UNIVERSITY OF GHANA, LEGON

AFRICAN REGIONAL POSTGRADUATE PROGRAMME IN INSECT SCIENCE

(ARPPIS)

IDENTIFICATION OF RESISTANCE CULTIVARS OF COWPEA [*Vigna unguiculata* (L.) Walp] TO FLOWER THRIPS (*Megalurothrips sjostedti* Trybom) AMONG BENIN GERMPLASM

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DECLARATION AND APPROVAL

I do hereby declare that, except for references to works by other researchers which have duly been referenced, this research, is submitted entirely as my work, conducted at both IITA-Benin Research Station and at Zakpota and Gbaffo Districts in Benin. I therefore submit this research work for the award of a Master of Philosophy (M.Phil) Degree in Entomology to the African Regional Postgraduate Programme in Insect Science (ARPPIS) at the University of Ghana, Legon. I further declare that no part of this work has been presented for another degree elsewhere.

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The supervisors of this work agree and permit that the results generated for the work account may be used by the student for scientific publications.

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DEDICATION

The accomplishment of this work is the result of important contributions for which I express my gratitude. To my father Alain F. Tossou and my mother Claudine B. Allomagba; You, who have always given the best of yourself for my wellbeing, and to offer me the essentials: education and training; for your innumerable sacrifices, receive my sincere gratitude and renewed affection. May God bless and grant you long life. Besides, I also dedicate this work to my lovely wife, Murielle D. Hounfandan, as well as my brothers and sisters for their unconditional support and constant sacrifices.

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LIST OF ABBREVIATIONS

%	Percentage
ANOVA	Analysis of Variance
ARPPIS	African Regional Post – Graduate Programme in Insect Science
cm	Centimetre
EC	Emulsifiable concentrate
g	Gram
g/L	Gram per liter
RH	Relative humidity
ºC	Degree Celsius
UG	University of Ghana
CRD	Completely Ramdomized Design
AMMI	Additive Main effects and Multiplicative Interaction
GGE	Genotype plus Genotype by Environment
FAO	Food and Agricultural Organization
CNRA	Centre National de Recherche Agronomique
pH	Hydrogen potential
CBIT	Capacity-building Initiative for Transparency
DAP	days after planting
km^2	square kilometers
cm	Centimetre
kg	kilogram
a.i.	Active ingradient
ha	Hectars
CP-15	knapsack sprayer for fifteen liter capacity

NPK Nitrogen, Phosphorus and potassium

SNK Student - Newman - Keuls

ABSTRACT

Cowpea [*Vigna ungriculata* (L.) Walp] is a leguminous plant and is one of the staple crops much cultivated in Benin and neighboring countries and in Africa as a whole. Cowpea production is hindered by many biotic and abiotic factors, with the flower bud Thrips, *Megalurothrips sjostedti* (Trybom) being the most damaging pest at flowering stage causing yield losses of 20 to 80%. Control of flower bud thrips in the field is difficult due to its cryptic behaviour. Thus, the combination of control measures in addition to the use of resistant lines is promising. However, there is insufficient data on Benin cowpea germplasm resistance to flower bud thrips. Therefore, this study was aimed at identifying resistant cultivars to thrips among Benin germplasm and provide lines for breeding programs for eventual improvement of cowpea to the flower bud thrips in Benin.

In order to identify resistant lines, the most damaging local population of flower bud thrips was selected among existing diversity, and cowpea accessions from greenhouses and the field screened for the trials.

Flower bud thrips were collected from seven locations where cowpea is produced within two agro-ecological zones in Benin. The varying populations were reared, characterized on Sewe and vita7 (susceptible and resistant checks, respectively), and used to infest genotypes in the greenhouse. In greenhouse, 48 accessions were evaluated using CRD with three replicates. A total number of 25-30 nymphs at the fifth larval stage (6-7 days after hatching) were placed on single experimental plants. Data from the thrips damage and yield parameters were subject to variance analysis. Results showed that there were significant differences among accessions in terms of thrips damage and cowpea yield. Fourteen accessions (*IT07K-243-1-10* (1), *Sèwé* (2), *Sanzibanili* (2), *Awlétchi* (3), *Awonlignikoun* (3), *Gléssissaffodo* (3), *IT83S-742-2* (3), *IT86D-888* (3), *Kpègnikoun* (3), *Kpodjiguèguè* (3), *Kumassi* (3), *Moussa* (3), *Nontché-Wagbèhami* (3) and *Tiligré* (3) were identified to be resistant (showing damage scores of 1 to 3) among the 48 tested, while the rest of the accessions presented high thrips damage scores (5-9).

In order to evaluate the effect of environment on thrips damages, the same accessions were planted in three different locations, where cowpea is produced in Benin. The accessions were planted in an Alpha lattice design with three replications. Susceptible check (Vita7) was used as spreader rows surrounding each replication. Data were collected on thrips damage, thrips population per genotype at weekly intervals for four weeks, based on the commonly used scoring scale (1-9). Thrips damage scores and grain yield were subjected to Additive Main effects and Multiplicative Interaction (AMMI) and Genotype plus Genotype by Environment (GGE) biplot analyses. Genotype and genotype by environment interactions effects were not significant. A significant ($P<0.001$) difference was found between the accessions for thrips damage, adults and larvae of flower bud thrips on cowpea. Four accessions (*IT84S-2246-4*, *Mawougbadonou*, *IT07K318-33*, and *IT93K-452-1*) were found to be the most resistant and stable lines across locations. Based on the suitable environment analysis, the high yielding and the most adapted genotypes were *Tawa*, *IT93K-452-1* and *Kpodjiguègué*, with yield values of 101.88 Kg/ha^{-1}; 227.16 Kg/ha^{-1} and 186.35 Kg/ha^{-1}, respectively. This study provided status of screened accessions of which somes are resistants and others are high yielding and stable across environments. These accessions are relevents for breeders and could be used to improve cowpea's resistance to the flower bud thrips and hence improve productivity and incomes of farmers in Benin.

CHAPTER ONE

I. INTRODUCTION

1.1. Background

Cowpea (*Vigna unguiculata* L. Walp.) is an annual herbaceous legume grown for grains and leaves for consumption by humans and livestock. The species *V. unguiculata* is likely native to the southern region of Africa, whereas it may have been domesticated in West Africa 5,000-6,000 years ago (Small and Ernest, 2009). The first written reference of the word 'cowpea' appeared in 1798 in the United States (Small and Ernest, 2009). According to Kimko *et al*. (2007), “this leguminous plant would have had its name because of its use as an important source of hay for cows in the southeastern United States and elsewhere”.

Cowpea is a dicotyledon of the order *Fabales*, family *Fabaceae*, subfamily *Fabiodeae*, tribe *Phaseoleae*, subtribe *Phaseolinae*, genus *Vigna* and section *Catiang* (Verdcourt, 1970). In the tropical and subtropical regions, more than 100 different species are registered for the genus *Vigna* with a large morphological and ecological diversity (Oyewale *et al*., 2014). Its global production is estimated at 5,249,571 tons of which over 64% are produced in Africa (Pottorff *et al*., 2012; FAOSTAT, 2013). About 96% (4.9 million tonnes) of cowpea is produced in sub-Saharan Africa alone (FAO, 2014).

