. frugiperda* in Sub-sudanese and Guinean Zones

4.1.1.1 Description of development stage

- **Eggs**

The eggs are spherical in sharpe. The eggs measure about 0.38 mm in diameter and 0.29 mm in height. At the time of the oviposition they are green colour and become light brown prior to the hatching. The eggs are usually laid in mass on the surface of the leaf and covered with a protective setae rubbed off from the female abdomen. (Figure 29)

- **Larva**

S. frugiperda had six larva stage. The neonates, just after hatching have greenish black head. The head turning in more orange color in L2 stage. In L3 stage, lateral white lines begin to form on the dorsal surface of the body. From L3 stage the body bears white subdorsal and lateral lines. Elevated black spots occur dorsally on the body and bear spines. From L5 to L6 a white inverted 'Y' appears on the head and four large spots that form a square on the upper surface of the last segment appear as well (Figure 30).

- **Purpae**

Before a prepupal period when the last instar larvae L6 stop feeding, the larvae construct a loose oval cocoon by web together leaf debris. The pupae is reddish brown in color, measuring about 12.6 mm in length and about 4.1 mm in width (Figure 31 and 32)

- **Adults**

Adults moths of *S. frugiperda* have a wingspan. In the male moth, the forewings are generally shaded gray and brown with triangular white spots at the tip and near the center of the wing. Differently, the forewings of female are less distinctly marked with a uniform grayish brown colour, sometime mixed of fine motting gray and brown. In both sexes, the hind wing is iridescent silver-white (Figure 33).

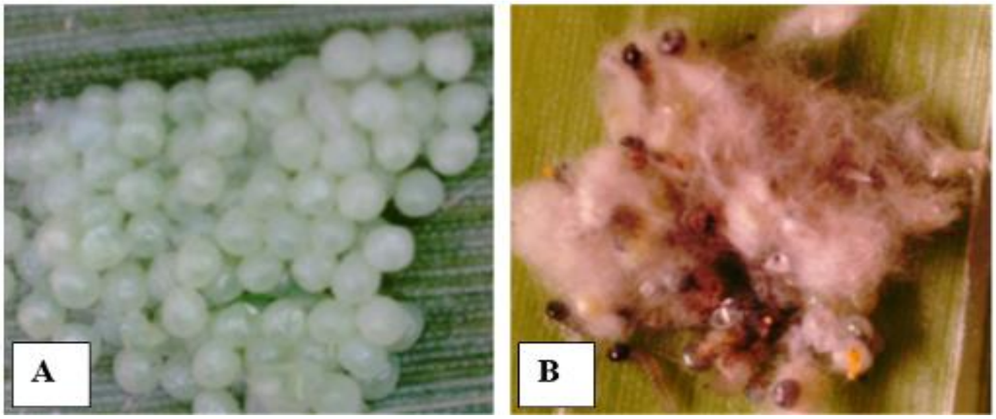

Figure 29: Eggs stage

(**A:** Fresh laid eggs; **B**: Hatching eggs cover with setea)

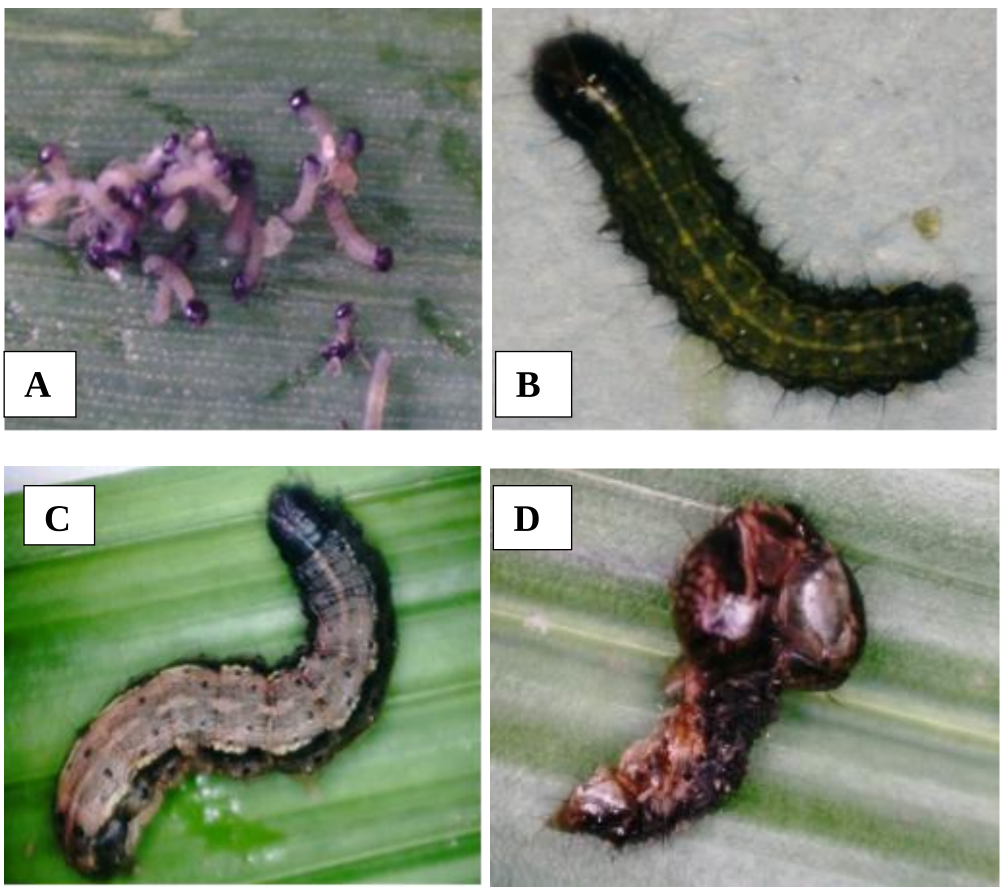

Figure 30: Larvae stage

(**A**: Neonates with black head; **B**: L3 larvae stage; **C**: L6 Larvae stage; **D** : Larva exuvie)

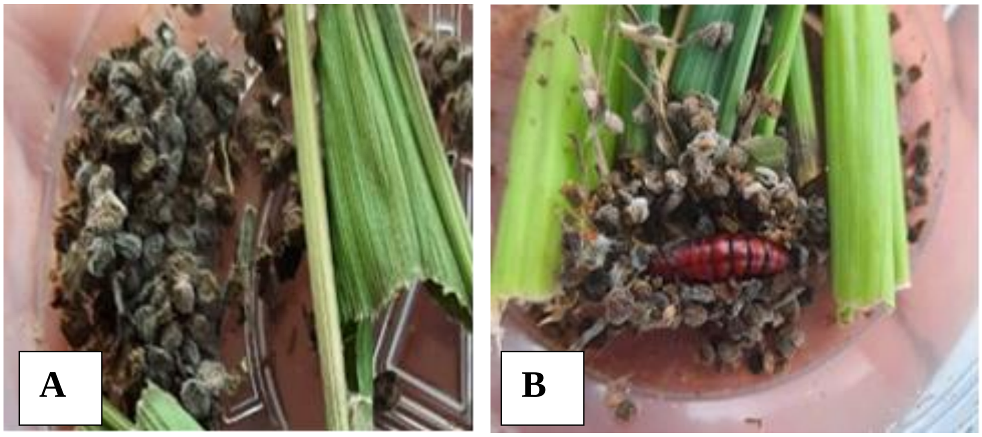

Figure 31: Nymphale stage

(**A**: Larva webing together excrement debris; **B**: Larva during pupation)

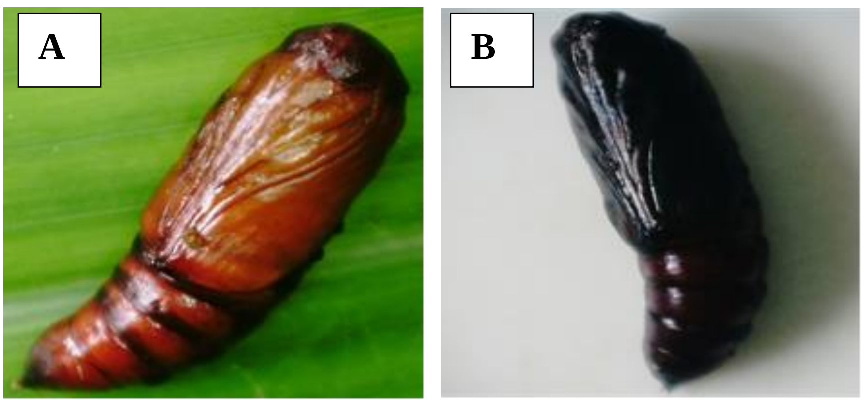

Figure 32: Pupae stages (**A**: Fresh pupae; **B**: Pupae prio to adult emergence)

Figure 33: Adult stage

4.1.1.2 Biological parameters of *S. frugiperda*

4.1.1.2.1 Average pre-oviposition time in Sub-sudanian and Guinean zones

In Sub-sudanian zone, the average duration of pre-oviposition was longer in dry season with 6.66 ± 1.06 days and shorter in rainy season with 2.83 ± 0.70 days (t-test = 16.52185; $p < 0.05$) (Figure 34).

The average pre-oviposition time in Guinean zone was shorter in dry season (2.53±1.25 days) and longer in rainy season (3.37±1.07 days) (t-test = -2.77542; $p < 0.05$) (Figure 34).

4.1.1.2.2 Average oviposition time in Sub-sudanain and Guinean zones

The average egg-laying time was significantly different in the two seasons. In the dry season, it was longer with 7.7 ± 0.99 days and shorter in the rainy season with 3.9 ± 0.92 days (t-test = 15.39591; $p < 0.0001$).

4.1.1.2.3 Average number of eggs laid in Sub-sudanian and Guinean zones

The average number of eggs laid per female in Sud-sudanian zone was more with 204.3 ± 6.52 eggs in dry season and less (149.9 ± 11 eggs) in rainy season. (t-test = 23.30123; $p < 0.05$) (Figure 35).

In Guinean zone, female laid more eggs (195.3 ± 10.74 eggs) in dry season and less in rainy season with 141.9 ± 12.72 eggs (t-test = 17.56709; $p<0.05$) (Figure 35).

4.1.1.2.4 Average incubation time in Sub-sudanian and Guinean zones

In Sub-sudanian zone the average incubation period was shorter in dry season with 2.9 ± 0.30 days and longer in rainy season with 3.97 ± 0.18 days (t-test = -16.4306; $P <0.0001$) (Table 6).

Incubation of eggs in Guinean zone was shorter (3.9±0.3) in dry season and longer (5±0) in rainy season (t-test = -19.47456; $P <0.00001$) (Table 7).

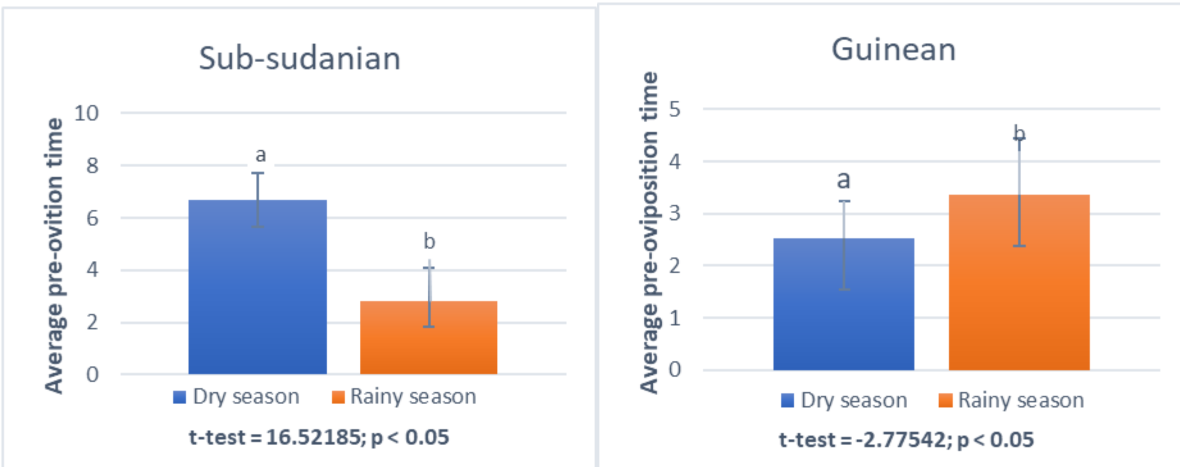

Figure 34: Average pre-oviposition time by season

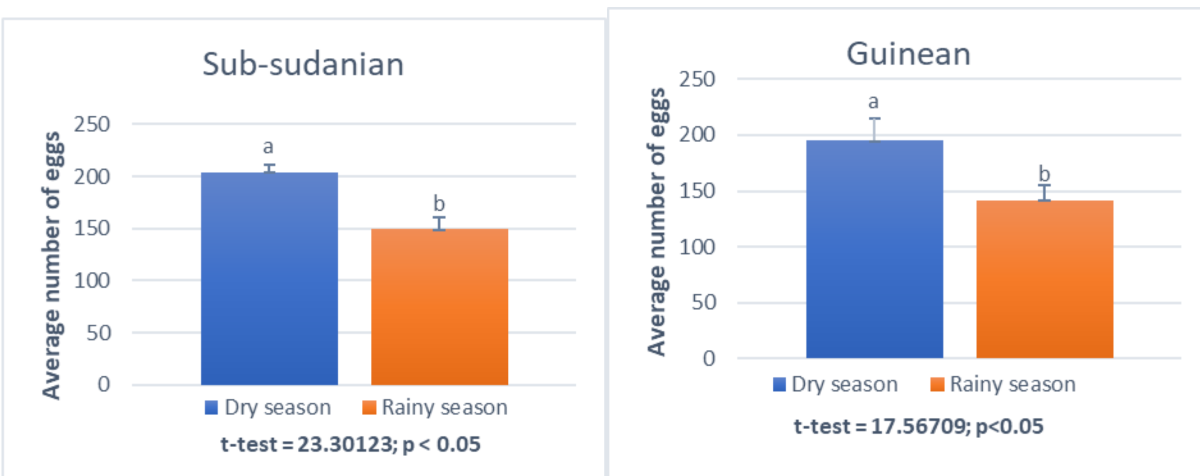

Figure 35: Average number of eggs laid per female by season

4.1.1.2.5 Average larval development time in Sub-sudanian and Guinean zones

❖ **Average larval development time in Sub-sudanian zone**

The development time from larval stage 1 (L1) to adult emergence varies for each season. It was significantly longer (32.47 ± 1.83 days) in rainy season and shorter in dry season (27.93 ± 1.01 days) (t-test = -11.8497; P < 0.05). The development duration of larval stages differs between the two seasons. From L1 to the L2 larval stage, the development time was significantly longer in rainy season with 5.3 ± 0.59 days and shorter in dry season with 4.43 ± 0.68 days (t-test = -5.2546; P <0.05). The time taken by L3 larval to become L4 larval was significantly longer in rainy season with 3.17 ± 0.6 days than in dry season with 2.4 ± 1.10 days (t-test = -3.28571; $P < 0.05$). However, no significant difference between the transition from L4 to L5 larvae stage was observed (t-test = 0.485317; $P > 0.05$). In addition, no significant difference was observed between the passage from L5 to L6 larval stage (t-test = 0.485317; $P > 0.05$). Furthermore, a significant difference was observed from L6 larval stage to pupa, which was longer in rainy season with 3.17 ± 1.31 days than in dry season with 2.3 ± 1.18 days (t-test = -2.687620; $P < 0.05$). The transition from pupa to adult was significantly longer in rainy season with 11±1.70 days, and shorter in dry season with 9.67 ± 0.55 days (t-test = -4.08542; $P < 0.05$). The development time of different stages in Sub-sudanian zone is presented in Table 6.

- **Average larval development time in Guinean zones**

The overall development time from larval stage 1(L1) to adult varies according to season (t-test = -12.5087; $P < 0.05$). It was longer in rainy season with 45.83±3.26 days and shorter in dry season with 36.97±2.1 days. The development of the different larva stages varies during season. The development time from L1 to L2 larval stage was shorter in dry season (6.4±0.77) and longer in rainy season (7.07±0.98) (t-test = -2.92914; $P < 0.05$). However, no significant difference was observed from L2 to L3 (t-test = 1.055615; $P > 0.05$). The time taken by L3 larval to become L4 larval was longer in rainy season (5.27±0.9 days) and shorter in dry season (2.73±1.02 days). Furthermore, from L6 to pupa, a significant difference was observed between season (t-test = -2.16234; $P < 0.05$), it was longer in rainy season (4.1±1.15 days) and shorter in dry season (3.73±1.55 days). From pupa to adult, the transition was significantly different between season (t-test = -7.383; $P < 0.05$), it was shorter in dry season with 11.57±0.6 days, and longer in rainy season with 13.03 ±0.8 days. The development time of different stages in Guinean zone is presented in Table 7.

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Table 6: Average development time of *S. frugiperda* in Sub-sudanian zone

Season	PI	L1-L2	L2-L3	L3-L4	L4-L5	L5-L6	L6-P	P-E	Development time
Dry season	2.9 ± 0.30[b]	4.43 ± 0.68[b]	2.33 ± 1.06[b]	2.4 ± 1.10[b]	2.1 ± 1.03[a]	1.8 ± 0.61[b]	2.3 ± 1.18[b]	9.67 ± 0.55[b]	27.93 ± 1.01[b]
Rainy season	3.97 ± 0.18[a]	5.3 ± 0.59[a]	1.83 ± 0.65[a]	3.17 ± 0.65[a]	1.97 ± 1.1[b]	2.07 ± 0.45[a]	3.17 ± 1.31[a]	11 ± 1.70[a]	32.47 ± 1.83[a]
Test-t	-16.4306	-5.254640	2.202567	-3.28571	0.485317	-1.92666	-2.687620	-4.08542	-11.8497
Ddl	59	59	59	59	59	59	59	59	59
P	0.0001	0.000002	0.031613	0.001729	0.629279	0.058927	0.009376	0.000137	0.0001

Table 7: Average development time of *S. frugiperda* in Guinean zone

Season	PI	L1-L2	L2-L3	L3-L4	L4-L5	L5-L6	L6-P	P-E	Development time
Dry season	3.9±0,3[b]	6.4±0.77[b]	3.5±1.57[a]	2.73±1.02[b]	2.53±0.73[b]	2.6±0.5[b]	3.73±1.55[a]	11.57±0.63[a]	36.97±2.1[b]
Rainy season	5±0[a]	7.07±0.98[a]	3.13±1.08[a]	5.27±0.9[a]	3.73±1.341[a]	4.1±1.15[a]	4.5±1.17[a]	13.03±0.89[b]	45.83±3,26[a]
Test-t	-19.7456	-2.92914	1.055615	-10.1937	-4.31346	-6.53047	-2.16234	-7.383	-12.5087
Ddl	59	59	59	59	59	59	59		
P	0.00001	0.004852	0.295522	0.00001	0.000063	0.00001	0.034729	0.00001	0.00001

4.1.1.2.6 Average larval survival rate of *S. frugiperda* in Sub-sudanian and Guinean zones

❖ **Average larval survival rate in Sub-sudanian zone**

The survival rates of the larval stages were significantly different from one season to another. However, for the L2 larval stage there was no significant difference between the two seasons (t-test = 1.675591; P > 0.05). For the L1 larval stage, the survival rate was significantly higher in dry season (85.79 ± 7.5%) compared to rainy season (74.6 ± 5.19%) (t-test = 6.659; P<0.05). For the L3 larval stage, the survival rate was significantly higher in dry season with 97.8 ± 2.3% and lower in rainy season with 95.89 ± 2.5% (t-test = 3.079727; P < 0.05). At the L4 larval stage, the survival rate was significantly shorter during rainy season (96.77 ± 3.1%) compared to dry season (99.27 ± 1.9%) (t-test = 3.686991; P < 0.05). For the L5 larval stage, survival was significantly higher in the dry season (99.7 ± 1.3%) compared to rainy season (96.17 ± 3.81%) (t-test = 4.7867; P < 0.05). At the L6 larval stage, it is significantly higher during dry season (100 ± 0 %) than during rainy season (94.7 ± 4.79%) (t-test = 6.0563; P <0.05). Average survival rate of the different larval stage in Su-sudanian zone is presented in table 8.