The world's greatest cultivation and consumption of cowpea are in West Africa, which accounts for more than 87% of world production and use (FAO, 2014). In Africa, nations like Niger, Mali, Malawi, Nigeria, and Myanmar in South East Asia are the biggest producers of cowpea (Fowler, 2000). In Benin, cowpea occupies more than 7% of the planted area (all crops put together) and production was estimated at 81,152 tons (Gbaguidi *et al.*, 2015b).

Cowpea is well known in West Africa for its importance for human and livestock as well. It is rich in proteins containing 20-30% on dry weight basis (Phillips *et al*., 2003). Cultivated as a multi-purpose crop in the tropics, it is used especially in Benin as vegetable protein against deficiency and malnutrition. Cowpea and other pulses constitute altenative measures of alleviation and correction of protein deficiency (Simon, and Thirion, 2011). Apart from its nutritional value for food and feed and its ability to fertilize the soil, cowpea is also readily available and inexpensive. Cowpea has the property of fixing the atmospheric nitrogen in the soil, contributes to reduction of erosion and also serves as green manure for the small producers (Emelike *et al*., 2020). Cowpea contributes about 30 - 125 kg N/ha to the soil because of its nitrogen-fixing properties (Ennin-Kwabiah and Osei-Bonsu, 1993), and is also used as a green manure to fertilise soil. Cowpea production is limited by many biotic and abiotic factors. Among the abiotic factors, temperature, RH, rainfall, windspeed and sunshine are key, while the biotic factors include diseases such as (bacteria, fungi and virus) and insect pests (Abadassi Justin. 2014). Some of the common pests include the Groundnut or Cowpea aphid (*Aphis craccivora* Koch) (Malgwi and Onu, 2004), the Legume pod borer (*Maruca vitrata* Fabricius), the flower bud thrips (*Megalurothrips sjostedti* Trybom), and the Brown pod-sucking bug (*Clavigralla tomentosicollis* Stål) (Karungi *et al.*, 2000), the Cowpea weevil (*Callosobruchus maculatus* Fabricius), the Pulse beetle *(Callosobruchus chinensis* Linnaeus) (Tripathi *et al.*, 2015) and the Cowpea witchweed (*Striga gesnerioides* Willd.) (Emechebe *et al.,* 1991). The most damaging insect at flowering stage has been reported to be *Megalurothrips sjostedti*, which can cause damage ranging from 20-80% of cowpea yield (Agbahoungba *et al*., 2017). Both adults and larval stages feed by piercing plant tissues with their mouthparts and sucking the content of plant cells (William Kirk, 1985). The parts attacked by thrips become dehydrated and lead to the falling of the organ. When attacks are severe, an early abortion occurs, preventing the formation of pods. Attack of stamens can lead to premature loss of pollen, reducing pollination and grain formation (Singh and Allen, 1979). Control of the flower bud thrips requires a combination of many cultural practices due to its cryptic behaviour. Thrips pupate in the soil prior to emerging into adults (Teulon *et al*., 1998). Therefore good ploughing and harrowing before planting can destroy pupae in the field. It has also been reported that early planting helps the crop to establish well and withstand thrips infestation (Sani and Umar, 2017). This is because thrips populations are generally lower during the rains and increase when conditions are drier (Tamò *et al.*, 1993; Natural Resources Institute, 1996).

Studies have shown that the entomopathogenic fungus, *Metarhizium anisopliae* (Metchnikoff) has a pathogenic effect on thrips in horticulture and floriculture in Africa (Ekesi *et al.*, 2000). In addition, strains of *M. anisopliae* interfere with reproduction and longevity as well as on the feeding of *M. sjostedti*. (Ekesi and Maniania, 2020) Some plants such as *Piper nigrum* L. *Cinnamomum zeylanicum* Blume and *Cinnamomum cassia* J.Presl, have been identified, and have high repulsive power against female thrips (Abtew *et al.*, 2015). Recent studies have created Bt cowpea crop to control the legume pod borer through genetic modification (GM) (Bett *et al.*, 2017; Huesing et al, 2011). Cowpea expressing the lepidopteran-active Cry1Ab protein from *Bacillus thuringiensis* is the first-generation Bt-cowpea that had been created for West Africa. (GM Crops, 2011).

In the recent past, numerous research projects have been carried out on botanicals against *M. sjostedti* (Oparaeke, 2006). The insecticidal property of Black pepper has been identified in West Africa to be effective in reducing the population of thrips in cowpea flowers (Oparaeke, 2006). It is reported that oviposition of female thrips and larval development in nymphs are affected by neem products (Sani and Umar, 2017). Botanical pesticides such as garlic, rotenone, ryania, pyrethrum, neem, sabadilla and nicotine are therefore recommended for thrips control (Sani and Umar 2017).

Calender application of insecticides is one of the commonest practices used to control thrips (Ekesi *et al.*, 1998; Nderitu *et al.*, 2008). Some of the insecticides used include Deltamethrin, Malathion, Monocrophos, Pirimphos-methyl Cypermethrin, Dimethoate and Lambda cyhalothrin (NRI, 1996; Africa Soil Health Consortium, 2014). This practice generally reduces cowpea pest infestation and markedly increases crop yields, and reduce the thrips population in flowers by about 80% (Morse *et al.,* 2005). On the contrary, this practice will lead to harmful consequences on the health of the soils, humans and animals, and does not promise sustainable agriculture. The indiscriminate use of these chemicals has induced issues such as insecticide resistance of pest species, augmentation of toxic residues level in foods, health hazards to consumers and livestock and environmental contamination (Oparaeke, 2006). A single method of controlling thrips is not effective and efficient. The combination of control measures in an integrated pest management approach is more appropriate. The use of resistant varieties in combination with other thrips control measures would be more efficient and economic (Richard, 2009; Sobda *et al.,* 2017). Genetic research has identified some cowpea genotypes showing different levels of resistance in West Africa. These accessions include *"IT 90K-277-2"*, *"KVx 404-8-1"*, *"TVx 3236-01G"*, *"IT91K-180" "Moussa Local"*, *"Sanzisabinli"*, *"Sewe"*, *"TVu 1509"*, and *"TVx 3236"* (Alabi *et al.*, 2003; Abudulai *et al.*, 2006; Amoah, 2010). Varieties such as *TVx 3236* have also developed resistance to damage by thrips (Natural Resources Institute, 1996).

1.2. Problem statement

Despite its importance, cowpea suffers from pest infestation which constantly reduces its yield. The complex of cowpea insects can completely destroy a farm if little or no control measures are applied. According to Adati (2007), important key pests of cowpea in the West African savannah include the Legume pod borer (*Maruca vitrata* Fabricius) (Lepidoptera: Crambidae), the Pod-sucking bug (*Clavigralla tomentosicollis* Stål), (Hemiptera: Coreidae) and the flower bud thrips (*Megalurothrips sjostedti* Trybom) (Thysanoptera: Thripidae). Among these insects, Agbahoungba *et al.* (2016) described *M. sjostedti* as the most destructive, and can cause damage ranging from 20-80% of cowpea yield under high pressure. The principal means of controlling the flower bud thrips has been through the use of chemical insecticides (Jackai and Adalla, 1997). Meanwhile, Sobda *et al.* (2017) indicated that repeated chemical spray does not control them effectively and can lead to rapid development of insecticide resistance. Furthermore, Heong *et al.* (2011) verified that when prophylactic insecticides are constantly applied, they destroy ecosystem services, cause pest outbreaks, and induce fast growth of insecticide resistance. Most resource-poor farmers are unable to afford both the needed chemicals and efficient spraying facilities. Therefore host plant resistance may serve as the best and the most effective strategy to control the pest. However, no targeted studies have been conducted on the resistance status of Benin cowpea germplasm and farmers are still growing susceptible varieties. Furthermore, cowpea grain yield is low (0.2t/ha) in farmer fields compared to the maximum potential yield of 3t/ha (Duke, 1990; Singh *et al.*, 1997). Surveys conducted by the Legume Innovation Laboratory and IITA in 2015-2016 in Benin revealed low grain yield of 320 kg/ha of cowpea compared to average yields ranging from 350 and 600 kg per hectare recorded in West African countries (Soule, 2002). Kamara *et al.* (2018) revealed that cowpea cultivation is primarily under traditional farming schemes and returns are small, particularly in the sub-region of West Africa (0.025–0.3 t / ha). Nevertheless, yields ranging from 0.5-2.76 t/ha have been reported in research stations when protection was given to the crops (Ajeigbe *et al.,* 2005; 2008). Tamo *et al.* (1993) and Arodokun *et al.* (2000) reported that *Megalurothrips sjostedti* does not go through diapause during the dry season and is able to feed and build up the population on alternative host crops in the absence of cowpea (Poda *et al.,* 2016).

1.1 Justification

In order to feed the ever-growing population, crop productivity needs to be increased through crop improvement and adaptability. Host plant resistance is an environmental-friendly, cost-effective and sustainable pest management option for minimizing the pests' incidence and severity. However, in recent years, public outcry against environmental damage, pest resistance, lethal effects of the indiscriminate use and abuse of synthetic insecticides on non-target organisms coupled with the demand for pesticide-free food has fostered an effort to find alternative management strategies for insect pests. Jackai and Adalla (1997) indicated that host plant resistance has the ability to limit or eliminate reliance on chemical control. The use of host plant resistance may be the best approach for managing flower bud thrips and reducing or eliminating the reliance on environmentally toxic chemicals that farmers are not well equipped to handle (Omo-Ikerodah *et al.,* 2008). Sobda *et al.* (2017) reported that the use of resistant accessions combined with other control measures has benefit in controlling flower bud thrips. It has been noted that a more sustainable strategy would be to implement genetic resistance against infestation, which may be possible as several cowpea accessions have been shown to suffer only limited harm when infested with flower bud thrips (Agbahoungba *et al.,* 2017; Sobda *et al.,* 2017). Hence, Benin has a rich diversity of cowpea that has never been well assessed and extensively collected (except the few samples studied by Gbaguidi *et al.* (2004a), while many varieties seem to be disappearing (Gbaguidi *et al.,* 2013). The greatest genetic diversity of cultivated cowpea is found in West Africa, in the savanna region of Burkina Faso, Ghana, Togo, Benin, Niger, Nigeria and Cameroon (Jackai and Adalla, 1997).

Since host plant resistance may form a major component in a pest management strategy against this insect, it is essential that the resistance status of Benin cowpea cultivars to *M. sjostedti* be known through screening.

In this study, the genetic variability for flower bud thrips resistance among Benin cowpea germplasm was evaluated for the identification of resistance sources to *M. sjostedti*. This will serve as a preliminary study to breeding programs for the development of improved accessions of cowpea against the pest in Benin.

1.3.Objectives

The main objective of this study was to reduce the yield loss caused by flower bud thrips (*Megalurothrips sjostedti*) through the identification of the resistant and high yielding cultivars of cowpea in the Benin germplasm

Specifically, the study aimed to:

- Morphologically identify the different biotypes of flower bud thrips across Benin agroecological zones;
- Identify the most damaging local population of flower bud thrips among the collected biotypes;
- Determine the reaction of cowpea accessions to flower bud thrips under greenhouse conditions;
- Identify the resistance cultivars to flower bud thrips from Benin cowpea accessions under field conditions.

CHAPTER TWO

II. LITERATURE REVIEW

2.1. Cowpea [Vigna ungriculata (L.) Walp]

2.1.1. Taxonomy and botanical description of cowpea

Cowpea [*Vigna unguiculata* (L) Walp], belongs to the order of *legumes*, the family of *Fabaceae*, the tribe of *Phaseoleae* and the genus *Vigna* (Maréchal *et al.*, 1978); hence its botanical name *Vigna unguiculata* (L.) Walp. The karyotype of this species is 2n = 22 chromosomes (Maréchal *et al.*, 1978). Cowpea is an erect or creeping plant mainly autogamous, although a certain degree of allogamy has been reported which would depend on the activity of insects ensuring pollination (Rachie and Robert, 1974). Its area of origin seems to be disputed between Africa and Asia. Cowpea was first observed in West Africa, and more specifically in Nigeria (Rachie and Robert, 1974). Also, the abundance of wild forms of cowpea in Africa would be one of the proofs of its African origin. However, the precise location of the center of origin of the species is very difficult to determine since cowpeas are cultivated today in all tropical zones, in the Mediterranean basin and in the United States (Singh *et al.*, 1997). It has a taproot, creeping or climbing root (Porter *et al.*, 1975). The stems are cylindrical, slightly grooved and voluble. The leaves are alternate and trifoliate. The flowers evolve to give pods, which will be harvested at maturity.

2.1.2. Ecology and and geographical distribution of cowpea

Cowpea is a tropical herbaceous legume. Its evolution is due to a temperature of at least 8 to 11 ° C and is necessary at all stages of its development. The optimal temperature is around 28° C (Craufurd *et al.*, 1997). Cowpea can be grown in rainfed conditions, under irrigation or with residual soil moisture along rivers, or in the lake plains in the dry season, provided that the minimum and maximum temperatures (night and day) range from 28 to 30 ° C during the growing season (Dugje *et al.*, 2009). Cowpea is a crop of low and medium altitudes which requires for its development a rainfall of 750 to 1500 mm, daytime temperatures of 25–35ºC and nighttime temperatures above 15ºC. It is most productive on deep well-drained soils and does not tolerate frost and temperatures above 35ºC which can cause flowers and pods to fall (Madamba *et al.,* 2006). Cowpea can thrive under varied environmental conditions and on poor soils without adding nitrogen fertilizers. It is sown in pure culture or in association with other cultures where the spatial arrangements, the sowing date as well as the number of associated cultures vary from one region to another.

Its geographical distribution is wide, and cowpea accepts hot, tropical and humid temperature zones. West and Central Africa, are areas where cowpea is well cultivated. Nigeria and Niger are the biggest producers followed by their neighboring countries (FAO, 2004).