❖ **Average larval survival rate in Guinean zone**

The larval survival rate was not significantly different between season respectively for stage L2 (t-test = 0.981; P > 0.05), L3 (t-test = -0.6357; P > 0.05), L4 (t-test = -0.58307; P > 0.05) and L5 (0.381615). However, significant difference was observed for L1 and L6. According to L1, the survival rate was higher during dry season with 89.19±7.46% and lower in rainy with 80.91± 8.93% (t-test = 3.899952; P < 0.05). For L6 it was longer in dry season (100±0%) and lower in rainy season (96.52± 0.75%) (t-test = 25.39257; P < 0.05). Average survival rate of the different larval stage in Guinean zone is presented in table 9.

4.1.1.2.7 Fertility rate in Sub-sudanian and Guinean zones

In Sub-sudanian zone, fertility rate was significantly different between season (t-test = -25.8745; P < 0.05). It was lower in dry season with 26.77± 6.44% and higher in rainy season with 71.64± 6.9%. (Table 10) Fertility rate in Guinean zone was significantly different according to season. It was lower in dry season with 29.56± 6.98% and higher in rainy season with 74.97± 5.18%. (t-test = -28.633; P < 0.05 (Table 11).

Table 8: Average larval survival rate of *S. frugiperda* in Sub-sudanian zone

Season	Tsv L1 (%)	Tsv L2 (%)	Tsv L3 (%)	Tsv L4 (%)	Tsv L5 (%)	Tsv L6 (%)	Tsv I (%)
Dry season	85.79 ± 7.55[a]	95 ± 3.92[a]	97.8 ± 2.3[a]	99.27± 1.99[a]	99.7 ± 1.30[a]	100 ± 0[a]	100 ± 0[a]
Rainy season	74.64 ± 5.19[b]	93.18 ± 4.53[a]	95.89 ± 2.50[b]	96.77 ± 3.14[b]	96.17 ± 3.81[b]	94.7 ± 4.79[b]	94.93 ± 4.25[b]
Test-t	6.659535	1.675591	3.079727	3.686991	4.786752	6.056327	6.524568
Ddl	59	59	59	59	59	59	59
P	0.0001	0.099202	0.003164	0.000502	0.000012	0.0001	0.0001

Numbers followed by the same letters in the same column are not significantly different at 5% threshold

Table 9: Average larval survival rate of *S. frugiperda* in Guinean zone

Season	Tsv L1 (%)	Tsv L2 (%)	Tsv L3 (%)	Tsv L4 (%)	Tsv L5 (%)	Tsv L6 (%)	Tsv I (%)
Dry season	89.19±7.46[a]	85.45±4.14[a]	90.09±3.38[a]	94.08±3[a]	96.25±2.42[a]	100 ± 0[a]	100±0[a]
Rainy season	80.91±8.93[b]	84.39±4.29[a]	90.88±5.94[a]	94.62±4.1[a]	95.69±2.54[a]	96.52±0.75[b]	90.04±3.19[b]
Test-t	3.899952	0.981	-0,635708	-0.58307	0.881631	25.39257	17.09044
Ddl	59	59	59	59	59	59	59
P	0.000252	0.330667	0.527467	0.562107	0.381615	0.00001	0.00001

Numbers followed by the same letters in the same column are not significantly different at 5% threshol

4.1.1.2.8 Emergence rate in Sub-sudanian and Guinean zones

Emergence rate was significantly different among season in both zones. In Sub-sudanese zone, it was higher in rainy season (40.36± 8.49%) and lower in dry season (21.19± 5.89%) (t-test = -25.9; = 58; P < 0.05) (Table 10).

According to Guinean zone, the emergence rate was higher in rainy season with 36.8± 7.22 % and lower in dry season with 19.08 ±7.2% (21.19± 5.89%) (t-test = -9.51602; P < 0.05). (Table 11).

4.1.1.2.9 Adult life span and sex ratio in Sub-sudanian and Guinean zones

- **Adult life span and sex ratio in Sub-sudanian zone**

The sex ratio in dry season differed significantly from the one in rainy season with 0.72 ± 0.17 and 1.22 ± 0.15 respectively (t-test = -11.9686; P <0.05) (Table 10). The average lifespan of male and female differed significantly within periods. The lifespan of females was higher with 7.7±0.99 days and the one of males shorter with 3.07±0.74 days during dry season (t-test = 20.56392; P <0.05) (Figure 37). In rainy season, no significant difference was observed in the life span of adults (t-test = 0.856841; P > 0.05) (Figure 36). Furthermore, the average lifespan of adults varies significantly over the two study periods. It was longer during dry season with 10.77 ± 1.13 days and shorter during rainy season with 8 ± 1.43 days (t-test = 8.2701; P <0.05) (Table 10).

- **Adult life span and sex ratio in Guinean zone**

In Guinean zone, the sex ratio was not significantly different between seasons (t-test = -0.413732; ddl = 58; P >0.05). The average lifespan of male and female differed significantly within seasons. During rainy season, the lifespan of females was shorter with 10.33± 2.56 days (t-test = -7.5954; P <0.05) and the one of males longer with 11.4± 1.52 days (t-test = -12.6937; P <0.05) (Figure 36). Furthermore, the average lifespan of adults varies significantly over the two study periods. It was longer during rainy season with 21.73 ± 3.27 days and shorter during dry season with 12.27 ± 2.26 days (t-test = -13.0512; P <0.05) (Table 11).

Table 10: Fertility rate, emergence rate, adult life span and sex ratio in sub-sudanian zone

Season	**Fertility rate (%)**	**Emergence rate (%)**	**Adult life span (days)**	**Sex-ratio**
Dry season	26.77 ± 6.44[b]	21.19 ± 5.89[b]	10.77 ± 1.13[b]	0.72 ± 0.17[a]
Rainy season	71.64 ± 6.98[a]	40.36 ± 8.49[a]	8 ± 1.43[a]	1.22 ± 0.15[b]
Test-t	-25.8745	-25.8745	8.270111	-11.9686
Ddl	59	59	59	59
P	0.00001	0.00001	0.00001	0.00001

Table 11: Fertility rate, emergence rate, adult life span and sex ratio in Guinean zone

Season	**Fertility rate (%)**	**Emergence rate (%)**	**Adult life span (days)**	**Sex-ratio**
Dry season	29.56±6.98	19.08±7.2	12.27±2.26	0.92±0.23
Rainy season	74.97±5.18	36.8±7.22	21.73±3.27	1.17±0.31
Test-t	-28.633	-9.51602	-13.0512	-0.413732
Ddl	59	59	59	59
P	0.00001	0.00001	0.00001	0.680596

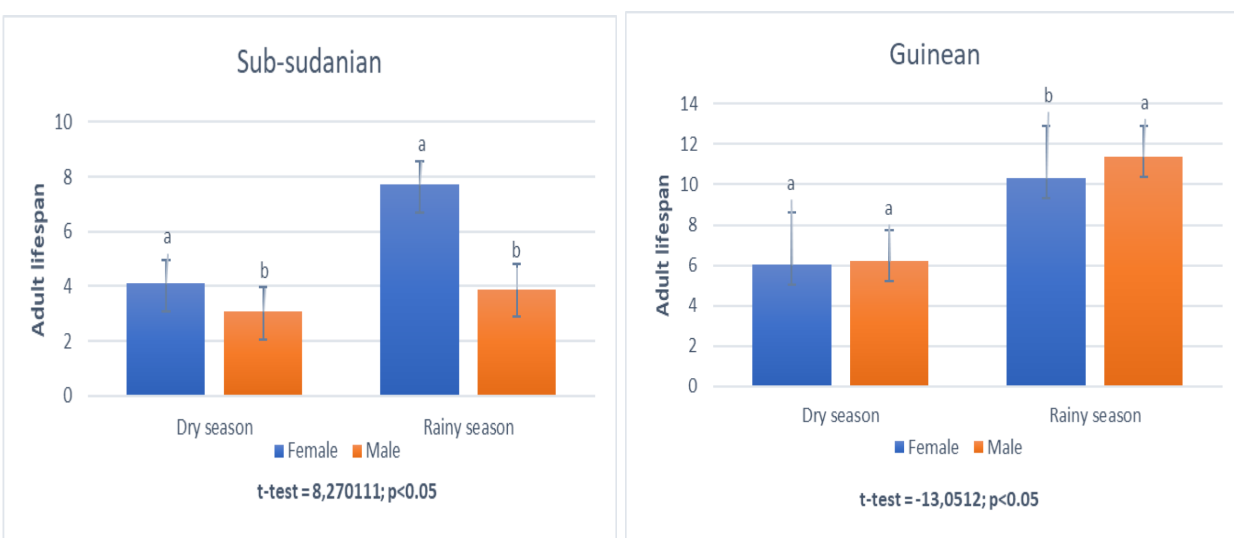


Figure 36: Adult lifespan

4.1.1.3 Demographic parameters of *S. frugiperda* in Sub-sudanian and Guinean zones

- **Demographic parameters in Sub-sudanese zone**

The analysis indicated that the net reproductive rate, intrinsic rate of natural increase, generation time and doubling time of the population differed significantly between the study periods (Table 12). The net reproduction rate (Ro) was higher in rainy season (27.67 ± 7.82%) compared to dry season (25.43 ± 7.61%) (t-test = -1.1208; $P < 0.05$). The intrinsic rate of natural population increase (Rm) was higher in rainy season 0.26 ± 0.01 compared to the dry season rate (0.24 ± 0.03) (t-test = -4.9187; $P < 0.05$). As for the generation time (Tg) the highest was observed during rainy season (35.93 ± 2.04 days) while the shortest is obtained in dry season (35.12 ± 1.47 days) (t-test = 3.826212; $P < 0.05$). For the population doubling time (DT), the *S. frugiperda* population was significantly lower in the rainy season with 2.62 ± 0.13 days compared to dry season, 2.93 ± 0.28 days (t-test = -2.58667; $P < 0.05$).

- **Demographic parameters in Guinean zone**

In Guinean zone the net reproductive rate, intrinsic rate of natural increase, generation time and doubling time were significantly different between rainy and dry season. The net reproduction rate (Ro) was higher in rainy season with 24.53 ± 6.34% and shorter in dry season with 19.27± 6.16% (t-test = -4.62281; ddl = 58; $P < 0.05$). The intrinsic rate of natural population increase (Rm) was higher during dry season (0.22 ±0.01) compared to rainy season (0.17±0.01). According to the generation time (Tg) and the population doubling time (DT), the highest was recorded during rainy season with respectively 48.93±3.2 days (t-test = -10.8456); $P < 0.05$) and 3.91±027 days (t-test = -12.7127; $P < 0.05$) (Table13).

Table 12: Biodemographic parameters of *S. frugiperda* in Sub-sudanian zone

Season	R_o	R_m	Tg (days)	D.T (days)
Dry season	25.43 ± 7.61[a]	0.24 ± 0.03[a]	35.12 ± 1.47[a]	2.93±0.28[a]
Rainy season	27.67 ± 7.82[a]	0.26 ± 0.01[b]	35.93 ± 2.04[a]	2.62±0.13[b]
Test-t	-1.12086	-4.9187	3.826212	-2.58667
Ddl	59	59	59	59
P	0.266969	0.000008	0.000321	0.012222

Ro : Net reproduction rate;

Rm : Intrinsic rate of natural increase;

Tg : Generation time;

DT : Population doubling time.

Table 13: Biodemographic parameters of *S. frugiperda* in Guinean zone

	R_o	R_m	Tg (days)	D.T. (days)
Dry season	19.27±6.16	0.22±0.01	41.27±2.18	3.11±0.21
Rainy season	24.53±6.34	0.17±0.01	48.93±3.2	3.91±0.27
Test-t	-4.62281	12.60508	-10.8456	-12.7127
Ddl	59	59	59	59
P	0.000022	0.00001	0.00001	0.00001

4.1.2 Seasonal Variation of *S.frugiperda* on Maize Field

4.1.2.1 Average numbers of adult moths according to days after sowing

- **Sub-sudanian zone**

The average number of moths trapped in the whorl stage of the crops grown in rainy and dry season was higher in whorl stage than in the other phenological stages (tasselling, maturation). In 2020, these numbers at whorl stage ranged from 118.33 ± 69.65 to 59.71 ± 17.21 and the lowest numbers recorded in the pod maturation ranged from 30.33± 13.05 to 11.67± 3.05 moths during rainy and dry season respectively. In 2021, the average numbers at whorl stage ranged from 103.28± 41.98 to 59.25± 23.97 and the lowest numbers recorded at pod maturation ranged from 49.33 ± 3.78 to 16 ± 1.03 moths respectively during rainy and dry season. The analysis of variance showed significant differences between the mean numbers recorded at the different phenological phases during in 2020 (F= 111.08; ddl = 3 P< 0.001) and 2021 (F=53.81; ddl = 3; P< 0.0001) (figure 34)

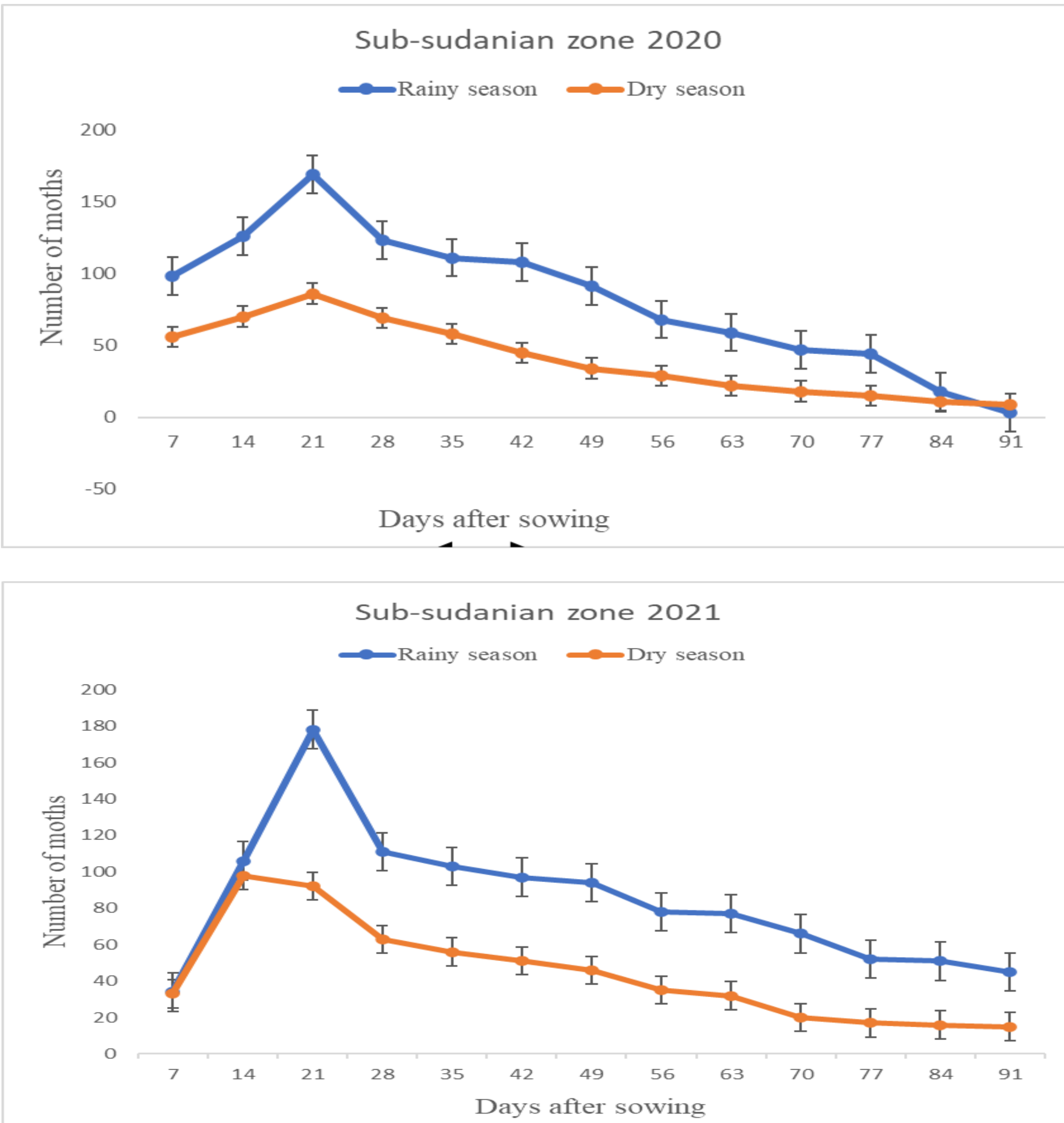


Figure 37: Evolution of moths according to days after sowing in Sub-sudanian zone in 2020 and 2021

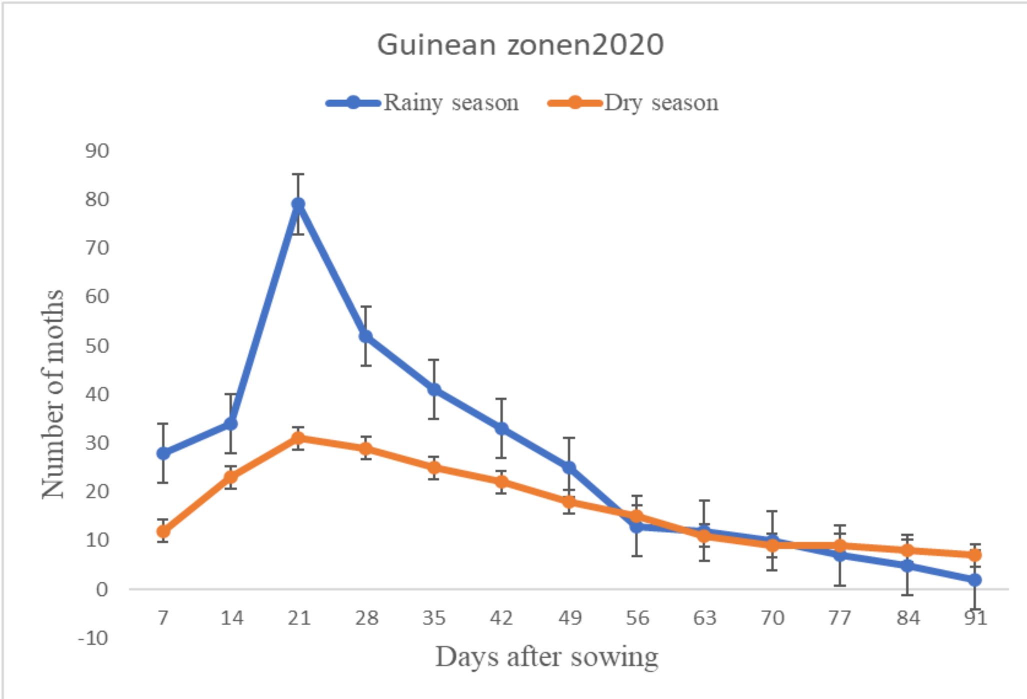
4.1.2.2 Average numbers of adult moths according to phenological stages

- **Sub-sudanian zone**

The average number of moths trapped in the whorl stage of the crops grown in rainy and dry season was higher in whorl stage than in the other phenological stages (tasselling, maturation). In 2020, these numbers at whorl stage ranged from 118.33 ± 69.65 to 59.71 ± 17.21 and the lowest numbers recorded in the pod maturation ranged from 30.33± 13.05 to 11.67± 3.05 moths during rainy and dry season respectively. In 2021, the average numbers at whorl stage ranged from 103.28± 41.98 to 59.25± 23.97 and the lowest numbers recorded at pod maturation ranged from 49.33 ± 3.78 to 16 ± 1.03 moths respectively during rainy and dry season. The analysis of variance showed significant differences between the mean numbers recorded at the different phenological phases during in 2020 ($F= 111.08$; ddl = 3 $P< 0.001$) and 2021 ($F=53.81$; ddl = 3; $P< 0.0001$) (Figure 39).