2.1.3. Importance of cowpea

Cowpea is an important staple food in sub-Saharan Africa, particularly in the arid savannas of West Africa (Dugje et al., 2009). About 5.59 million tons of cowpea is produced annually worldwide and West Africa alone contributes nearly 70% of this production (Erana Kebede and Zelalem Bekeko, 2020). In the West Africa subregion, production is 66% for Nigeria, 14% for Niger, 6% for Burkina Faso. The remaining 14% is shared between other countries including Benin (Centre National de Recherche Agronomique, 2013).

Cowpeas have become an important source of essential vegetable proteins. This position commonly gives it the name 'Meat of the poor' (Soule, 2002). It is a crop of social and food importance due to its protein content which is three to four times higher than that of millet and sorghum (Baoua *et al.*, 2013). Cowpea seeds are a valuable source of vegetable protein, vitamins, income for humans and fodder for animals (Dugje, 2009). Juvenile leaves and immature cowpea pods are eaten as a vegetable. According to the Beninese Center for Sustainable Development, this legume contributes 2.7% and 7.5%, respectively to the calorific and protein needs of Benineses (Aurélien Briffaz, 2017). In short, cowpea has perfectly integrated the food habits of populations in all of the coastal countries of West Africa. Agronomically, cowpea is tolerant of drought, however, thanks to the early and extra-early varieties, it can grow in the Sahel where the rainfall is less than 500 mm / year and adapts well to sandy and poor soils. It achieves its best yields on well-drained, sandy-loamy to loamy-clay soils, at pH 6 or 7. There is a large market for cowpea seeds and fodder in West Africa. According to the results of a study carried out in Nigeria, some farmers harvest and store cowpea fodder for sale during the dry season, which gives them an income 25% higher than sales in the regular season (Baoua *et al.*, 2013).

2.1.4. Main constraints to cowpea production

Despite these multiple attributes, cowpea cultivation, storage and protection today require special attention because of disease and its susceptibility to insect pests. The cowpea plant suffers from at least 35 major diseases caused by viruses, fungi and bacteria (Singh and Allen, 1980). The most formidable pests are those that cause damage to cowpeas from flowering to the maturity of the pods. The main ones are the flowering thrips (*Megalurothrips sjostedti* Trybom) (Thysanoptera: Thripidae), the pod borer (Maruca vitrata Fabricius) (Lepidoptera: Crambidae) and the pod and seed sucking complex which are the bugs dominated by *Clavigralla tomentosicollis* Hemiptera: Coreidae) (Jackai and Daoust, 1986; Singh, 1990; Jackai and Adalla, 1997).

2.2. Flower bud thrips, *Megalurothrips sjostedti* [Trybom]

2.2.1. Biology

Most members within the family Thripidae (order Thysanoptera) have a characteristic life cycle that consists of six stages: an egg, two active larval stages, an in active and non-feeding pupal stage and adult stage (male and female) (Reitz *et al.,* 2009). According to Salifu (1992), development of thrips from egg to adult takes about 19 days at 29ºC and adult thrips live for about 23 days or less. Eggs are deposited in flower buds and calyx of new and fresh flowers (Natural Resources Institute, 1996). The eggs are very tiny; a single egg is 0.25 mm long and 0.1 mm wide. The eggs are white in colour when freshly laid and change to pale yellow when mature (Richard, 2009). Incubation period takes an average period of 2 to 3 days. Thrips are described as haploidiploid because the males of thrips have half the number of chromosomes and the other half (haploid number) is found in females (Looman, 2003). Flower bud thrips undergo six developmental stages. Translucent to white colour in the first and second instar larvae, they change to yellow after 2 to 3 days and the yellow form lastes for 2 to 3 days and change to orange form which lastes for 3 to 4 days before pupation (Ogol *et al.*, 1988). Larvae actively feed on plant, but the second stage larvae are non-active in feeding, and molt to pupate in the ground (Looman *et al.*, 2003). Reitz (2009) explains that the first pupal instar is termed the propupa, a non-feeding stage that is followed by the pupa, another non-feeding pupal stage, with the entire pupation period ranging from 4 to 7 days (Ogol *et al.*, 1988), and winged adults emerge from the pupae. Flower bud thrips life cycle is about 12 to 14 days (Natural Resources Institute, 1996 and Tamò, 1991). In addition, Ogol *et al.* (1988) found that parthenogenesis can occur in *M. sjostedti* and give rise only to male progeny.

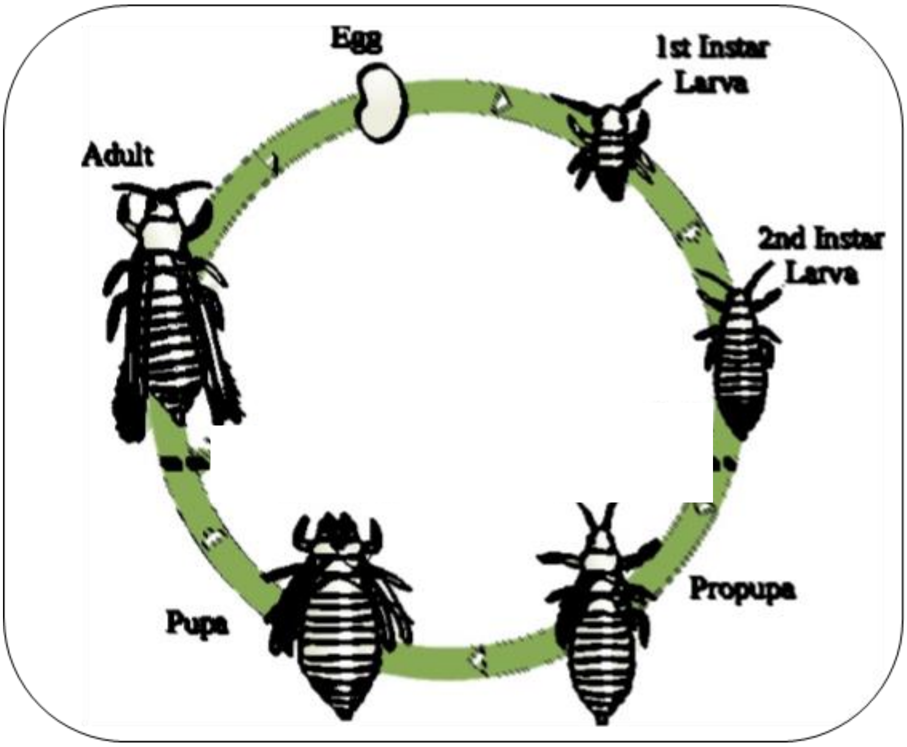

Figure 1: Generalized Life cycle of *Megalurothrips sjostedti.* Source: Vera Krischik (2017)

Females lay eggs on the plant organs. When the eggs hatch, larvae go through instar 1 and 2 and drop into soil to pupate as shown by figure 1. The propupa is then transformed into pupa for the adult to emerge. The propupa and pupae are non-feeding development stages which occur in soil.

2.2.2. Ecology, distribution and diversity of flower bud thrips

Thrips are small, elongated insects 1 to 3 mm long and difficult to observe, capture and determine. Their long, narrow wings are fringed with long bristles allowing for a gliding flight. Thrips colour can vary from yellow to black, red and brown. Different colours can be observed within the same species depending on the temperature during pre-imaginal stages and hereditary factors. Temperature can influence the size as the case in tobacco thrips. Occasionally adults of flower bud thrips fly from plant to plant, commonly over short distances. This attitude does not prevent them from spreading quickly. Thrips are sexually dimorphic (Figure 2), the female are larger and darker then male. Their dispersed can be aided or facilitated by the movement of infested objects (substrates, laboratory instruments, workers' clothing and plants), mowever males are vivid and can move fast (Bryan and Smith, 1956).

Figure 2: Photo showing the general habitat of Male (left) and female right) of flower bud thrips. Source: G. GOERGEN, IITA, Benin (2007).

Thrips, including the flower bud thrips, have a broad range of host plants on which they feed. Apart from cowpeas, thrips can be found on many other plants in families such as Fabaceae, a few Mimosaceae and Cesalpiniaceae, and a non-leguminous plant, *Cochlospermum planchonii* Hook (Bisaceae), commonly called "kokrosabia" in Ghana (Tamò *et al*., 1993). Generally, heavy rains break down thrips populations. The populations of flower bud thrips increase under dry conditions or when there is delay in the growth of a crop following the lack of water. According to Tamo *et al.* (1993), legumes such as *Vigna unguiculata* (cowpea), *Cajanus cajan* L. (pigeon pea) and *Phaseolus vulgaris* L. (common beans), appear to be the main host plants of the flower bud thrips, *M. sjostedti*. flower bud thrips have spread in Sub-Saharan Africa and can be found from the humid zones of the West to the semi-arid zones of Kenya and Sudan.

While in Nigeria, they are dominant where cowpea is produced in the dry Savannah areas (Tamo *et al.*, 1993).

Flower bud thrips are sensitive to temperature variations. Their development is affected when temperature is below 15°C and above 35°C. Mating of *M. sjostedti* begins just after their emergence into adult, and the females can lay eggs on the day of emergence (Ogol, 1988). This could be explained by the lack of courtship observed in that species (Salifu, 1986). Like temperature, moisture also affects egg hatching and development. Under optimun condition of temperature (24-32.5°C) and relative humidity (39% - 60.5%) with food available, adult longevity in females can vary from 5-22 days, and from 1-2.5 days in case of lack of food. With regard to the males, they may live for 1-8 days when food is provided, and for 1-4 days when food is not provided (Salifu, 1986).

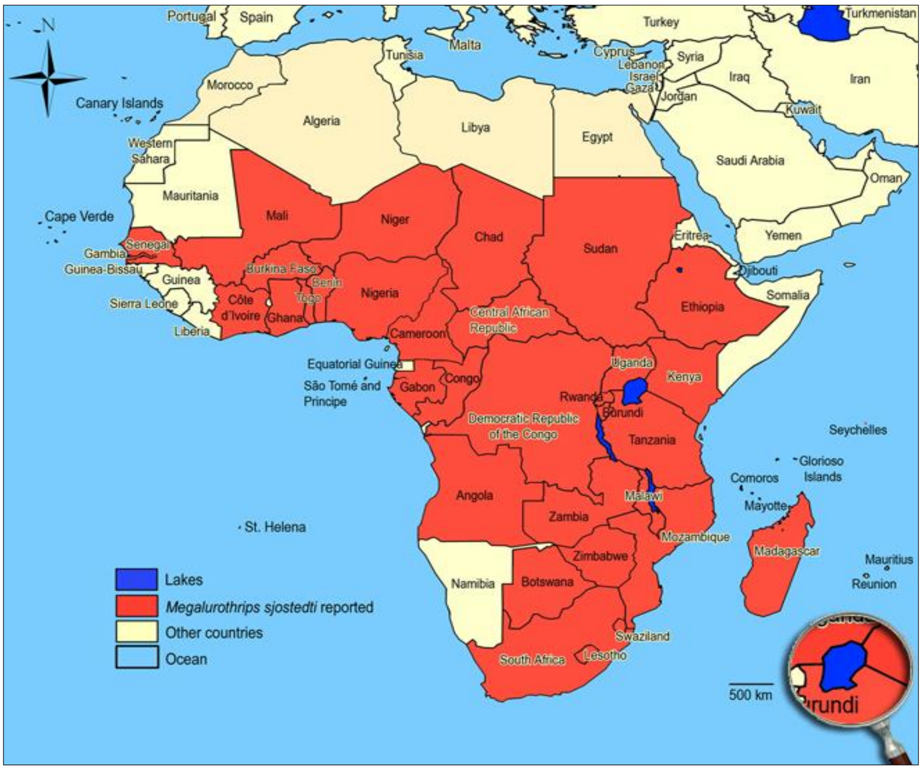

Figure 3: Geographical Distribution of Thrips in Africa (in red). Source: Andnet *et al*. (2015).

Worldwide, species of thrips are at least about 6,000 in numbers (Hanson, 2016). Approximately 5,500 described species of thrips in two suborders encompass eight families (Morse *et al.,* 2005). Family Thripidae is the most dominant among the families of order Thysanoptera. Thrips are distributed worldwide in tropical and temperate zones inhabiting forests, grasslands, bushes, leaves and flowers (Iftikhar *et al.*, 2016). Members of the genus *Megalurothrips*, which live and breed in legume flowers, are widespread and commonly distributed throughout the old World, tropics and subtropics (CBIT, 2013). The African species, *M. sjostedti* and two of the Asian species, *M. usitatus* (Bagnall) and *M. distalis,* are known to be pests of leguminous crops (Abtew *et al.*, 2015).

Table 1*:* Major species of thrips attacking crops in Africa

S/N	Common names	Scientific names
1	African bean flower thrips	*Megalurothrips sjostedti*
2	Coffee thrips	*Diarthrothrips coffeae*
3	Blossom or Cotton bud thrips	*Frankliniella schultzei*
4	Black tea thrips	*Heliothrips haemorrhoidales*
5	Banana thrips	*Hercinothrips bicinctus*
6	Citrus thrips	*Scirtothrips aurantii)*
7	Cacao or red banded thrips	*Selenothrips rubrocinctus*
8	Tomato thrips	*Ceratothripoides brunneus*
9	Cereal thrips	*Haplothrips spp*
10	Tea thrips	*Scirtothrips kenyensis*
11	Onion thrips	*Thrips tabaci*
12	Western flower thrips	*Frankliniella occidentalis*

Previous studies have reported that, there are at least two other species of thrips that are found on cowpea in Africa: *Frankliniella schultzei* (Trybom) (Thysanoptera: Thripidae) and *Sericothrips occipitalis* Hood (Thysanoptera: Thripidae). These are known to be minor pests of cowpea (Singh *et al.*, 1978).