- **Guinean zone**

The average number of moths during rainy and dry season was higher in whorl stage than in tasselling and pod maturation stage. In 2020, the highest number of moths was recorded at the whorl stage with 41.71± 18.7 moths and the lowest at pod maturation with 4.66± 2.51during rainy season. In 2021, the average numbers at whorl stage ranged from 68.83± 28.88 to 29.85± 10.24 and the lowest numbers recorded at pod maturation ranged from 8 ± 3.07 to 7.67 ± 1.15 moths respectively during rainy and dry season. The analysis of variance showed significant differences between the mean numbers recorded at the different phenological phases during in 2020 ($F= 133.59$; ddl = 3; $P< 0.0001$) and 2021 ($F=65.913$; ddl = 3; $P< 0.001$) (Figure 39).



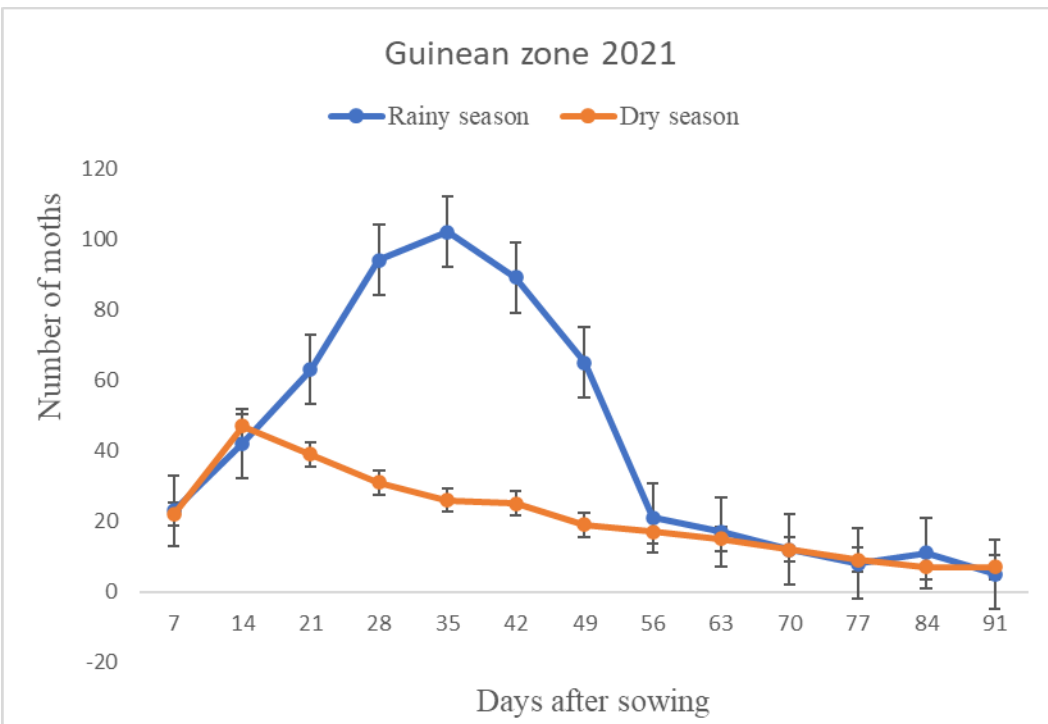


Figure 38: Evolution of moths according to days after sowing in Guinean zone in 2020 and 2021

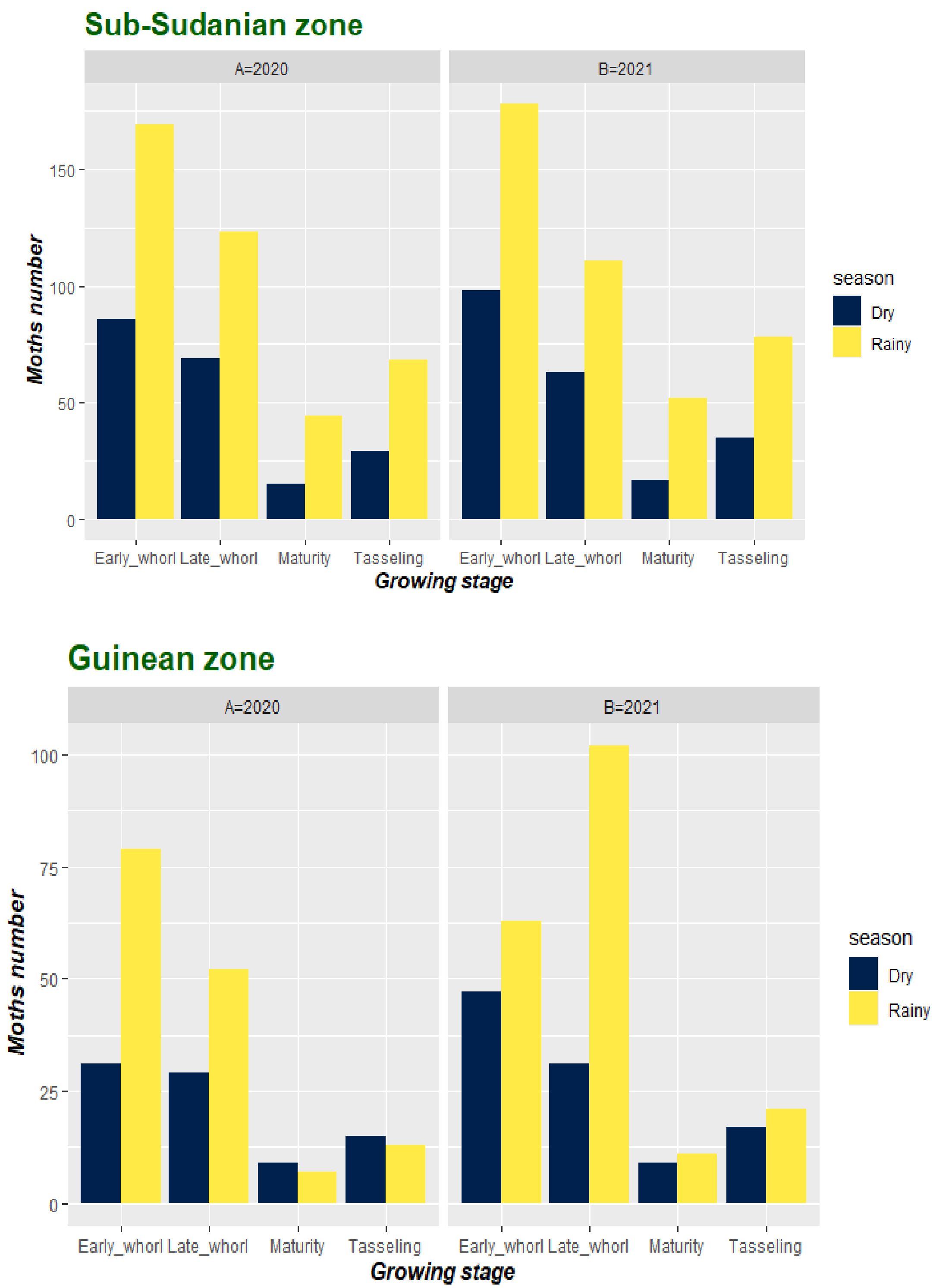
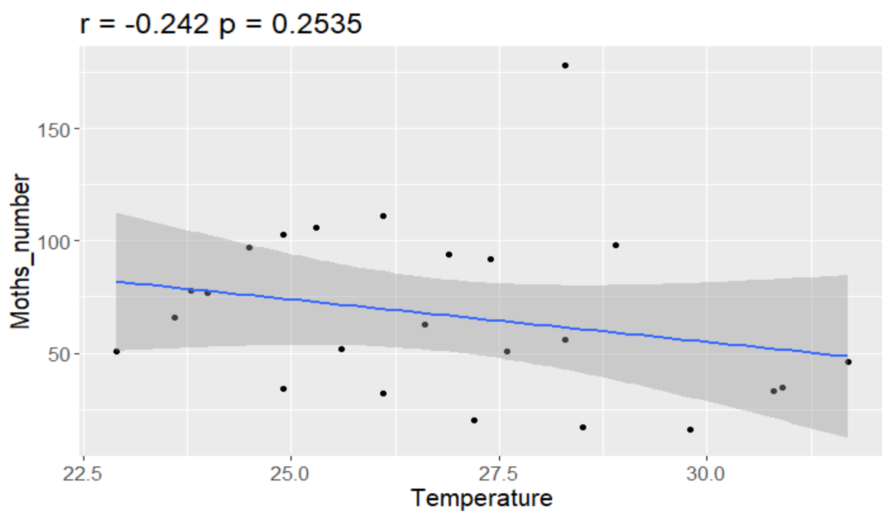


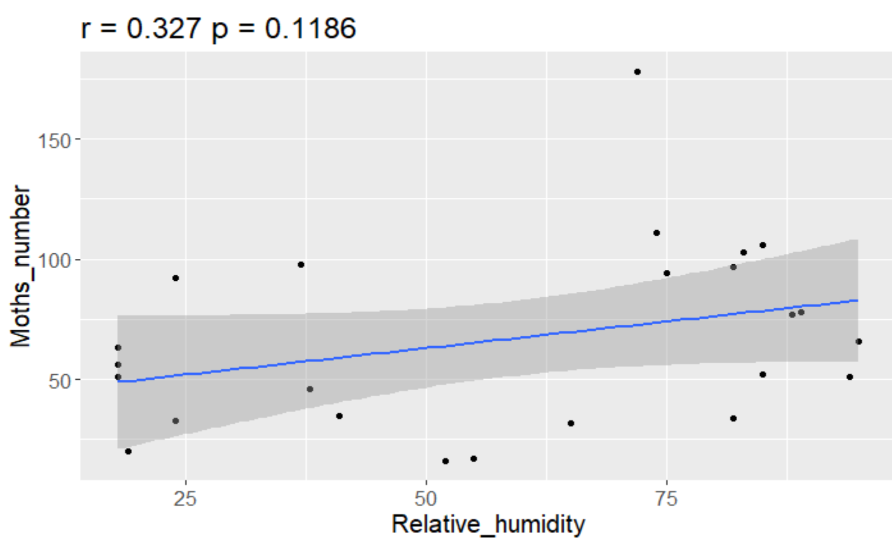
Figure 39: Number of moths according to phenological stage in Sub-sudanain and Guinean zones during 2020 and 2021

4.1.2.3 Relationship between moth numbers and some climatic factors

- **Sub-sudanian zone**

The study of the relationship between the numbers of moths and climatic factors in 2020 revealed no significant negative correlations with temperature (r= -0.242). No significant positive correlations were obtained between moths numbers and relative humidity (r=0327) and no significant positive correlation between moths numbers and rainfall (r= 0.0125) (Figure 40)





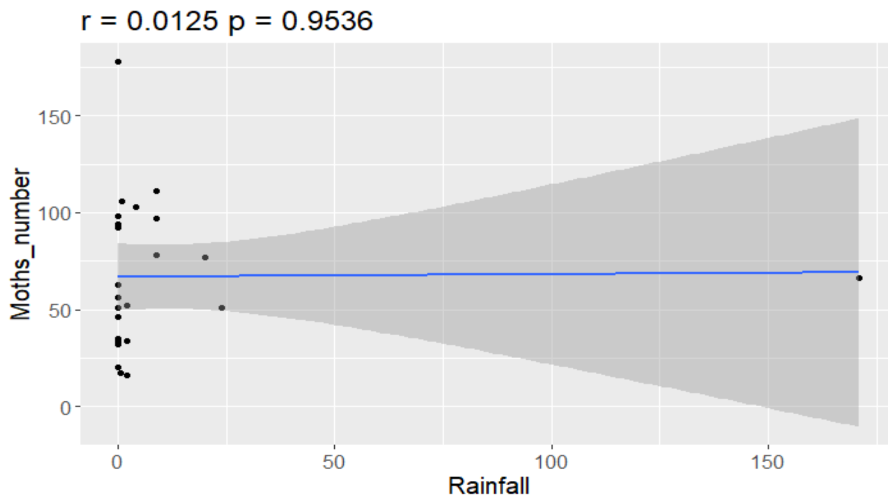


Figure 40: Correlation between number of moth and climatic factors in Sub-sudanian zone

- **Guinean zone**

There was a no significant negative correlation between number of moths and temperature (r=-0.242). Therefore, relative humidity and rainfall were no significantly and positively correlated number of moths with respectively r=0.3271 and r=0.0125. (Figure 41)

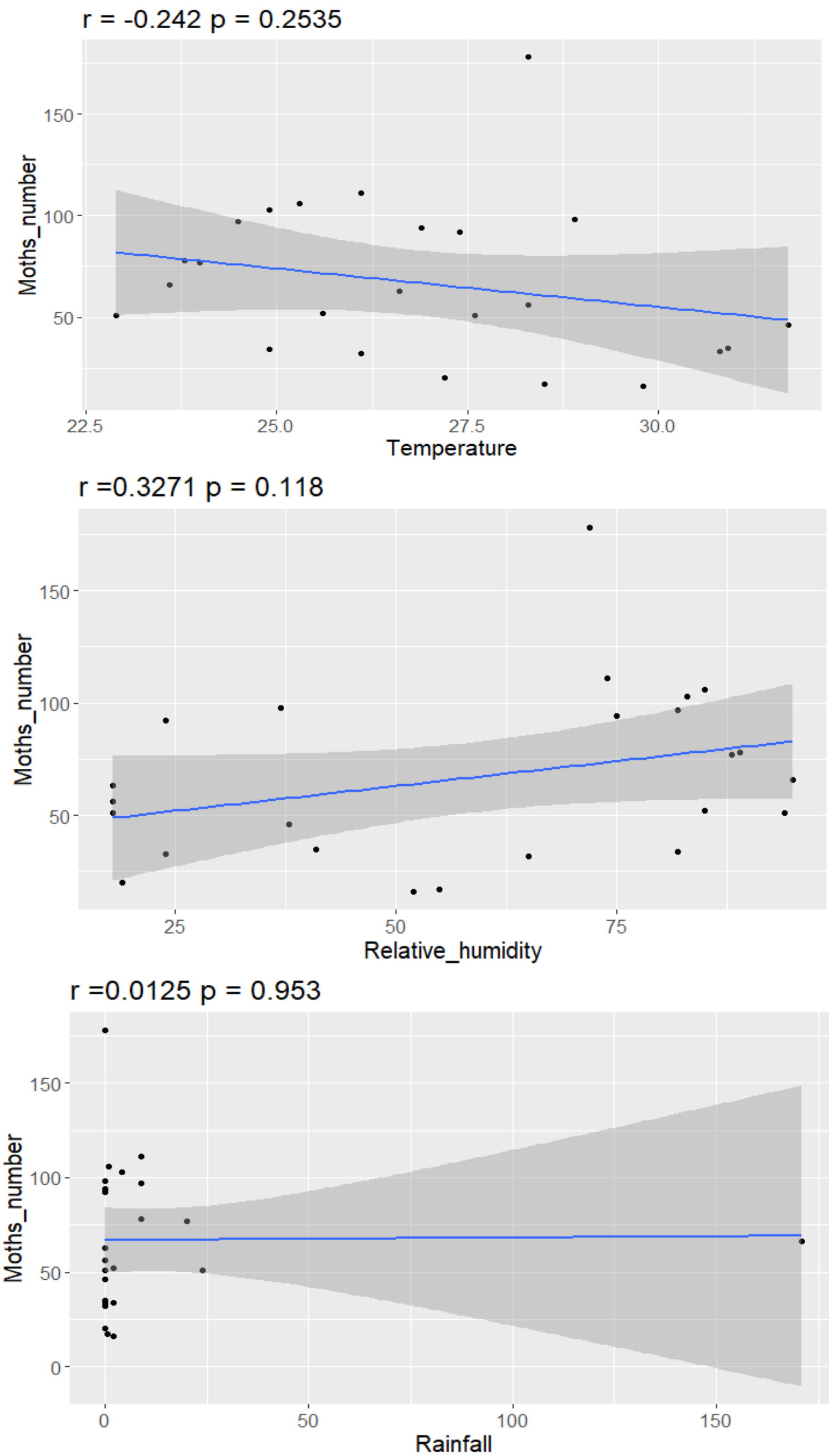


Figure 41: Correlation between number of moth and climatic factors in Guinean zone

4.1.2.4 Damage caused by *S. frugiperda* during seasons on maize

- **Description of *S. frugiperda* damage**

In Sub-sudanian and Guinean zones, during rainy and dry seasons damages caused to leaves was done by larva of *S. frugiperda.* There were observed during the whorl stage and pod maturation stages of the plant. The larva preferentially consumed the leaf blade of newly formed tender leaves, leaving holes with ill-defined contours (Figure 42). In case of heavy infestation, the leaf blade was almost completely destroyed. Delayed growth and was observed in some heavily attacked plants. *S. frugiperda* occasionally attacked pod, especially during the rainy season The damage to the pods was less severe than the damage to the leaves exposing the plant to pathogens. (Figure 42).

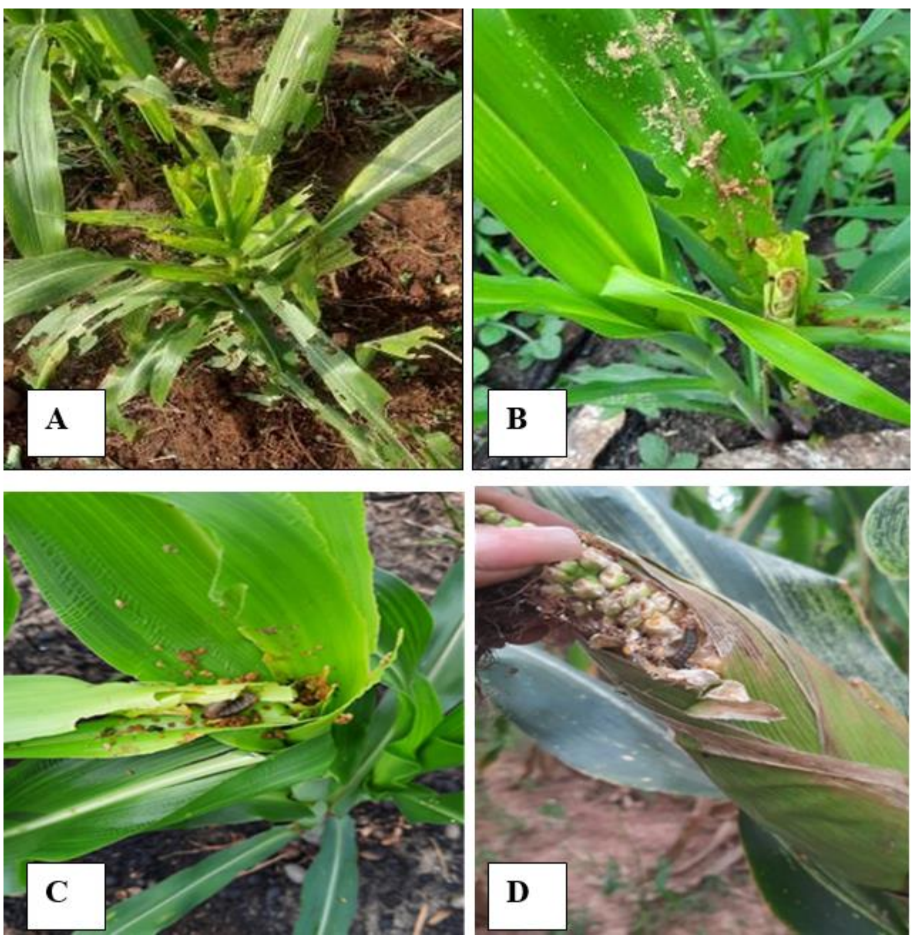


Figure 42: Some damage caused by *S. frugiperda* on maize plant

A: Holes on leaves; **B**: cutting of whorl; **C**: Destruction of whorl; **D**: Damage on pod

4.1.2.5 Damage caused by *S. frugiperda* days after sowing

The average percentages of damaged leaves per 100 plants and the leaf damage indices varied from 7th to 91st days after sowing during the different seasons of the two periods in 2020 and 2021.

- **Sub-sudanian zone**

- **Rainy season**

In 2020, the average percentages of damaged leaves and leaf damage indices increased progressively from 14th to 35th days after sowing. The highest average percentage of damaged leaves and leaf damage indices were recorded at 21st after sowing (late whorl stage). These percentages were 94.65±1.48 % and 4.04±0.04 indicating that the percentage of destruction of the plant leaf surface was higher than 50%. Statistical analysis revealed significant differences between mean percentages (F = 9.51; ddl=8; P < 0.001) and between leaf damage indices (F = 6.34; ddl=8; P < 0.001). In 2021, the highest average percentage of damaged leaves was recorded also at 21st days after sowing. This percentages 98.96±0.60 %, with a leaf damage indice higher than 4 (4.28±0.11). Statistical analysis showed significant differences between the mean percentages (F = 3.04; ddl=8; P = 0.007) and no significant difference between the leaf damage indices (F = 0.53; ddl = 8; P = 0.83) (Table 14).

- **Dry season**

In 2020, the highest average percentage of damaged leaves damage was observed at 21st day after sowing (late whorl stage) with 45.94±1.01% and the lowest average percentage was 1.36±0.48%, recorded during maturation stage. The highest index was also recorded at the 21sh day after sowing with 2.60±0.08. Statistical analysis revealed significant differences between mean percentages (F = 7.27; ddl=8; P < 0.001) and between leaf damage indices (F = 4.71; ddl=8; P < 0.001). In 2021, the highest average percentage of damaged leaves (49.94±1.01 %) was recorded at 21st after sowing (late whorl stage). From 49th day after sowing (tasseling stage) to 91st day after sowing (pod maturation), the percentages ranged from 26.91±3.57 to 3.75±0.09 %. Leaf damage indices at different days after sowing ranged from 2.03±2.28 to 0.36±1.02. Statistical analysis revealed significant difference between the mean percentages (F = 3.58; ddl =

8; P < 0.05) and no significant difference between the leaf damage indices (F = 1.72; ddl = 8; P = 0.68) (Table 15).

Table 14: Damage during rainy season in Sub-sudanian zone

		Rainy season			
		2020		2021	
Phenological stages	Days after sowing	Percentage of damage	Indices of damages	Percentage of damage	Indices of damages
Whorl stage	14	93.31 ± 0.76^{c}	4.12 ± 0.05^{c}	97.39 ± 0.80^{b}	4.36 ± 0.19^{a}
	21	94.65 ± 1.48^{bc}	4.04 ± 0.04^{bc}	98.96 ± 0.60^{ab}	4.28 ± 0.11^{a}
	35	71.87 ± 2.96^{ab}	3.78 ± 0.25^{ab}	98.47 ± 0.93^{ab}	4.39 ± 0.10^{a}
	42	52.22 ± 8.61^{a}	2.23 ± 0.19^{a}	66.32 ± 0.41^{a}	2.88 ± 0.15^{a}
Tasselling	49	49.94 ± 1.20^{a}	2.11 ± 0.13^{a}	45.98 ± 2.30^{a}	1.94 ± 0.1^{a}
	63	15.64 ± 4.10^{a}	1.63 ± 0.26^{a}	22.51 ± 0.62^{a}	1.72 ± 0.25^{a}
	70	12 ± 0.89^{a}	1.32 ± 0.18^{a}	7.98 ± 0.13^{a}	0.91 ± 0.16^{a}
Maturation	77	5.38 ± 0.47^{a}	0.54 ± 0.82^{a}	3.42 ± 0.10^{a}	0.79 ± 0.12^{a}
	91	2.64 ± 0.51^{a}	0.35 ± 0.15^{a}	3.75 ± 0.09^{a}	0.22 ± 0.07^{a}
	F	9.51	6.34 a	3.04.	0.53
	Ddl	8	8	8	8
	P	0.00002	0.002	0.007	0.89

Numbers followed by the same letters in the same column are not significantly different at 5% threshold

Table 15: Damage during dry season in Sub-sudanian zone

		Dry season			
		2020		2021	
Phenological stages	Days after sowing	Percentage of damage	Indices of damages	Percentage of damage	Indices of damages
Whorl stage	14	44.45±0.92^{ab}	1.97±0.08^{b}	45.87±0.89^{b}	2.09±0.09^{a}
	21	45.94±1.01^{ab}	2.60±0.08^{b}	49.94±1.01^{ab}	2.60±0.08^{a}
	35	45.16±2.28^{ab}	2.27±0.13^{b}	45.98±2.30^{ab}	2.17±0.15^{a}
	42	32.64±4.10^{ab}	1.80±0.28^{ab}	37.92±1.54^{a}	1.91±0.17^{a}
Tasselling	49	17±0.43^{b}	1.46±0.15^{b}	26.91±3.57^{ab}	1.80±0.26^{a}
	63	10.32±0^{b}	0.99±0.17^{b}	15.60±1.20^{ab}	1.51±0.13^{a}
	70	6.78±1.2^{b}	0.75±0.08^{b}	8.69±0.83^{ab}	0.96±0.09^{a}
Maturation	77	4.23±0.51^{a}	0.41±0.73^{a}	2.16±3.14^{ab}	0.53±0.28^{a}
	91	1.36±0.48^{b}	0.28±0.06^{b}	2.03±2.28^{ab}	0.36±1.02^{a}
	F	7.27	4.71	3.58	1.72
	Ddl	8	8	8	8
	P	0.0000061	0.01	0.045	0.68

Numbers followed by the same letters in the same column are not significantly different at 5% threshold

- **Guinean zone**

- **Rainy season**

In 2020, the highest average percentage of damaged leaves damage was observed at 21st day after sowing (late whorl stage) with 92.43±3.43 % and the lowest average percentage was 2.16±0.09 %, recorded during maturation stage. The highest index was also recorded at the 14th day after sowing with 4.15±0.11. Statistical analysis revealed no significant differences between mean percentages F = 0.48; ddl=8; P =0.86) and between leaf damage indices (F = 0.46; ddl=8; P=0.54). In 2021, the highest average percentage of damaged leaves (97.64±1.07 %) was recorded at 21st after sowing (late whorl stage). From 49th day after sowing (tasseling stage) to 91st day after sowing (pod maturation), the percentages ranged from 40.72±3.21 to 3.12±0.07 %. Leaf damage indices at different days after sowing ranged from 1.84±1.02to 0.31±0.12.

Statistical analysis revealed no significant difference between the mean percentages (F = 0.92; ddl=8; P = 0.99) and between the leaf damage indices (F = 0.13; ddl = 8; P = 0.89). (Table 16).

- **Dry season**

In 2020, the average percentages of damaged leaves and leaf damage indices increased progressively from 14th to 35th days after sowing. The highest average percentage of damaged leaves and leaf damage indices were recorded at 21st after sowing (late whorl stage). These percentages was 59.91±9.73% 3.77±0.07 indicating that the percentage of destruction of the plant leaf surface was lower than 50%. Statistical analysis revealed no significant differences between mean percentages (F = 3.15; ddl=8; P =0.09) and between leaf damage indices (F = 2.91; ddl=8; P=0.12). In 2021, the highest average percentage of damaged leaves was recorded also at 21st days after sowing. This percentages 70.38±3.42%, with a leaf damage indice lower than 4 (3.12±0.08). Statistical analysis showed no significant differences between the mean percentages (F = 2.74; ddl=8; P = 0.16) and no significant difference between the leaf damage indices (F = 0.28; ddl = 8; P = 0.97) (Table 17).

Table 16: Damage during rainy season in Guinean zone

		Rainy season			
		2020		2021	
Phenological stages	Days after sowing	Percentage of damage	Indices of damages	Percentage of damage	Indices of damages
Whorl stage	14	91.78±2.00[a]	4.15±0.11[a]	96.71±1.41[a]	4.31±0.21[a]
	21	92.43±3.43[a]	4.12±0.19[a]	97.64±1.07[a]	4.26±0.18[a]
	35	66.41±2.55[a]	3.85±1.88[a]	91.62±1.77[a]	2.99±0.26[a]
	42	48.94±1.01[a]	2.17±0.15[a]	51.35±1.89[a]	2.08±0.07[a]
Tasselling	49	36.23±1.65[a]	1.90±0.08[a]	40.72±3.21[a]	1.84±1.02[a]
	63	13.10±1.71[a]	1.58±1.41[a]	15.67±0.09[a]	1.33±0.2[a]
	70	9.96±0.60[a]	1.11±0.19[a]	9.72±0.6[a]	0.8±0.34[a]
Maturation	77	3.12±1.70[a]	0.7±0.21[a]	5.48±1.01[a]	0.56±0.02[a]
	91	2.16±0.09[a]	0.5±0.18[a]	3.12±0.07[a]	0.31±0.12[a]
	F	0.48	0.46	0.92	0.13
	Ddl	8	8	8	8
	P	0.86	0.54	0.99	0.89

Numbers followed by the same letters in the same column are not significantly different at 5% threshold

Table 17: Damage during dry season in Guinean zone

		Dry season			
		2020		2021	
Phenological stages	Days after sowing	Percentage of damage	Indices of damages	Percentage of damage	Indices of damages
Whorl stage	14	52.22±8.16[a]	2.55±0.19[a]	56.67±7.96[a]	2.55±0.19[a]
	21	59.91±9.73[a]	3.77±0.07[a]	70..38±3.42[a]	3.12±0.08[a]
	35	38.62±3.36[a]	1.97±0.14[a]	65.11±1.42[a]	2.87±0.03[a]
	42	21.38±2.21[a]	1.54±0.25[a]	46.27±9.73[a]	1.84±0.35[a]
Tasselling	49	15.22±1.89[a]	1.32±0.36[a]	21.59±1.35[a]	1.26±0.15[a]
	63	7.64±1.73[a]	1.01±0.06[a]	12.44±1.55[a]	1.13±0.14[a]
	70	4.31±1.89[a]	0.92±0.26[a]	7.38±1.89[a]	0.91±0.18[a]
Maturation	77	2.28±2.21[a]	0.37±0.07[a]	2.28±0.10[a]	0.32±0.6[a]
	91	1.13±1.08[a]	0.25±0.12[a]	1.95±0.06[a]	0.29±1.15[a]
	F	3.15	2.91	2.74	0.28
	Ddl	8	8	8	8
	P	0.09	0.12	0.16	0.97

*Numbers followed by the same letters in the same column are not significantly different at 5% threshold***.**

4.1.3 Control of *S. frugiperda* Using Aqueous Extracts of Local Plants

4.1.3.1 Effect of Aqueous extracts on Anti-appetent Rate of *S frugiperda*

The level of anti-appetent of *S. frugiperda* is presented in Table 18 according to the concentration of the aqueous extract used. In general, the level of anti-appetence of the pest increased with increasing concentration of the aqueous extract. Overall, the use of 90 g/L of each aqueous extract gave the best anti-appetence levels. The highest rate was obtained with the aqueous extract based on *A. indica* for a value of 90.05%, while *L. multiflora* recorded the lowest anti-appetent rate (61.77%).

Statistical analysis revealed significant differences between the anti-appetent rates for the same aqueous extract depending on the concentrations used. However, no significant differences were observed for the use of 70 g/L and 90 g/L aqueous extracts based on *A. indica*, *T. vogelii* and *L. multiflora* except for *R. communis*.

Table 18: Anti-appetent rate of *S. frugiperda*

Concentrations of aqueous extract	**Anti-appetent rate of *S. frugiperda* (%)**			
	A. indica	***T. vogelii***	***R. communis***	***L. multiflora***
10g/l	34.91 ± 3.1^{c}	26.12 ± 3.27^{b}	14.70 ± 4.34^{c}	9.43 ± 2.35^{a}
30g/l	36.12 ± 3.22^{c}	21.55 ± 3.76^{b}	22.53 ± 3.92^{c}	11.47 ± 3.59^{a}
50g/l	58.64 ± 3.15^{a}	49.36 ± 3.78^{a}	53.92 ± 4.85^{b}	43.76 ± 3.57^{b}
70g/l	88.74 ± 4.01^{b}	60.37 ± 3.60^{ac}	64.03 ± 4.11^{b}	54.37 ± 4.15^{bc}
90g/l	90.05 ± 3.37^{b}	72.39 ± 4.34^{c}	84.97 ± 4.67^{a}	61.77 ± 2.83^{c}
F	10.6542	5.8578	19.4815	0.83768
Ddl	4	4	4	4
P	0.00001	0.00001	0.00001	0.52460

Numbers followed by the same letters in the same column are not significantly different at 5% threshold

4.1.3.2 Effect of aqueous extracts on the mortality of *S. frugiperda*

- **Mortality rate**

Figure 43 shows the mortality rate of *S. frugiperda* after using the aqueous plant extracts at different concentrations. In general, the mortality rate of the insect increased with increasing concentration. The highest mortality rates were observed when the aqueous plant extracts were used at the concentration of 90 g/L. However, the aqueous extract from *R. communis* was the most effective in controlling the pest with over 65% mortality at 90 g/L concentration. The aqueous extract from *L. multiflora* was the least effective in this control with less than 40% mortality rate at 90 g/L. In addition, statistical analysis revealed for most of the aqueous extracts, a significant difference in mortality rate at different concentrations. However, no significant difference was observed in the mortality rate of *S. frugiperda* when the aqueous extracts based on *A. indica* and *T. vogelii* were used at the concentrations of 70 g/L and 90 g/L. The statistical analysis showed that there no significant difference among concentration for each aqueous extracts for *Azadirachta indica* (F = 18.01; ddl = 3; p < 0,001); *Tephrosia vogelii* (F = 18.01 ; ddl = 3 ; p < 0.001); *Lippia multiflora* (F = 18.90 ; ddl = 3 ; p < 0.003) and *Ricinus communis* (F = 15.23 ; ddl = 3 ; p < 0.006).

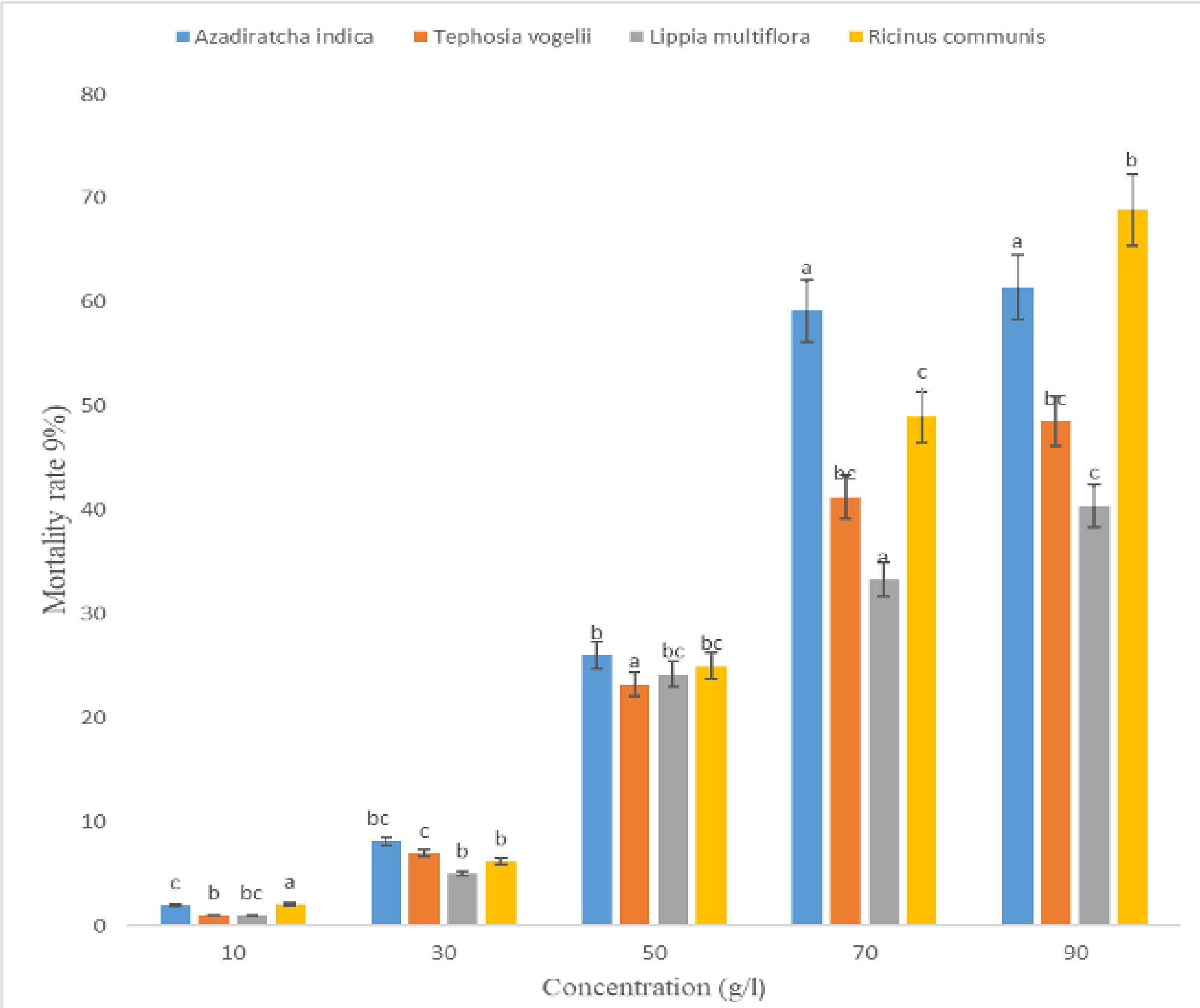


Figure 43: Mortality rate of *S. frugiperda* at different concentrations

- **Lethal concentration**

The lowest lethal concentration for *Azadirachta indica, Tephosia vogelii, Ricinus communis* and *Lippia multiflora* was recorded at 10 g/l with repectively 2.02, 1.02, 2.08 and 1.01. at 50 g/l the lethal concentration was between 20 and 25 for all plants. For *Azadirachta indica,* the lethal concentration was higher than 50 at 70 g/l and 90 g/l with respectively 59.18 and 61.45. The lethal concentration with *Ricinus communis* was higher than 50 at 9g/l with 68.87 (Table 19).