In Africa, foliage thrips, *Sericothrips occipitalis* Hood, are found on cowpea seedling during drought stress, causing malformed distorted leaves with light yellow patches sometimes confused as signs of viral infection or leafhopper damage (Singh *et al.*, 1978). These thrips are dark brown, the adults and nymphs both feed in the leaf buds. The foliage thrips population declines markedly with the onset of rains, and under normal crop –growing condition the foliage thrips are not noticed (Ho and Chen, 1992). They are often found on seedlings in greenhouses or in irrigated pots during the dry season. Rarely do their populations increase enough in the field to cause economic losses (Singh *et al.*, 1978). Insecticides effective against legume bud thrips are also effective in controlling foliage thrips. Granular application of synthetic insecticides in soil such as carbofuran has been found to be effective.

2.2.3. Economic importance and damage of flower bud thrips in Africa.

Generally, cowpeas cultivated for grain are more exposed to thrips damage than that grown for fodder. In fact, for fodder production, thrips susceptibility may be advantageous as the cowpea plant may continue to produce foliage in the absence of flower and pod production (Okike, 2000). Gbaguidi *et al.* (2015b) reported that insect attack in fields were higher than other factors that could reduce yield. In the West African sub region, low levels of cowpea yield (200-350 kg/ha) obtained by some farmers are directly attributed to insect pest damage in the field (IITA, 2007).

The flower bud thrips in West Africa is one of the insects which causes more damage to cowpea. This insect is able to induce yield losses of about 20 to 80% depending on the level of attack (Ngakou *et al.*, 2008; Omo-Ikerodah *et al.*, 2009; Agbahoungba *et al.*, 2017). Both adult and nymphs of thrips, attack leaves and flower buds of cowpea (Bediako, 2012). The nymphs of flower bud thrips and adults feed on flower buds and can completely suppress flower population. The racemes of severely infested plants do not have any flower buds; they turn brown, dry up and fall off. The attack begins before the flowers open, and causes the flower buds to become dry and brown, progressively aborting to leave dark red scars (Childers and Achor, 1995). They pierce and suck the sap through their mouthpart, thereby inducing dehydration, malformation of pods, abortion and falling of infected organs (Abtew, 2015). Thrips also reduce photosynthetic capacity of plants when sucking nutrients (Tang, 2015). Apart from the direct damage caused by thrips, flower bud thrips also serve as vectors of diseases (Ullman *et al.*, 1997 and 2002). Injuries caused by thrips feeding may serve as entry points for bacterial or fungal pathogens. As a result of indirect feeding damage, it has been documented that this species can transmit virus, fungi and bacteria to cowpea (Mound, 2005). These diseases may cause serious damage to plant species (Mound, 2005). For example infection by Fusarium ear rot in maize is facilitated by the Western flower thrips, and purple blotch in onions by the Onion thrips. Among the known 1,710 species of Thripidae only 14 thrips species are currently reported to transmit tospoviruses (Kumar *et al.*, 2016). Flower bud thrips can induce losses of up to 100% if little or no control measures are applied.

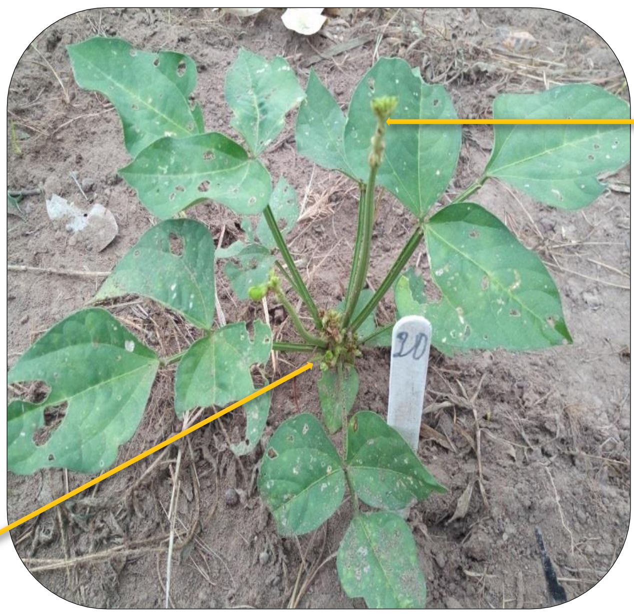

Figure 4: Photo showing a Thrips-infested plant. *Source: H. TOSSOU*

2.3. Screening techniques for host-plant resistance to flower bud thrips

Considerable work has been done at llTA on the development of screening techniques for cowpea resislance to flower bud thrips, *Megalurothrips sjostedti* Trybom. (Thysanoptera: Thripidae). Screening has been highly successful in the field, but a number of screenhouse techniques have also been carried (lITA, 1983). Technics developed to ensure uniform and high infestation in the field were simple. These included planting dwarf pigeon pea cultivars all around the field about 30 days before planting the test material (Jackai and Singh, 1983). Along the border, *Crotalaria juncea* (L.) was planted at the same time to serve as a trap crop for legume pod borer, thus reducing the pod borer population on the cowpeas (Jackai and Singh, 1983**)**. The test cultivars were planted in single rows, and known susceptible checks were planted every 10th row. About 35 Days after planting, endosulfan was sprayed at the rate of 200g a.i./ha to ensure that legume pod borer populations did not interfere with legume bud thrips infestations (Jackai and Singh, 1983**)**. Plants were rated for thrips resistance at 45 and 55 days after planting. Cultivars with the last thrips damage were further tested in replicated field trials for confirmation. While Agbahoungba *et al.* (2017) modified slightly this proposal, by using only VITA7 as spreader row and rating the tested plants from 37^{th} to 51^{th} days after planting at weekly basis and were able to identify the resistance sources among the screened germplasm. The same work was done by Alabi *et al.* (2011). An increase in thrips population was achieved by planting a susceptible cultivar (Vita 7) as spreader rows in a checkerboard design two weeks prior to planting the experimental materials. At the raceme stage of the test plants, the spreader rows were uprooted and plants laid between rows of the test plants. This caused the thrips to move away from the drying plants to those of the test green rows (Alabi *et al.*, 2011).

Abudulai *et al.* (2006) and Togola *et al.* (2019) followed the same method but applied synthetic pyrethroid insecticide, ‘Cyper-Diforce EC’, composed of Cypermethrin (30g/L) and Dimethoate (250g/L) as active ingredients, at podding stage to control other pests such as

Maruca vitrata (Fabricius) (Lepidoptera: Crambidae) and the pod sucking bugs complex. No trap crop for legume pod borer as *Crotalaria juncea* L. was planted to reduce Maruca's infestation on test plants.

2.4. Available resistant cowpea varieties in Africa

Plant resistance was defined by Snelling (1941) as those characteristics which enable a plant to avoid, tolerate or recover from the attacks of insects under conditions that would cause great injury to other plants of the same species. Host-plant resistance has been researched extensively at the International Institute of Tropical Agriculture (IITA) in the pest (Singh *et al.*, 1978). A germplasm collection of about 12,000 cowpea cultivars has been screened in the field for resistance to thrips (Jackai and Singh, 1983**)**. Many screening of cowpea germplasms have been conducted in Africa and resistance sources were identified. For instance, Alabi *et al.* (2011) found the cowpea lines Moussa local, TVu1509, TVx3236, Sewe and Sanzibanili to be able to withstand *M. sjostedti* in field conditions while KVx404-8-1 was shown to be tolerant. Alabi *et al.* (2010) found in field trails the cowpea lines IT90K-277-2, Sanzibanili, Moussa local, Sewe to be resistant to thrips and had low thrips population compared to IT91K-180 and Kpodjiguegue and TV×3236 that displayed slightly higher damage index and thrips numbers than the others. In Uganda, Agbahoungba *et al*. (2017), identified eleven cultivar resistant to flower bud thrips including IT2841*Brown, MU20B, EBELAT*NE39, WC17, WC29, MU24C, WC5, NE46, WC30, NE67 and NE51. The varieties "IT 90K-277-2", "KVx 404-8-1", "TVx 3236-01G", "IT91K-180" "Moussa Local", "Sanzisabinli", "Sewe", "TVu 1509", and "TVx 3236" were reported to be resistant to cowpea flower thrips in West Africa (Amoah *et al.*, 2001). Screening carried by Singh, (1977) identified TVu 1509 and TVU 287 to be resistant to thrips. TVu 1509 has the higher tevel of resistance and has been used in the breeding program at llTA to develop several advanced breeding lines with resistance to thrip (Singh, 1977). In several tests, the early maturing cowpeas ER-1 and ER-7 have shown a moderately resistant.

However, they are susceptible to thrips under greenhouse tests, but escaped thrips infestations when planted in the field and, thus, appeared resistant (Jackai and Singh, 1983). Togola *et al.* (2019) reveled that the resistance levels observed in genotypes TVu8631, TVu16368, TVu8671 and TVu7325 were similar to that of Sanzisabinli.

2.5. Agroecological zones in Benin and the study areas

Benin is a West African country between 6 ° 10 N and 12 ° 25 N latitudes and 0 ° 45 E and 3 ° 55 E longitudes. The country is subdivided into 12 regions grouped into five agro-ecological zones (Vissoh *et al.*, 2004; Djagba *et al.*, 2017). The south and center are relatively wet with two rainy seasons and annual average rainfall of 1100 to 1400 mm/year (Yabi and Afouda, 2012). The north is arid or semi-arid and characterized by a single unpredictable rainy season with irregularly annual average oscillating between 800 and 950 mm/year. Benin is borderd by the Nigeria, Togo, Niger, Burkina-Faso and the Ocean Atlantic. The country is divided into eight agricultural zones.

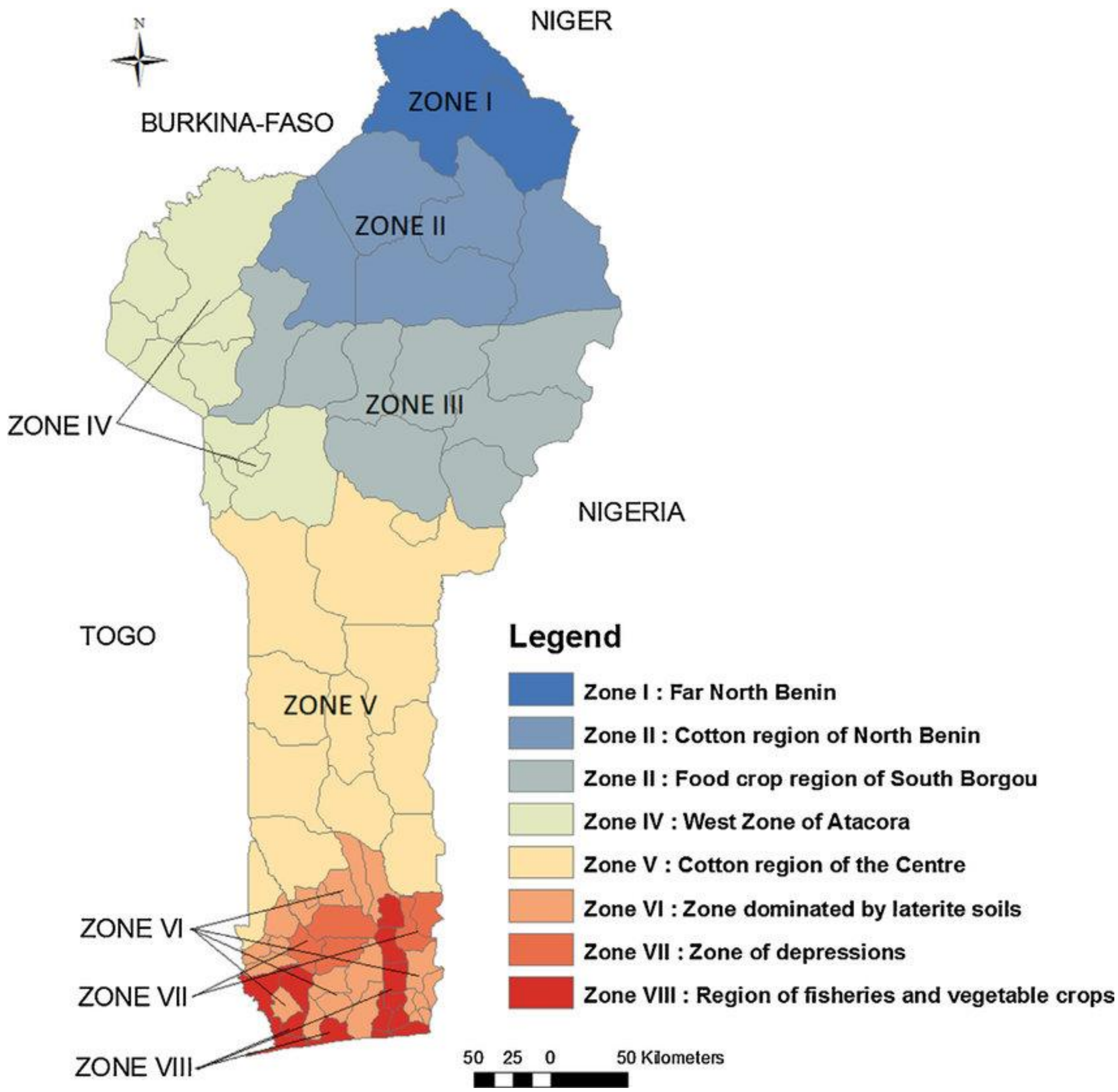

Figure 5: Benin map showing the agricultire zones. Source: Akossou et al. (2016)

2.5.1. Physical and environmental conditions in the various agro-ecological zones

The field trials were conducted in three different locations: IITA-station (Abomey-Calavi); Gbaffo (Dassa-Zoumé) and Zakpakpame (Zakpota).

Abomey Calavi is located in the Southern part of the Republic of Benin close to the Atlantic Ocean. It is boarded in the North by the district of Zè, in the South by the Atlantic Ocean, in the East by the districts of Sô-Ava and Cotonou, and in the West by the districts of Tori-Bossito and Ouidah. It covers an area of 539 m² representing 0.48% of the national surface of Benin

(Biaou, 2006). The main features are a sandy strip with littoral cords, a bar land plateau and depressions and swamps. The climate is sub-equatorial with two rainy seasons and two dry seasons. The greatest part of the territory of the district is occupied by tropical ferruginous soils. The cultivable land is estimated at 464.5 km² (Africa Council, 2006).