Table 19: Lethal concentration of aqueous extract on *S. frugiperda*

Extracts Concentrations	**Mortality rate of *S. frugiperda* (%)**			
	A. indica	***T. vogelii***	***R. communis***	***L. multiflora***
10g/l	2.02	1.02	2.08	1.01
30g/l	8.16	7.03	6.25	5.05
50g/l	26.04	23.26	25.00	24.24
70g/l	59.18*	41.31	48.95	33.33
90g/l	61.45*	48.56	68.87*	40.40

***** *mortality rate > 50 %*

4.1.3.3 Effect of aqueous extract on living maize plants

In Sub-sudanainan zone the attack rate at different concentration was significantly different for *A. indica* (F= 572.338, ddl= 2, P<0.001*)*; *T. vogelii* (F= 483.123, ddl= 2, P<0.001*)*; *R. communis* (F= 535.818, ddl= 2, P<0.001*)*. For *A. indica* the lowest attack rate was recorded at 90g/l (1.55± 0.7) and at 70g/l (6.33±1.62) For *T. vogelii* and *R. communis*, the lowest attack rate was recorded at 90g/l with 9.08± 0.96 and 5.86±1.08 respectively. The attack rate for the untreated plot was higher with 90.28± 1.99 (Table 20).

In Guinean zone the attack rate at different concentration was significantly different for *A. indica* (F= 474.231, ddl= 2, P<0.001*)*; *T. vogelii* (F= 521.142, ddl= 2, P<0.001*)*; *R. communis* (F= 465.732, ddl= 2, P<0.001*)*. The attack rate was lower at 90g/l for *A. indica* (0.87± 3.54), *T. vogelii* (9.18± 1.21) and *R. communis* (4.16±1.11). At 50g/l, the attack rate was between 20 and 25 for all plants tested. The attack rate for the untreated plot was higher with 89.21± 3.54 (Table 21).

Table 20: Effect of aqueous extract on attack rate on living maize plants in Sub-sudanian zone

Extracts concentrations	Attack rate of *S. frugiperda* (%)		
	Azadirachta indica	***Tephrosia vogelii***	***Ricinus communis***
50g/l	34.53 ± 4.66^{b}	36.00 ± 1.74^{b}	31.88 ± 1.79^{b}
70g/l	6.33 ± 1.62^{c}	20.55 ± 1.85^{b}	25.66 ± 1.45^{b}
90g/l	1.55 ± 0.79^{d}	9.08 ± 0.96^{c}	5.86 ± 1.08^{c}
Untreated	90.28 ± 1.99^{a}	90.28 ± 1.99^{a}	90.28 ± 1.99^{a}
F	572.338	483.123	535.818
ddl	2	2	2
P	0.00001	0.00001	0.00001

Numbers followed by the same letters in the same column are not significantly different at 5% threshold.

Table 21: Effect of aqueous extract on attack rate on living maize plants in Guinean zone

Extracts concentrations s	Attack rate (%)		
	Azadirachta indica	***Tephrosia vogelii***	***Ricinus communis***
50g/l	23.51 ± 2.17^{b}	28.09 ± 2.43^{b}	25.23 ± 1.95^{b}
70g/l	5.14 ± 1.53^{c}	15.65 ± 1.25^{b}	23.62 ± 1.84^{b}
90g/l	0.87 ± 0.11^{d}	9.18 ± 1.21^{c}	4.16 ± 1.11^{c}
Untreated	89.21 ± 3.54^{a}	89.21 ± 3.54^{a}	89.21 ± 3.54^{a}
F	474.231	521.142	465.732
Ddl	2	2	2
P	0.00001	0.00001	0.00001

Numbers followed by the same letters in the same column are not significantly different at 5% threshold.

4.1.3.4 Phytochemical screening of the local plants

- **Qualitative phytochemical screening**

Various phytochemicals were present in the different plant extracts. None of the tested plants had all the phytochemicals. Polyphenols, saponins, flavonoids, tannins gallic, steroids and terpenoids were found in all plants tested. Tannins catechic was present only in the leave of *Azadirachta indica.* Steroids, terpenoids, Leucoanthocyanes and quinones were not seen in all plants leaves. whereas, glycosides were absent in all plants except *Azadirachta indica* (Table 22).

Table 22: Qualitative phytochemical screenning

	A. indica I	*R. communis*	*L. multiflora*	*T. vogelii*
Saponins	+	+	+	+
Polyphenols	+	+	+	+
Flavonoids	+	+	+	+
Tannins gallic	+	+	+	+
Tannins catechic	-	+	+	+
Steroids et terpenoids	-	-	-	-
Quinones	-	-	-	-
Akaloids	-	-	-	-
Leucoanthocyanes	-	-	-	-
Glycosides cardiotonics	+	-	-	-

(+) = présence du métabolite, (-) = absence du métabolite

- **Quantitative phytochemical screening**

The phytochemicals present in all plants tested were suggested to quantitative phytochemicals test. The highest polyphenols quantity was observed in *Ricinus communis* (87.33±0.57) follow by Lippia multiflora with76.33±2.7. Higher quantity of flavonoids was found in *Ricinus communis* (91±1.7) and *Lippia multiflora* than the others plants.

Ricinus communis gave considerably maximum of tannins with 753.62±10.47 than others plants follow by *Lippia multiflora* (753.62±10.47) (Table 23).

Table 23: Quantitative phytochemical screenning

	Polyphenols	Flavonoids	Tanins	Tanins condense
Azadirachta indica	58.33±1.15	55.67±2.7	545.9±4.2	23.73±1.04
Ricinus communis	87.33±0.57	91±1,7	834.5±6.1	132.11±3.01
Lippia multiflora	76.33±2.7	74.33±2.08	753.62±10.47	118.01±1.9
Tephrosia vogelii	61±1.7	35±2	560.8±10.7	81.14±2.9

4.1.4 Modelling the current and future distribution Of *S. frugiperda* under changing climatic condition

4.1.4.1 Model performance evaluation

As a whole 112 candicates models were run with all combinaison of 17 regularization multiplier settings 29 feature class combinaison and 4 distinct sets of environmental variables. Among candidate models that were statistically significant, 104 were meeting omission rate criteria while 3 models met AICc criteria. Only 1 model significantly met omission rate and AICc criteria (Figure 44).

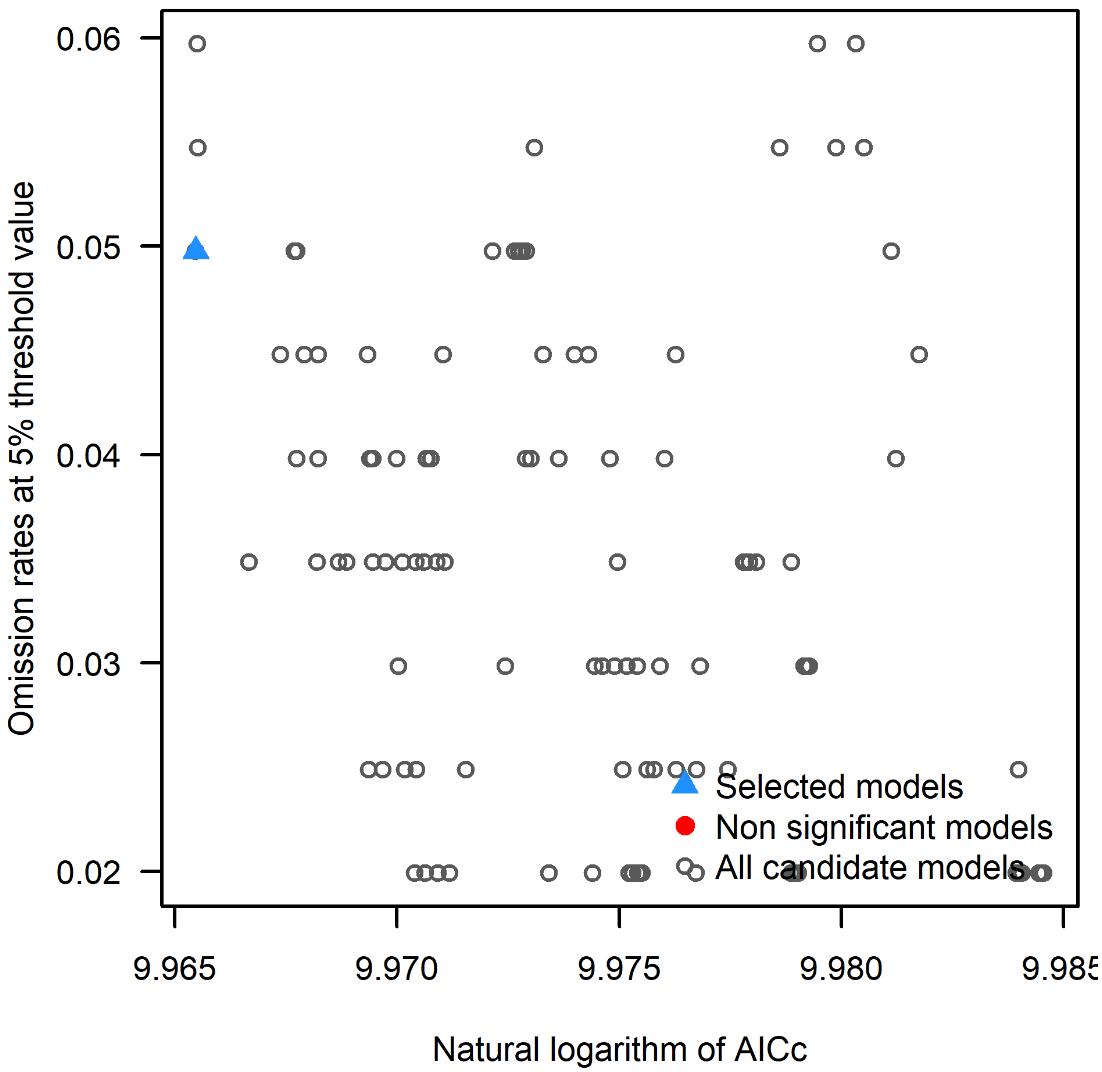


Figure 44: Calibration results

The ROC curve showed that the average AUC value of the model was 0.727, which was much higher than the AUC value of the random prediction model (0.5), indicating that the prediction had good accuracy. The model-predicted distribution area had a good fit to the actual distribution area of the species (Figure 45).

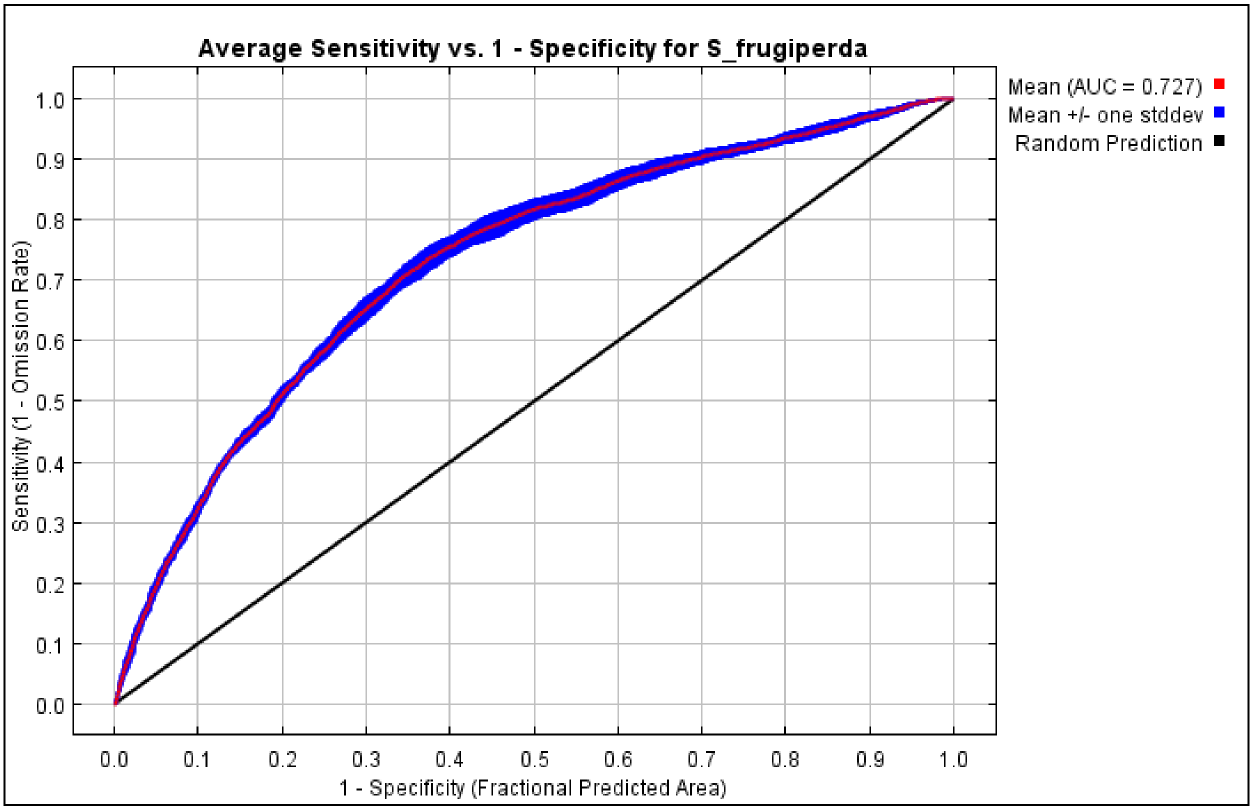


Figure 45: Average sensitivity- specificity for *S. frugiperda*

4.1.4.2 Variable importance

The curves in Figure 46 show how the predicted probability of presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample. An increase in variables such as bio3, bio5 and bio12 trend to predict absence whereas an increase in bio1 and bio17 predict a presence of the species.

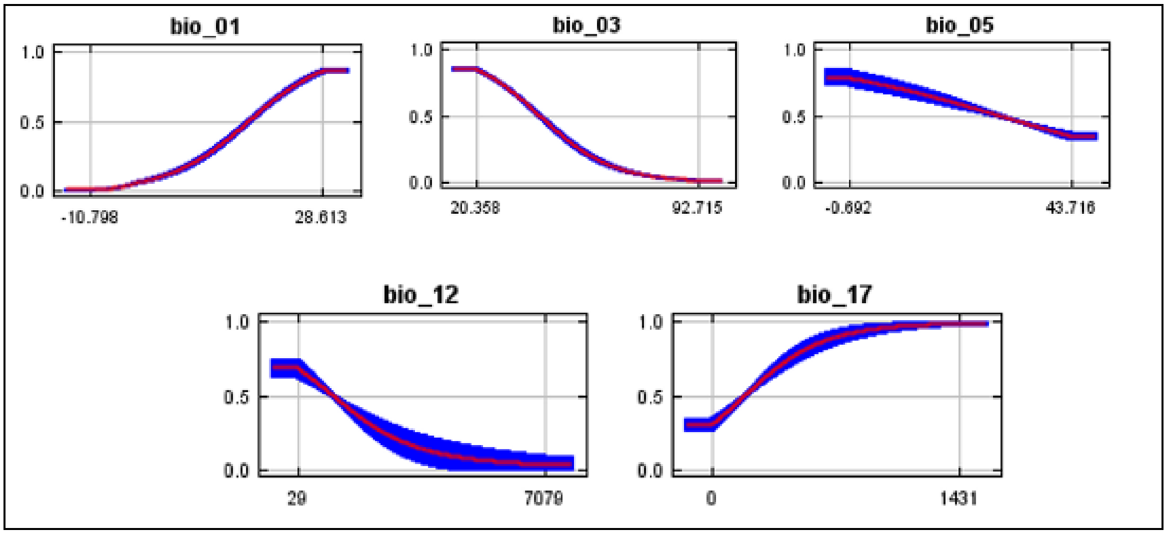


Figure 46: Variables affecting MaxEnt prediction

4.1.4.3 Percentage contribution of predictor variables.

The main variables for predicting potential distribution of *S. frugiperda* were bio3 (Isothermality), follow by bio1 (Annual mean temperature), bio5 (Max temperature of warmest month), bio17 (Precipitation of driest quarter) and bio12 (Annual precipitation) with a contribution of 40.8%, 21.2%, 15.3%, 5%, 5.3% respectively. Bio12 was the least contributing variable (Figure 47).

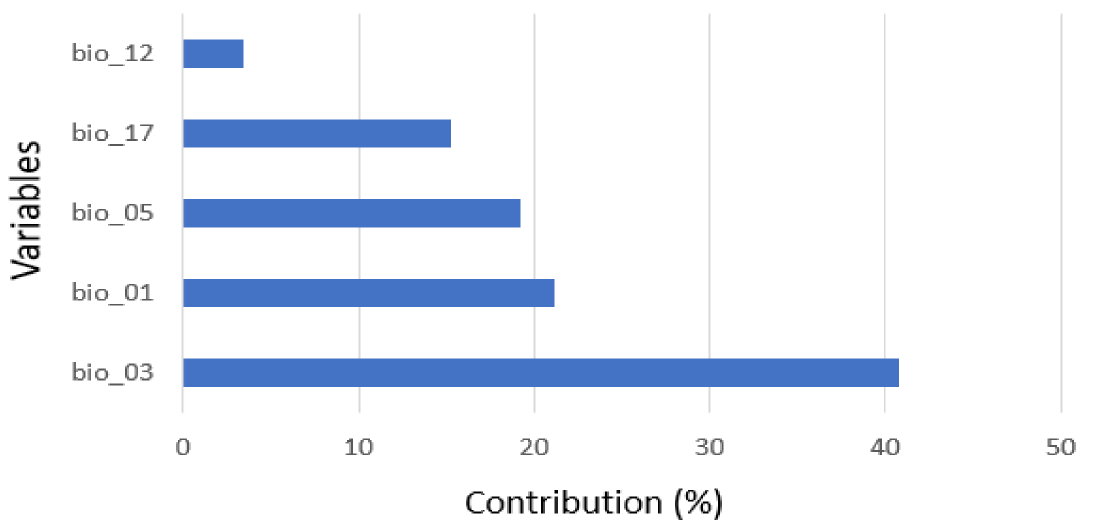


Figure 47: Variables contribution

4.1.4.4 Current and future habitat suitability of *S. frugiperda* in Côte d'Ivoire

The projection of the current distribution of *S. frugiperda* show that most areas (79.04%) of Côte d'Ivoire are highly suitable, except the western part (29.95%) of the country which is unsuitable (Figure 48). The results showed that, in 2050, all over the country will be unsuitable for *S. frugiperda* according to MIROC and BCC-CSM1-1 projection for both RCPs scenarios compared to the current distribution(Figure 49) In 2070, according to MIROC and BCC-CSM1-1 projection for the RCP 4.5 Cote d'Ivoire will remain unsuitable. For the RCP 8.5, according to MIROC projection, all the country will remain unsuitable, while, according to BCC-CSM1-1 projection only 2.79% will be suitable (Figure 50).

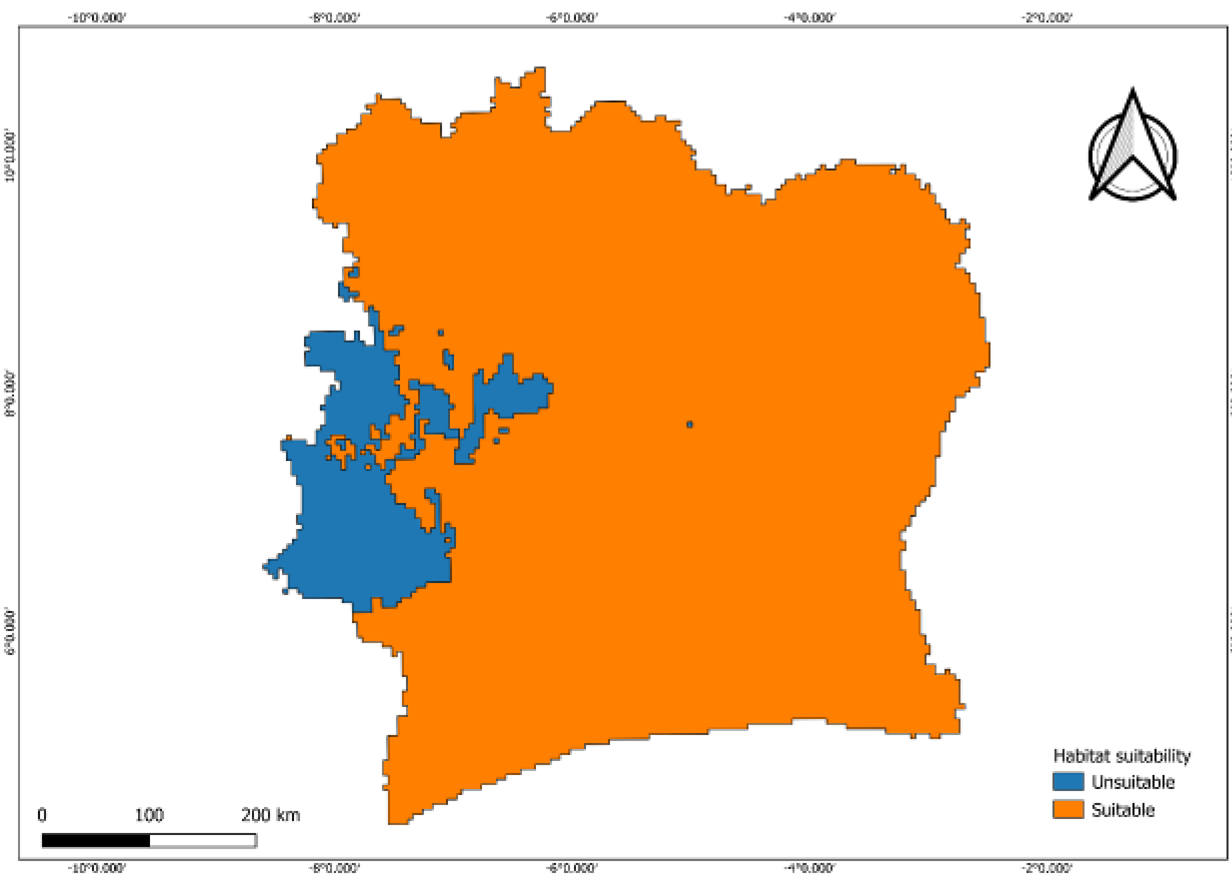


Figure 48: Current habitat suitability of *S. frugiperda* in Cote d'Ivoire

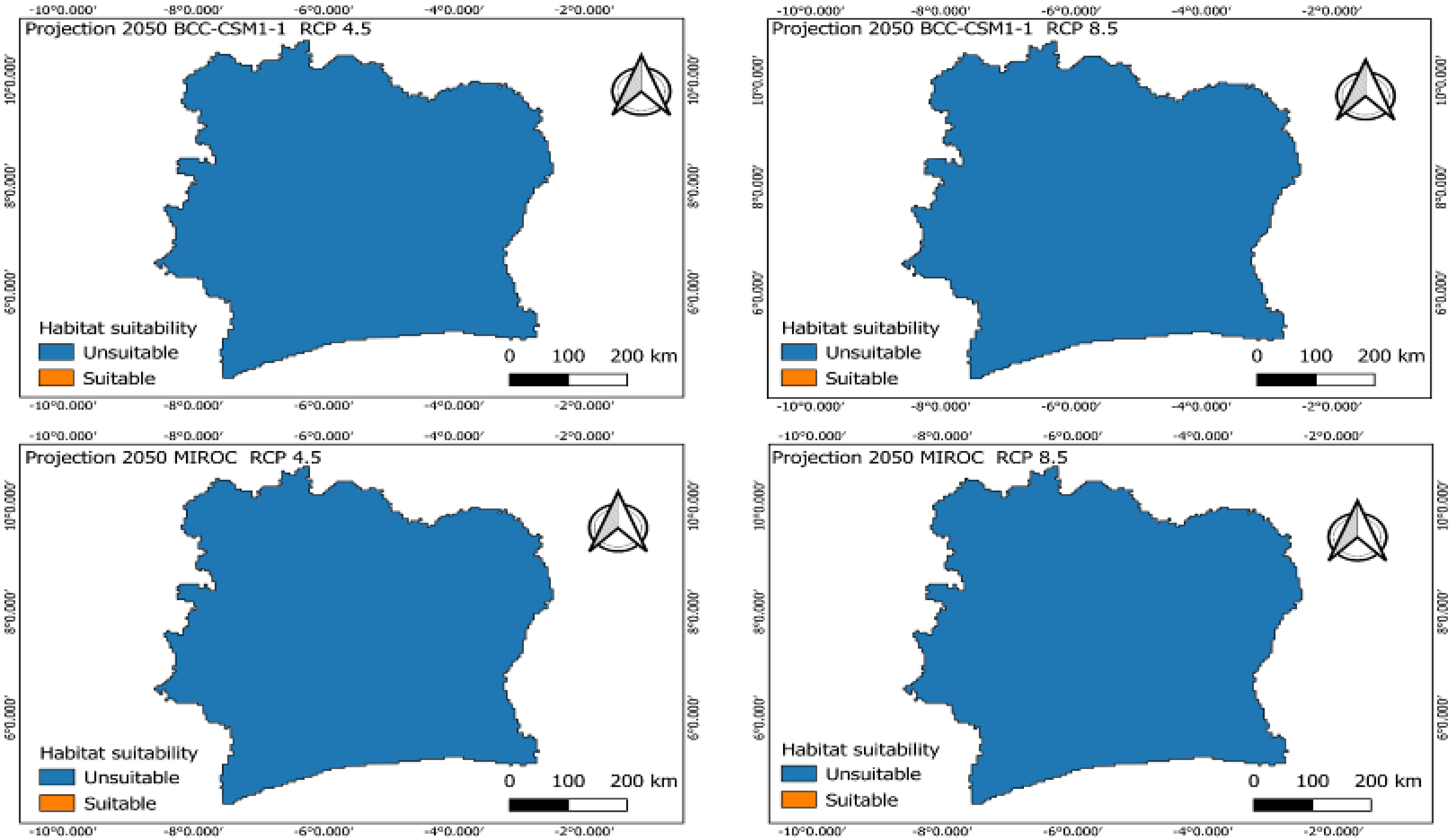


Figure 49: Habitat suitability of S.fugiperda in Cote d'Ivoire for the projection 2050

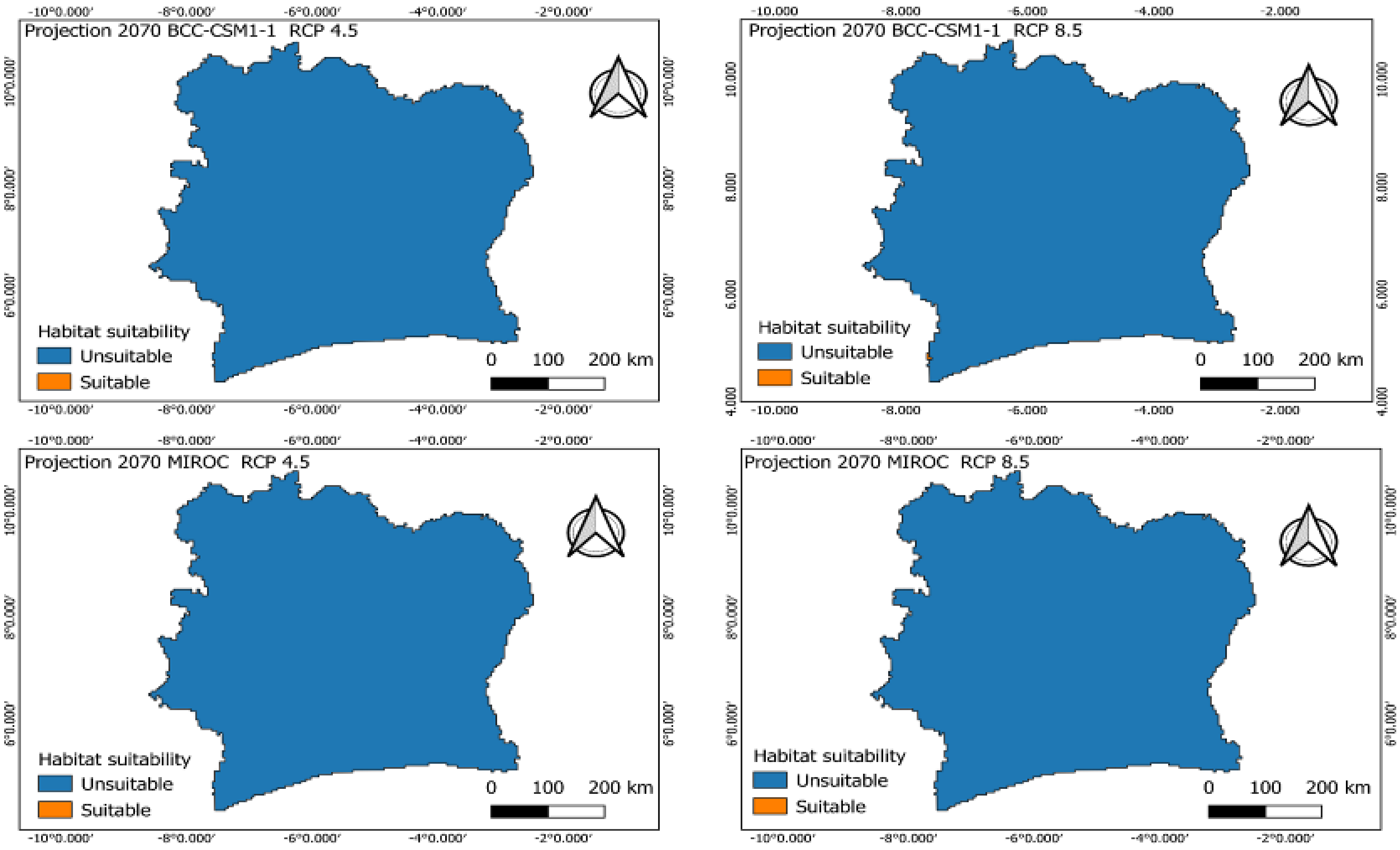


Figure 50: Habitat suitability of S.fugiperda in Cote d'Ivoire for the projection 2070

4.2 Discussion

- **Biodemographical Parameters of *S. frugiperda***

This work allowed us to study the influence of season on the development cycle of *Spodoptera frugiperda*. The reproductive parameters of *S. frugiperda* female moths were significantly affected by temperature and humidity in both seasons. The mean pre-oviposition duration of 2.83 ± 0.70 days during rainy season in Sub-sudanain zone and Guinean zone observed in our study is close to that of (Hauverset et al., 2021) who obtained 2.52 ± 0.52 days at a temperature range of 24 to 26°C and a relative humidity (RH) of 60 to 63%. This is in agreement with the results of (Luginbill, 1928), who obtained a pre-oviposition period of 3 to 4 days. (Habib et al., 1982) Reported that *Spodoptera* species have a relatively short pre-oviposition period. According to these authors, adults reach sexual maturity and mate shortly after emergence. The average oviposition period was longer in the dry season than in the rainy season. According to (Prasanna et al., 2018), this could be explained by the fact that after a pre-oviposition period of 3 to 4 days, the female normally lays most of her eggs during the first 4 to 5 days of her life. However, some oviposition occurs up to 3 weeks. In this study, female *S. frugiperda* laid eggs in both seasons. Insect eggs require large amounts of nutrients for their development until they hatch (Hilker and Meiners, 2003). The average number of eggs laid per female in dry season was higher than in rainy season. Our results do not corroborate those of (Barfield and Asley, 2010), who obtained 1929 eggs at 25°C, 1086 eggs at 30°C. This difference could be explained by the fact that in our study, the work was carried out on maize in the vegetative phase in contrast to those of these authors, who carried out their study on maize in the reproductive phase. Survival rates were high in both seasons. We also observed an increase in larval survival rates during the evolution of the different instars. The imaginal survival rates were also high in dry season as well as in rainy season. These results show that the optimum temperature and relative humidity threshold for larval and imaginal survival of *S. frugiperda* would be between 25.55°C - 27.61°C and 49.87% and 78.55%.

During our study, not all eggs hatched. This finding does not corroborate the results of (Luginbill, 1928), who reported that *S. frugiperda* was very fertile with a fertility rate of 100%. According to (Milonas and Savopoulou-Soultani, 2000), fecundity generally increases with temperature, between a lower and an upper threshold, up to the optimal point. In this study, most eggs hatched in the rainy season at an average temperature of 25.65°C, which would indicate that the optimal temperature range for oviposition would be between 25°C and 26°C. (Schlemmer, 2018), showed that constant high temperatures of 30 and 32°C had a negative impact by reducing the fertility of female *S. frugiperda* moths. This observation is in line with our results obtained in the dry season. Concerning the pupal emergence rate, it was higher in the rainy season and lower in the dry season. Our results differ from those of (Truzi et al., 2021), who obtained higher pupal emergence rates of 80.0 ± 5.71%; 88.0 ± 4.64% and 78.0 ± 5.92% at 25 ± 1°C with a relative humidity of 70 ± 10%,during rearing of *S. frugiperda* with artificial diets containing different protein levels. This difference could be due to the higher relative humidity in the rainy season. The lifespan of adults was longer during the dry season and shorter during the rainy season in the southern. Our results agree with those of (Hauverset et al., 2021) who obtained an average of 10.00 ± 0.92 days in the southern Sudanese zone at a temperature range of 24 - 26°C and a relative humidity of 60 to 63%. Furthermore, the lifespan of males was much lower than that of females during the dry season. Our observations agree with those of (Truzi et al., 2021) who reported that *S. frugiperda* females had a longer life span than males. Furthermore, at temperatures close to 30°C, the wings of adults tend to deform, especially in males (Rios-Velasco et al., 2011), thus reducing the motor skills of males, which would affect their feeding and copulation abilities. Indeed, fecundity would be able to reduce adult survival due to the costly production of gametes or survival could be reduced due to the risk of courtship and mating behaviour (Bell and Romine, 1986). The lifespan of males and females was the same in the rainy season. The results obtained are different from those of (Sharanabasappa, Kalleshwaraswamy, Maruthi, et al., 2018) who obtained in males and females of the fall armyworm a complete life cycle of 32 - 43 days and 34 - 46 days, respectively at temperatures ranging from 24°C - 26°C with humidity between 60 - 63%. This difference may be due to the fact that the longevity of adults from larvae that have fed and developed on host plants of low nutritional value under unfavourable temperature conditions may be adversely affected (Pencoe and Martin, 1981). According to (Luginbill, 1928), the longevity of *S. frugiperda* moths varies between 6 and 23 days, depending on temperature and food sources, with an average of 10 days. These authors concluded that the longevity of adults depended on diet and temperature. The difference in results between the present study and (Barfield and Asley, 2010) is explained by the fact that there was a difference between the larvae diet . (Barfield and Asley, 2010), reared the larvae on maize tissue in the early and late vegetative stages. However, in our rainy season work, the larvae were fed on maize tissue at the reproductive stage. The sex ratio obtained in this study was in favour of males in the rainy season and in favour of females in the dry season. This trend was also reported in the work of (Hauverset et al., 2021). As for the average incubation times obtained in the dry season, they agree with those of (Dahi et al., 2020) who obtained an average incubation time of 3.4 and 2.1 days at 25°C and 30°C. We found that the average incubation time decreased with increasing temperature.

The duration of the different developmental stages varied with the seasons. The different larval stages were generally shorter in the dry season than in the rainy season. The duration from pupation to adult emergence was also shorter in the dry season than in the rainy season. These variations in the duration of the different stages are thought to be related to natural conditions (temperature, relative humidity and rainfall). Several authors (Barrientos et al., 2007; Ekien et al., 2016; G et al., 2017; Ossey, 2017b) have reported the effect of abiotic factors on the duration of insect development. The total development time (egg-adult) in rainy season, falls within the range defined by (Sharanabasappa, et al., 2018) and (Hauverset et al., 2021) who obtained 32 - 46 days and 25 - 54 days respectively at similar temperatures. For dry season, the total cycle length of *S. frugiperda* falls within the range defined by (Tendeng et al., 2019) 23 - 29 days (25 ± 1°C, RH: 65 ± 5%). (Luginbill, 1928) reported that the development time and number of larval instars of *S. frugiperda* depended on temperature and diet. (Luttrel, 1990) then reported five larval instars for larvae reared on an artificial diet between 25°C and 29°C and six larval instars at rearing temperatures between 21 and 35°C on maize. During the rearing, we identified six larval stages at each period. This allowed us to detect the most voracious stages for maize. These were larval stages 4, 5 and 6. Our results are similar to those of (Luginbill, 1928) who states that the most damage is caused by the last three instars because of their high consumption rate (98%). This is due to the fact that, the larvae have more developed mouthparts at this stage.

Demographic parameters are parameters that integrate changes in insect growth, development, reproduction, survival and indicate the growth capacity of the population in a specific environment (Ning et al., 2017). The intrinsic rate of natural increase (rm) has varied over the seasons. The net reproduction rate (Ro) and intrinsic rate of natural increase (rm) were highest in the rainy season. Our results differ from those of (Golizadeh et al., 2009), who found in their study on *Plutella xylostella* (Lepidoptera: Plutellidae) that the net reproductive rate (Ro) increased with increasing temperature (10, 15, 20, 25, 28, 30 and 35 °C), while the generation time (Tg) decreased. This resulted an increase in the intrinsic rate of natural increase (rm) from 0.038 to 0.340 on cauliflower and from 0.033 to 0.315 on cabbage from 10 to 28 °C. This difference is due to the fact that temperature cannot be considered as a limiting factor in *Plutella xylostella* (Bahar et al., 2014). *Spodoptera frugiperda* performs much better in the rainy season at temperatures between 25.1°C - 26.2°C due to a slow development time, a short population doubling time (DT) and a high net reproduction rate

(Ro). The high value of rm in the present study can be explained by a higher value of Ro and Tg. Our results agree with those of (Mehrkhou et al., 2012), who studied the demographic parameters of *Spodoptera exigua* on nine soybean cultivar seeds and concluded that '033' was the most suitable host in terms of population increase compared to other host plants, due to a high value of r_m.

- **Seasonal dynamic of *S. frugiperda* on Maize field**

The average number of *S. frugiperda* adults' moths caught varied according to the phenological stages for both zones (Sub-sudanian and Guinean). During the different seasons, the average numbers of *S. frugiperda* obtained in whorl stage were higher than the other two phenological stages (tasselling and maturation).

These high numbers are due to the fact that the whorl stage is the stage during which *S. frugiperda* is attracted in large numbers of female adult moths. During this stage, maize, the host plant might emit the substances more attractive to female for laying eggs, so that, neonates hatch from eggs can feed on tender leaves. According to (Murúa and Virla, 2022), *S. frugiperda* plant age dependent and the most preferred stages are V3. For each season, the low numbers recorded at tasselling and maturation stage would be due to the advanced age of the plants, which would have more lignified leaves and therefore be very difficult to consumed by larva. There would have been very few newly formed tender leaves which would not have been able to maintain the high numbers of *S. frugiperda*. These results are in agreement with those of (Yoboue and Tano, 2021) who noted a gradual reduction of *Podagrica decolorata* and *Nisotra dilecta* on okra crop due to the advanced age of the plants. These two results are also close to those of (Adagba et al., 2015) who reported low number of *Leucinodes orbonalis* larva on aging eegplants. During rainy season of both zones, the gradual increase *S.frugiperda* adults at the beginning of maize crop cycle could be explained by the fact that the crop started several weeks after the first rains. They could have left other hosts plant or weeds to gradually colonize the maize plot.

In both zones, climatic factors (temperature, rainfall, relative humidity) are mostly correlated with climatic factors. These factors have diverse impact on *S. frugiperda* population. Rainfall is positively correlated with the population of *S. frugiperda.* Our results are different to (Caniço et al., 2020). Their study show that the negative influenced of pluviometric condition are due to the fact, when the whorl of maize is filled up with water, the larva present in whorl are forced abandon it. Also, the rain washes off the eggs and larva present on the leaves onto ground. These results are in contrast of those found by (Nboyine et al., 2020), who show that rainfall and *S. frugiperda* population in northern Ghana are positively correlated. According to them, rainfall provide luxurious growth of maize and reduce natural enemies. Therefore, excessive rains can reduce *S. frugiperda* abundance by creating better conditions for rapid growth of its entomopathogens that can maintain low infestation. Temperature is one of the key factors of *S. frugiperda* development and survival. The amount of rain that occur in the zone within the same period can nullified the effect of temperature. Its due to the fact that the mean temperature is not significant enough to create specific conditions which could have influenced *S. frugiperda* population (Caniço et al., 2020).

Damage to newly formed tender leaves was observed at all phenological stages of maize. Attacks during these three stages would be related to the fact that leaves were forming during the whole stage. Attacks on pods could be explained by the fact that these organs would contain nutritive resources that could help *S. frugiperda* adults to cope with their huge physiological needs (oviposition). The percentages of damaged leaves and leaf damage indices varied according to the days after sowing and the phenological stages at the different seasons. This would be related to the composition of the volatile substances emitted by the host plant during the different phenological stages. Indeed, these authors, in their studies on plant-insect interactions, reported that the composition of volatiles varies according to the developmental stage and age of the host plant.

- **Control of *S. frugiperda* using Aqueous Extracts of Local Plants**

Aqueous extracts of *Ricinus communis*, *Lippia multiflora*, *Azadirachta indica*, and *Tephrosia vogelii* showed insecticidal effects against the larvae of *S. frugiperda*. The aqueous plant extracts at different concentrations caused mortality of larvae of *S. frugiperda* after treatment. In addition, they were able to reduce the consumption rate and attack rate in the field. These results agree with those (Phambala et al., 2020), who tested 10 pestidals plants on *S. frugiperda* larva and (Bidiga and Nacro, 2016), who mentioned the toxic effect of aqueous plant extracts in their various studies on Chrysomelidae adults. The mortality, lack of appetite and absence of damage to maize plants observed would be linked to the phytochemicals presents in the plants such as polyphenols, flavonoids, tannins, steroids, terpenoids and quinones. According to (Khatri et al., 2020), these phytochemicals are bioactive compounds that are responsible of their pesticidal propreties. Aqueous extracts of *Azadirachta indica, Ricinus communus* and *Tephrosia vogelii* caused mortality rates of more than 50% at 90 g/l. These three extracts could be considered effective against *S. frugiperda.*

This observation is in agreement with (Sellami et al., 2015) who reported that a substance with an insecticidal effect is only effective when it induces a mortality rate of at least 50% on a pest. Among all the extracts tested, Azadirachta indica extract induced the highest mortality rate than Ricinus communis extract and Tephrosia vogelii extract. It might due to the presence of glycoside present in Azadirachta indica and absent in the others plants. These results are similar to those of (Yoboue and Tano, 2021)who reported the high insecticidal effect of Azadirachta indica aqueous extracts than *Ricinus communis* and Tephrosia vogelii on *Coelaenomenodera lameensis* adults, the main pest of oil palm.

In both zones (Sub-sudanian and Guinean) the experiments conducted in the field with *Azadirachta indica, Ricinus communus* and *Tephrosia vogelii* reduce more plants attack at 90g/. Despite the presence of larvae, the severity of the attacks was lower than in the control. This is due to the high quantity of tanins present in the three plants; with 545.9±4.2, 834.5±6.1and 560.8±10.7 respectively for *Azadirachta indica, Ricinus communus* and *Tephrosia vogelii.* Tannin is responsible for these effects. Its action can be explained by its growth inhibiting effect on the larva without killing them immediately. It would modify their growth and prevent them from developing because they can no longer feed and eventually die. Among these plants extracts, the plots treated *Azadirachta indica* extracts got the lowest attack rate with 1,55±0,79 in sub-sudanian zone and 0,87±0,11 in Guinean zone at 90g/l. Its due to presence of Azadirachtin. According to (Sane, 2021; Vaidya, 2022) Azadirachtin, the active ingredient in *Azadirachta indica* extract, stimulates specific deterrent cells in the chemoreceptors and also blocks the triggering of sugar receptor cells, which normally stimulate feeding, thus causing rejection of the food. Also,(Mondedji et al., 2015) reported the anti-appetite properties of Azadirachtin against *Plutella xylostella* (Lepidoptera: Plutellidae) and *Salhbergella singularis* (Heteroptera: Miridae) respectively.This high mortality rate observed during the experiment can be explained by the fact that *Azadirachta indica* extract contains many active ingredients that are toxic (Azadirachtin, meliantriole, salannin, desacetyl salannin, nimbin, desacetyl nimbin) (Mondedji et al., 2015)

Aqueous extract of *Ricinus communis* induce a high anti-appetente rate after *Azadirachta indica.* It could be explained by the fact that, *Ricinus communis* content the highest quantity of polyphenols (87.33±0.57 µg/g), flavonoids (91±1.7 µg/g) and tannins (753.62±10.47), which must have disturbed the insects' feeding. This result is consistent with that of (Arivoli and Tennyson, 2012)According to this author, *Ricinus communis* aqueous extracts induced consumption rates between 48 and 98% and resulted in a reduction of the consumption of *Spodoptera littura*.In addition, Aqueous extract of *Ricinus communis* got the highest mortality rate at 70g/l and at 90g/l. This mortality could be explained by the fact that it contains a high content of recin, which is toxic for insects, and that this compound induces an irreversible inhibition of protein synthesis in the cells of the insects by inactivating the ribosomes, leading to cell death. This result also confirms that of (Arivoli and Tennyson, 2012) who showed that *Ricinus communus* have a significant insecticidal activity against insects.

For the aqueous extract of *Tephrosia vogelii*, it reduces consumption of 72.39±4,34% if prepared at a concentration of 90g/l. This is explained by the fact that the leaves of this plant contain substances with a larvicidal effect. This observation corroborates the results of (Kidukuli et al., 2015) who showed a remarkable activity of *Tephrosia vogelii* leaves not only on the larvae of *Anopheles gambiaes* but also on the larvae of *Culex quinquefasciatus*. Several authors have also worked on the composition of the organs of this plant and their chemical properties. The characterisation of the extracts of the organs revealed the presence in major proportion of organic compounds such as Rotenone, Degulein and Tephrosin. These organic compounds could be the determinant in the larvicidal activity of *Tephrosia vogelii* on the different strains tested. The plant can therefore be used as a biological means in intervention programmes against the larvae of *S. frugiperda*. The extract of *Lippia multiflora* induced a low rate. The results obtained in this study differ from those of (Yoboue and Tano, 2021). This difference could be explained by the variation in the order of the insect or by the climatic conditions. In addition, this difference could be due to soil conditions or plant growth conditions but also to the phenology of the plant and the varieties of the species studied.

- **Current and future distribution of *S. frugiperda* in Côte d'Ivoire**

Native to tropical American region, *S. frugiperda* is a pest that continuously expanding to new areas and countries. Due to its invasion, economical losses are occurring in food crops, especially in maize production systems in Africa (Feldmann et al., 2019; Ramasamy et al., 2022). It has a strong flyer ability to migrate long distances in a short time (Sun et al., 2021). Our study revealed that isothermality, annual mean temperature, Max temperature of warmest month where the major factors in determining the potential distribution of *S. frugiperda* in Cote d’Ivoire. (Tepa-Yotto et al., 2021) and (Ramasamy et al., 2022) also find in their studies that annual mean temperature is the main factor that influence *S. frugiperda*. In a suitable temperature range, the growth rate of an insect increased with the increase of external temperature, but when the temperature rose to a certain extent, the development rate would decrease (Wang et al., 2020). (Valdez-Torres et al., 2012)showed that under laboratory conditions, the highest temperature thresholds for the development of *S. frugiperda* is 39.8 C. These results suggested that high temperature can be an important factor to extend the distribution of *S. frugiperda*. Temperature can impact insect development and physiology through the physiology of the hosts. Depending on the strategy of development of the insect, temperature can have different effects. Some crop pests develop more rapidly during periods of time with suitable temperatures(Anand et al., 2014). Insects reproduction is greatly affected by the external temperature(Baloch et al., 2020). Low temperature tends to decrease the birth rate and increase the death rate

of insect species. Within a certain temperature range, the reproductive capacity of the female moth increases with temperatures increase (Feldmann et al., 2019). In contrast, (Early et al., 2018) reported that, wet season rain was the main factor contributing to the distribution of *S. frugiperda*. Heavy rainfall and precipitation have a direct effect on survival on larva survival as, they cause larva to spill out from the whorl. They also cause collapse of tunnels pupation, that may affect moth emergence and survival (Murúa et al., 2006; Ramasamy et al., 2022).

According to the current distribution, the western part of the country is unsuitable for *S.frugiperda*, this might due to the fact that this part is the mountain climatic zone. This zone is characterized by a mountainous relief called Guinea range. In this zone, the mountainous slopes are steep, the differences in altitude are important and some summits are over 1000m. The climate is sub-equatorial type with a rainfall greater than 1800 mm by the alternation of two rainy and dry seasons. These mountains might prevent the pest to reach this area. The global habitat suitability of *S. frugiperda* in (Tepa-Yotto et al., 2021) study showed that, for the current distribution all area of Cote d'Ivoire is highly suitable, this difference might due to the fact that, these authors used native and invaded occurrences records in their distribution. These results is different from those find by (Fan et al., 2020), who showed that, the country is moderately suitable for *S.frugiperda* when use native occurrences compare to the highly suitability results by using occurrences records from Africa only. Indeed, (Ramasamy et al., 2022) current study showed that under present conditions global suitability of *S.frugiperda* in Cote d'Ivoire is moderate based on Coupled Model Intercomparison Project phase (CMIP6) data set. Under future climate change RCP 4.5 and RCP 8.5 for the years 2050 and 2070, Cote d'Ivoire will become unsuitable.(Ramasamy et al., 2022) find out that the future potential distribution based on MIROC model showed that, Cote d'Ivoire will remain moderately suitable in 2050 and 2070 according to low emission (SSP 2.6) and high emission (SSP 8.5). Whereas, according to BCC-CSM model, Côte d'Ivoire will become highly suitable for both scenarios. These differences might due to fact that, these authors, predict the potential worldwide distribution under Shared Socioeconomic Pathway (SSP). These results are also different from those found by (Tepa-Yotto et al., 2021), who find a highly suitable climate for *S.frugiperda* in Cote d'Ivoire according to the RCP 8.5.

Invasion of *S.frugiperda* into Côte d'Ivoire might due to human-assisted movement of individuals of the specie across biogeographic barriers(Blackburn et al., 2011). Its invasion process starts by transportation, introduction, establishment, and finally dispersal (Skendži´ et al., 2021). *S.frugiperda* in different stages (egg, larva, pupae and adults) of its life cycle could be moved by passive or active form of transport. Passive transport could be by wind and active transport could be by its own ability to fly long distance. changing circulation patterns may facilitate the introduction of *S.frugiperda* into Cote d'Ivoire(Skendži´ et al., 2021). According to (Y. P. Wang et al., 2020) climatic events such as storms or hurricanes could potentially transport insects long distances from their native region, as it is already known that climate change will increase the intensity and frequency of hurricanes(Reay et al., 2007). Furthermore, frequently, the transport of an invasive insects is related by human activities via human travel and international trade (Keller et al., 2011). Establishment is the process of forming a permanent population in a new geographic area different from the origin area of the species (Skendži´ et al., 2021). The establishment of *S.frugiperda* in Cote d'Ivoire might due to climate change. According to (Skendži´ et al., 2021), Climate change may facilitate the establishment of invasive species through two ways. Fist, the species that are currently unable to survive in a new environment due to climatic limitations may increasingly be able to survive and become established there; second, invasive species that can tolerate new climatic conditions may have a higher potential to overcome biotic constraints and establish permanent populations under climate change. Climate change can move native insect from their adapted conditions, which can, potentially, make them less competitive Invasive species may become established to new area, if climate change increases the competitiveness and spread rate (Byers, 2002).

Once an invasive insect is introduced, the chance for its establishment and persistence in new area depends on the biotic and abiotic factors that offer its new environment (Skendži´ et al., 2021). Biotic factors for any insect represent a set of traits that may be useful for the establishment of its population in a new area. Insects that possess these traits can be favoured by climate change and may pose a significant problem for agriculture in the future (Robinet and Roques, 2010). The main insect traits that are crucial for invasion success are: lifecycle strategy adaptation, diet breadth and phenological plasticity. Dispersal of any invasive species involves population growth and the dispersal capability of individuals of the specie

(Skendži´ et al., 2021). As the density increase, the insect species, its more suspectibible to disperse and expand their geographical range to new areas with suitable environmental conditions The biological effects of climate change on insect species include modifications in the abundance which cause direct physiological effects on individual species, change in reproductive potential and interaction with others insect species and the distribution (Hill et al., 2016) In Côte d'Ivoire, climate change are may be created more suitable conditions for its establishment and dispersal of *S.frugiperda,* as invasive species are generally considered to have a width range of tolerance than native insects, allowing alien insects to find a wider range of suitable habitats.

CHAPTER 5. CONCLUSION AND PERSPECTIVES

5.1 Conclusion

The establishment of an effective control method against *Spodoptera frugiperda* requires the determination of the developmental stages of the pest infesting maize, the duration of its developmental cycle and the demographic parameters. Thus, the study of biological parameters showed that *S. frugiperda* is a holometabolous pest with a developmental cycle of 6 larval stages with high survival rates for stages 2, 3, 4, 5 and 6. The net reproduction rate (Ro) and the intrinsic rate of natural increase (rm) were highest in the rainy season, indicating that *S. frugiperda* performs much better in this season. The climatic conditions are therefore important factors affecting the life cycle of *S. frugiperda.*Thus, considering, on the one hand the knowledge of the development cycle and on other hand the generation time and the intrinsic rate of natural increase of *S. frugiperda* population could set up an appropriate control schedule.

The study of the seasonal variation of *S. frugiperda* population and damage showed that the numbers of moth and damage percentage varied according to the phenological stages and seasons. The highest numbers of moths were obtained at whorl stage. During rainy season, the number of adults increases progressively to reach a peak at the late whorl stage. The damage was high at whorl stage, particularly in late whorl stage. The high numbers of moths were recorded during rainy season. This season, is the maize cultivation period. The lowest numbers were obtained at maturation stage during both seasons. The study of the relationship between *S. frugiperda* adult moths' numbers and some abiotic factors revealed that, temperature was positively correlated with number of adult moths in 2020 and 2021.Temperature is one of the abiotic factors that would reduce the abundance of this insect. Therefore, a control using botanicals could help reduce infestation and damage.

The aqueous extracts of four plants (*Ricinus communis, Azadirachta indica, Tephosia vogelii* and *Lippia multiflora* had toxic and anti-appetite effects on *S frugiperda*. The different aqueous extracts had an insecticidal effect. The highest mortality rate was caused by *Ricinus communis* follow by *Azadirachta indica*. Of all the aqueous extracts, *Ricinus communis* induced the highest overall mortality. Aqueous extracts of *Azadirachta indica*, *Ricinus communis* and *Tephosia vogelii* were effective from the concentration of 70 g/l inducing more than 50% mortality. The aqueous extract of *Azadirachta indica* leaves resulted in the highest anti-appentite rate. The aqueous extract of leaves *Ricinus communis, Azadirachta indica* and *Tephosia vogelii* could be used in the control of *S frugiperda* population because of their high insecticidal effects and the protection of maize crop. However, knowing the potential future suitability could provide a better understanding of the impact of climate change on the potential distribution of *S. frugiperda* in Côte d'Ivoire.

Temperature is the major factor determining the distribution *S.frugiperda* in Cote d'Ivoire. In a suitable temperature range, its growth rate increases with the external temperature. Temperature can impact the development and physiology of *S.frugiperda*. The current distribution *S.frugiperda* show that only the western part of Cote d'Ivoire is unsuitable. This area is characterized by a mountain relief which might prevent it to reach that area. The potential future suitability according to MIROC and BCC-CSM for the low emission RCP 4.5 and RCP 8.5 show Côte d'Ivoire will be unsuitable for *S.frugiperda*. in 2050 and 2070. The invasion of *S.frugiperda* in Cote d'Ivoire, either might due to human movement between continent that can allow the transportation of *S.frugiperda* in different stages (egg, larva, pupae and adults) new area or by its own movement to be able to across the biogeographic barriers. In the future, climate change may create more unsuitable conditions for its establishment and dispersal of *S.frugiperda*.

5.2 **Perspectives**

This work on control against *S.frugiperda* using aqueous extracts and the current and future distribution under changing climatic condition have provided a certain amount of information on *S.frugiperda* in two climatic zones in Côte d'Ivoire. However, this study remains an opening on research lines:

- The study must be extended the others climatic zones present in Côte d'Ivoire
- Knowing the perception of farmers on climate change and *S.frugiperda* in Côte d'Ivoire
- A biological control using natural enemies in Côte d'Ivoire.
- Knowing the genetic diversity of *S.frugiperda* in Côte d'Ivoire
- Extend the modelling of current and future of *S.frugiperda* to West Africa

Scientific valorisation

❖ Publication

S.M.K.A Konan., L. Kansaye., H.J.M Dakouri., N.R.L Aboua (2023). Biodemographic parameters of spodoptera frugiperda smith, 1797 (Lepidoptera: Noctuidae), a pest of maize crop, zea mays linnaeus, 1753 in sub-sudanese zone of Côte d'Ivoire. *International Research Journal of Insect Sciences*, *Vol. 8, No. 1, pp. 1-14. DOI: 10.18488/irjis.v8i1.3272*

❖ Communication

Manuela Klamansoni Akissi Konan (2022). Bioactivity of some local plants on Spodoptera frugiperda SMITH, 1779 (LEPIDOPTERA: NOCTUIDAE), Maize (Zea Maïs LINNÉ, 1753) pest in Côte d'Ivoire. *International Conference on Multidisciplinary Scientific Studies*, October 17-18, 2022 / Istanbul, Türkiye

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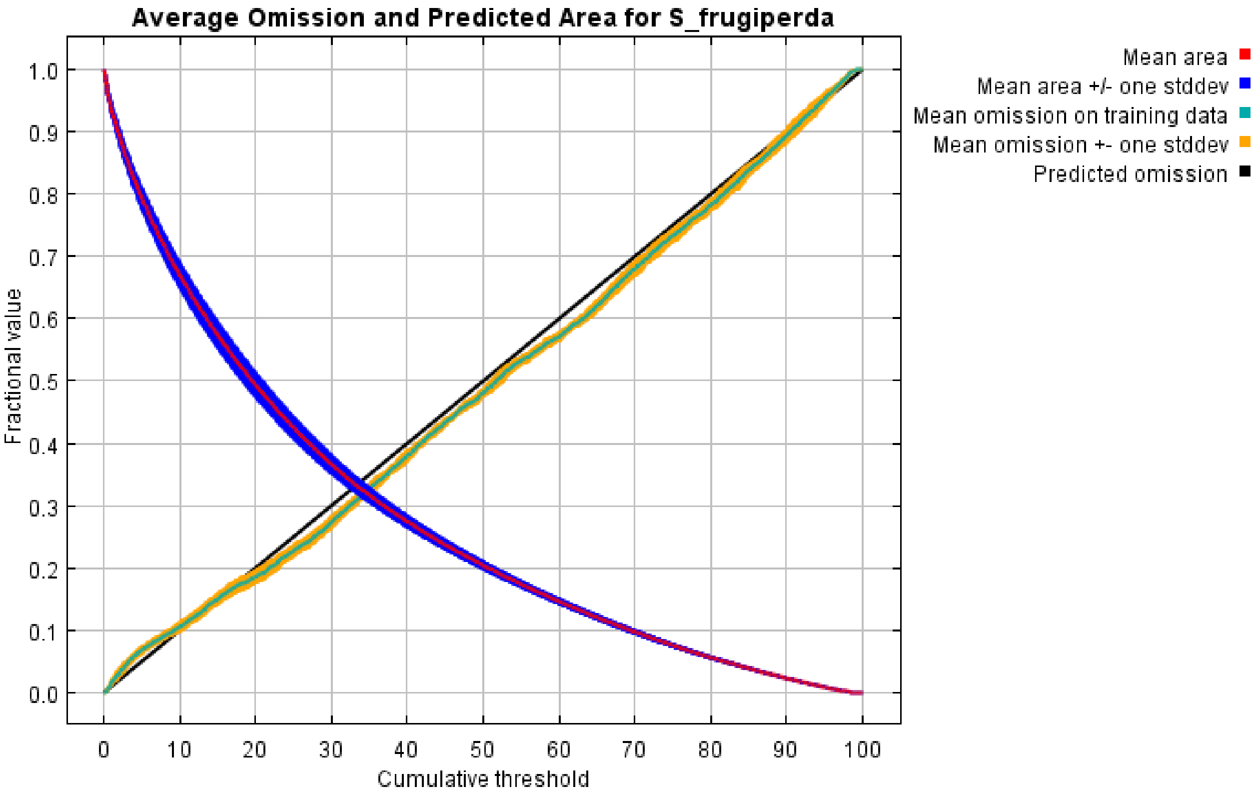
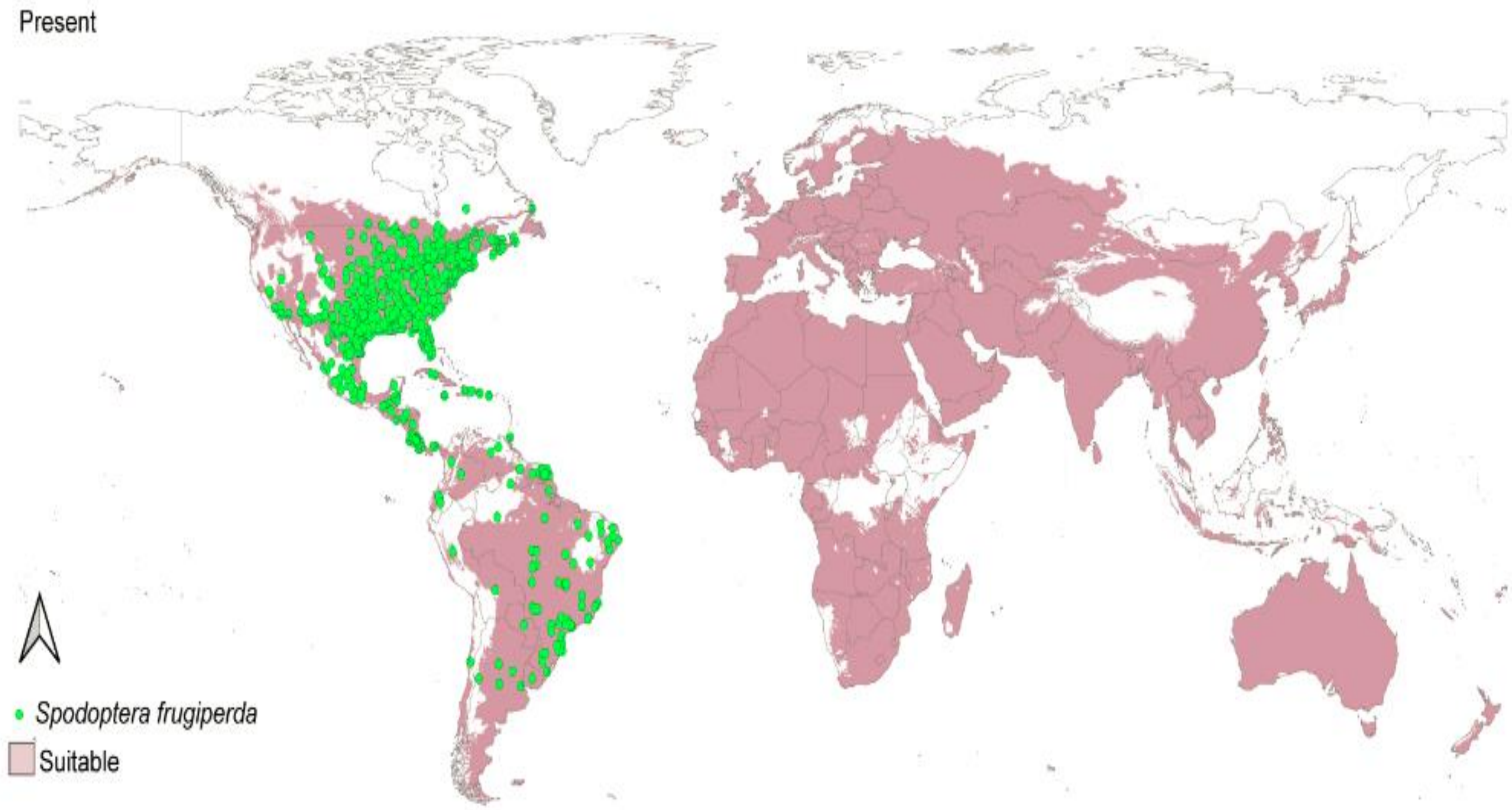
APPENDICES

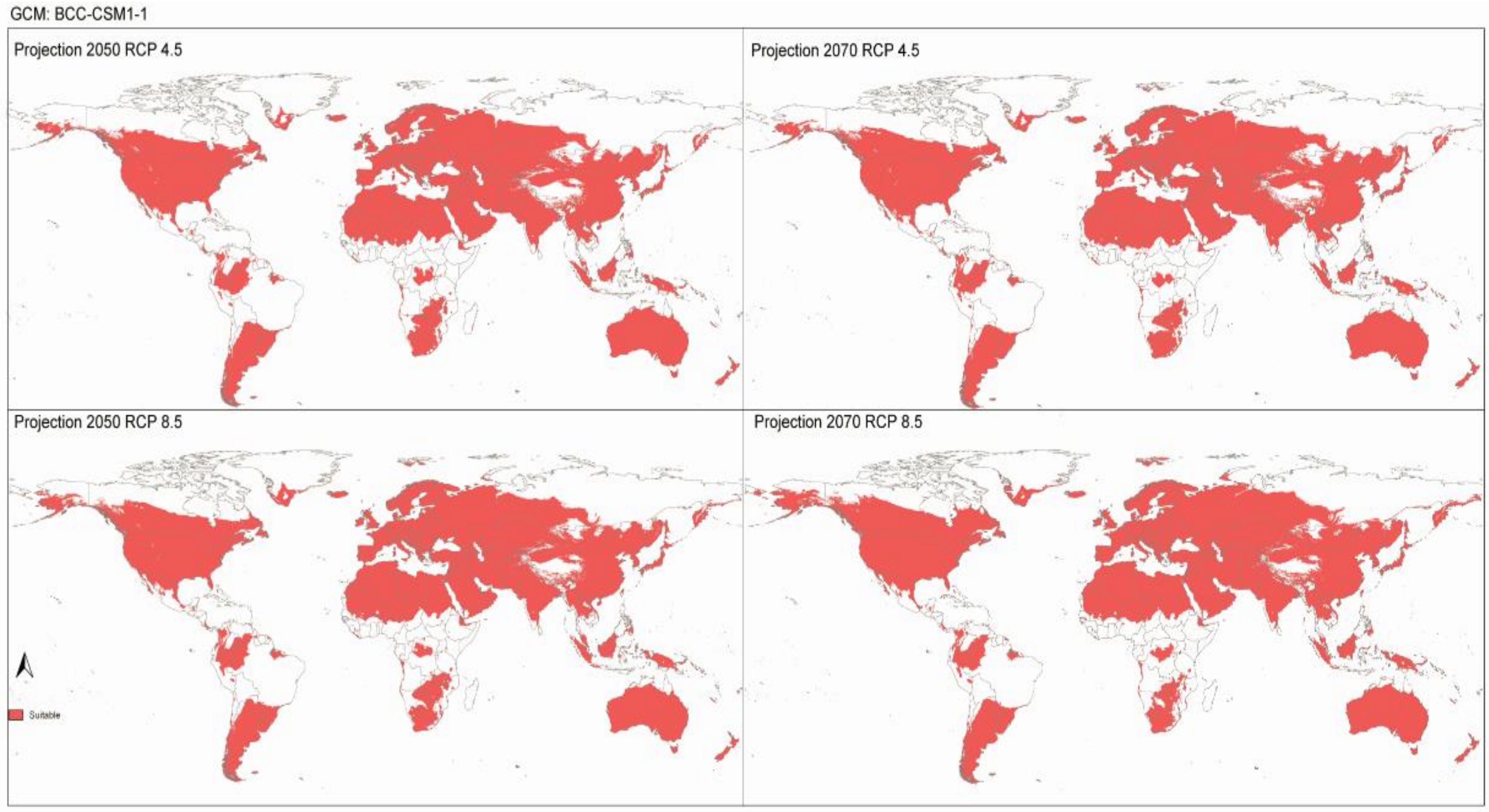
Appendice 1: Omission rate and Predited Area of *S.frugiperda*



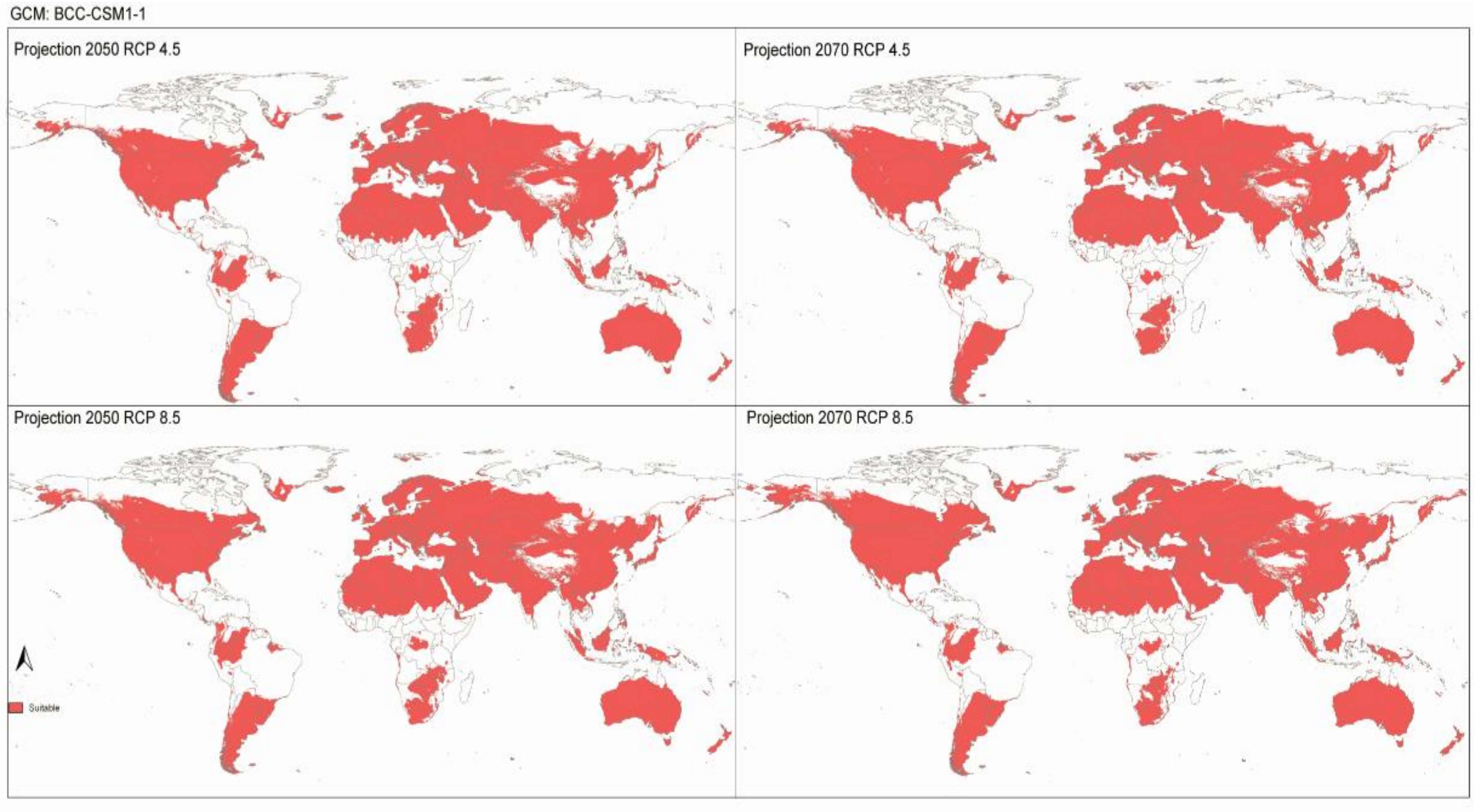
Appendice 2 : Current global habitat suitability of *S. frugiperda*



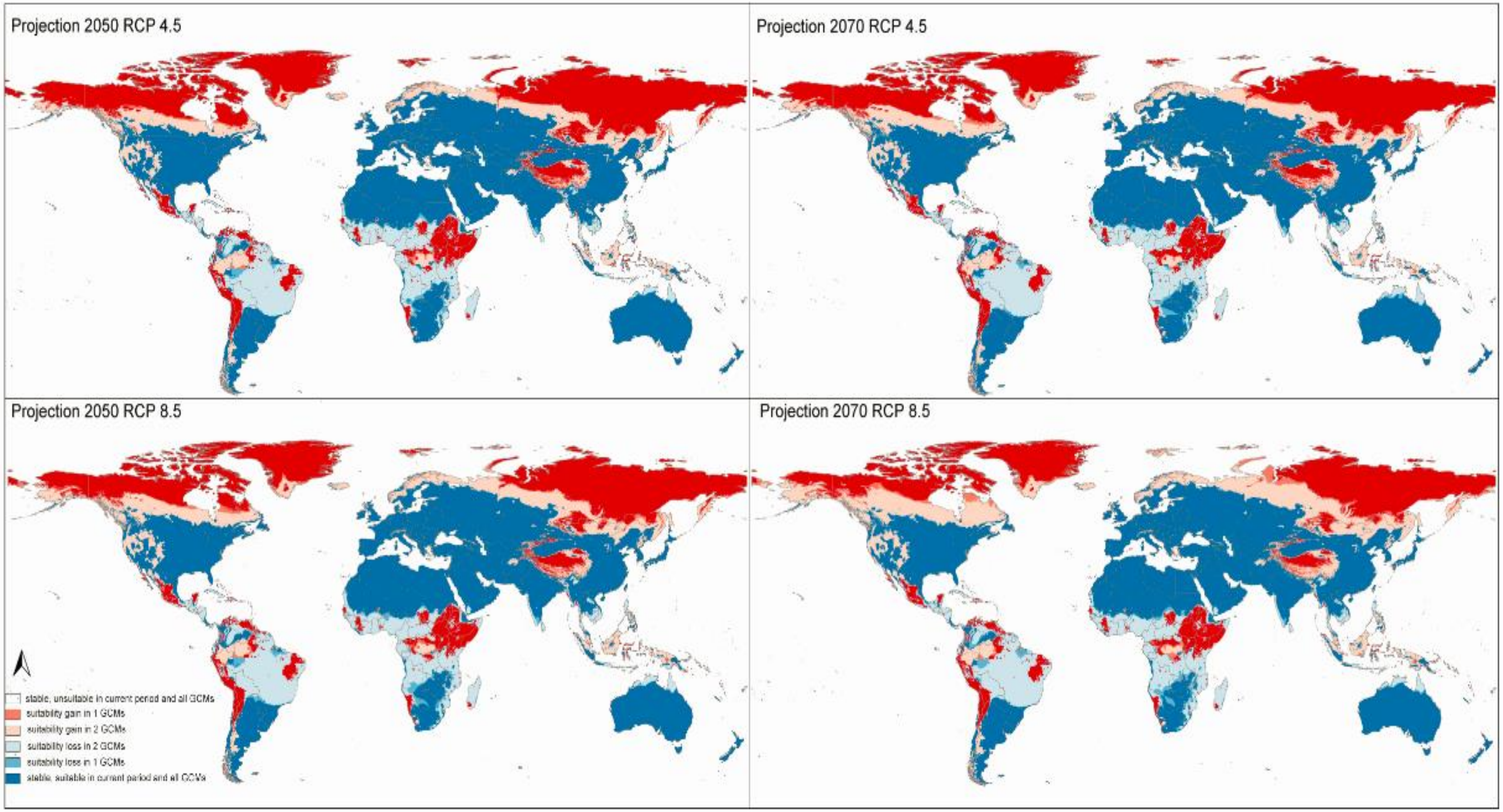
Appendice 3: Future global habitat suitability of *S.frugiperda* according to MIROC



Appendice 4: Future global habitat suitability of *S.frugiperda* according to BCC-CSM1-1



Appendice 5: Future global habitat suitability of *S.frugiperda* according to MIROC and BCC-CSM1-1



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Biodemographic parameters of spodoptera frugiperda smith, 1797 (Lepidoptera: Noctuidae), a pest of maize crop, zea mays linnaeus, 1753 in sub-sudanese zone of Côte d'Ivoire

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ABSTRACT

Spodoptera frugiperda is one of the main pests of maize (*Zea mays* L.) in Côte d'Ivoire. The control of this insect requires knowledge of biological and demographic parameters. The need to know the effect of seasons on the biodemographic parameters of *Spodoptera frugiperda* in Côte d'Ivoire led us to carry out work in the Sub-sudanese zone. The study was carried out in dry and rainy seasons on a maize plot from 2020 to 2021. The monitoring of newly emerged individuals on 3-week-old early variety with semi-serrated grains (EV 87/23-SR) maize plants under semi-natural conditions. The development cycle consisted of six larva stages. The development time was 27.93 ± 1.01 days in dry season and 32.47 ± 1.83 days in rainy season. Larval survival rates ranged from 85.79 to 100% in dry season and from 74.64 to 94.7% in rainy season. The average egg fertility rate was 21.19 ± 5.89% in dry season and 40.36 ± 8.49% in rainy season. The sex ratio was in favour of females. The net reproduction rate (Ro) and intrinsic rate of natural increase (rm) were highest in rainy season at 27.67 ± 7.82 and 0.26 ± 0.01 respectively. *Spodoptera frugiperda* performs much better in rainy season at temperatures between 25.1°C - 26.2°C due to a slow development time of 32.47 ± 1.83 days, a short population doubling time (D.T.) of 2.62 ± 0.13 and a high net reproduction rate (Ro) of 27.67 ± 7.82.

Contribution/Originality: Since the introduction of *Spodoptera frugiperda* in Cote d'Ivoire, maize production has decreased. Within the framework of biological control, this work address the effect of season on the life cycle of *Spodoptera frugiperda* in Sub-Sudanese zone, main zone of maize production in Côte d'Ivoire.

CERTIFICATE

of Participation

This certificate is proudly presented to

Manuela Klamansoni Akissi Konan

of participation in oral and technical presentation, recognition and appreciation of research contributions to

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INTERNATIONAL CONFERENCE ON MULTIDISCIPLINARY SCIENTIFIC STUDIES
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with the paper entitled

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