Dassa-Zoumé is among the six districts of the Region of hills, with an area of 1711 km^2. It is boarded on the North by the district of Glazoue, on the South by the districts of Zagnanado and Djidja, on the East by the districts of Savè, and on the West by the district of Savalou. The climate is subequatorial type and influenced by the southern domain Sudanese. It is characterized by two seasons in the year: a dry season (from November to March) and a rainy season (from April to October) which lasts for about 8 months (Capo-Chichi, 2006). The distribution of rains is regular enough, with a maximum generally recorded in July and an annual average rainfall oscillating around 1,100mm. This rainfall is sometimes increased due to the microclimate that prevails there. Temperature variations are relatively high, with extreme temperatures sometimes rising up to 38 °C. Low temperatures (23 °C) are often observed at night during the harmattan period (December- February). The hottest period is between February and March, with thermal differences varying from 11 ° to 13 ° (Africa Council, 2006).

Zakpota is boarded in the North-west by the district of Djidja, in the North-East by the district of Zagnanando, in the South-West by the district of Bohicon, in the East by the district of Covè, and on the Southeast by the district of Zogbodomey (Africa Council, 2006). Three types of soils are found in the district of Zakpota. These are: 1). Ferralitic soils commonly referred to as barre organic materials and minerals because of their long use, 2). Tropical ferruginous soils, but less poor, very shallow because concreted outcrops, and 3). Hydromorphic soils still rich and suitable for agricultural production are found in depressions and lowlands (FAHALA, 2006).

Zakpota, is influenced and dominated by the sub-equatorial climate characterized by two rainy seasons, a major one from mid-March to mid-July and a minor one from September to

November. There are also two dry seasons of which the major one spreads from December to March, and the small one covers the second half of July and the month of August. The average annual rainfall is 980 mm, with strong fluctuations over the past 40 years due to the uncertainties and climatic hazards in the locality. The temperature varies between 24 and 34 °C with average thermal amplitudes.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study areas

The study was done in two agro-ecological zones (south and centre) in comprising agriculture zones five, six and seven where cowpea is mainly produced. Experiemnts were conducted on three differents sites (localities). Abomey-Calavi is a barre land, denominated by laterite soils and suitable for cowpea production as well as Za-kpota. Gbaffo is one of the villages where cowpea is produced in the central region of Benin and is part of the Agroecological zone of the centre Benin. Za-kpota is located in the transitional zone of the south and the central agroecological zone and one of the places where cowpea farming is well particed (Figure 6).

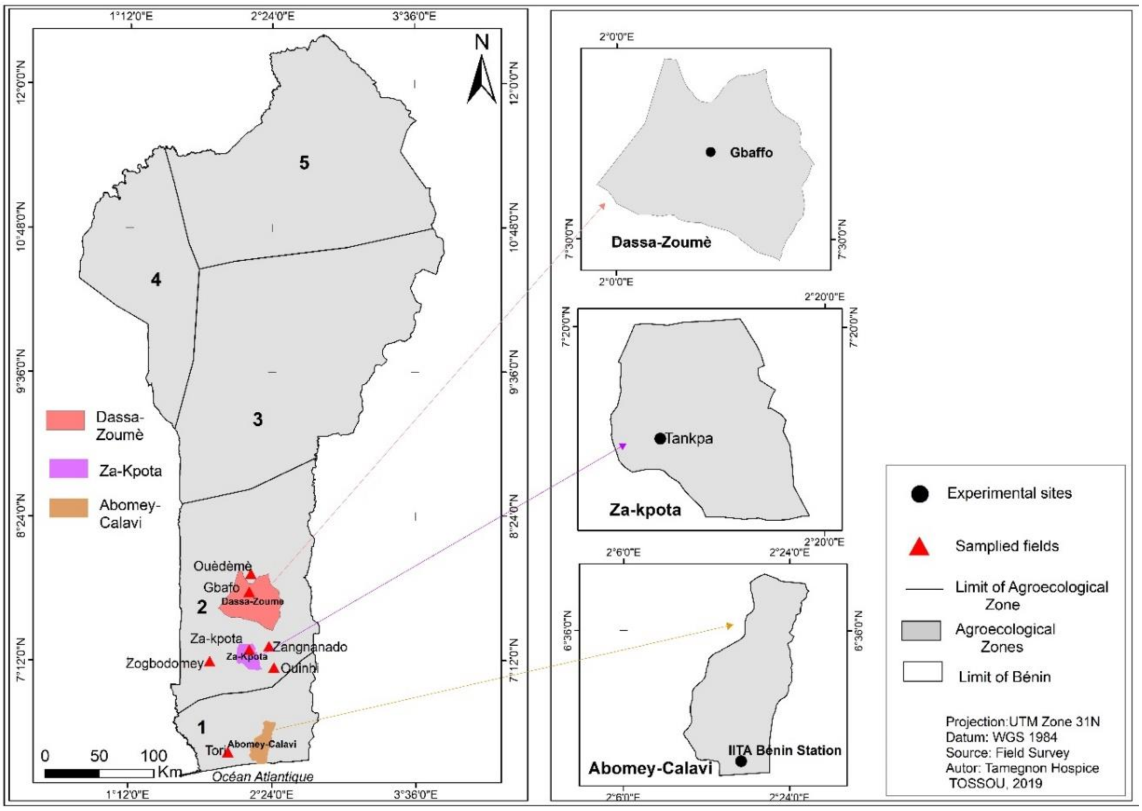

Figure 6: Map of Republic of Benin showing the different areas of study. Source: H. TOSSOU

3.1.1. Collection and morphological identification of flower bud thrips biotypes from different locations

The collection of cowpea accessions and flower bud thrips samples were carried out in the municipalities such as Gbaffo, Tori, Za-kpota/Tindji, Ouinhi, Zangnanado, Zogbodomey, and Oudèmè (Table 2). These regions are places where cowpea is produced and hence host-pot to *M. sjostedti*. The sampling sites were not evenly distributed among the agroecological zones. Sampling were done only in cowpea farms at flowering stages to ensure the presence of *M. sjostedti*. The sampling methodology followed that of Abadassi (2014), where in each district, one village with relatively high production and one village with relatively low production were selected, taking into consideration the main agro-ecological zones. In total, twenty (20) landrace accessions were collected from farmers. Twenty-eight (28) cowpea lines were also collected from the IITA gene bank, making the total number of accessions forty-eight (48) (Table 3). The grains of cowpea collected were conserved in envelop bags. At the same time, the thrips sample was taken from the fields. Cowpea flowers were collected in envelop bags. Naturally infested flowers were collected from the fields the known susceptible cultivars and other pulses as well. Samples of flower bud thrips were fed on fresh pods of cowpea in glossary bags. Once in the laboratory, flowers were stripped and flower bud thrips were aspirated (extract) and reared. All samples collected, seeds, as well as flower bud thrips, were georeferenced using Global Position System (GPS). The sampling of both germplasms and thrips was done in June 2018.

Table 2: List of local populations of thrips collected from the different localities

S/N	Localies	Insect familly	Country	Region	Host plant	Latitude(N)	Longitude(E)
1	Gbaffo	Thysanoptera	Benin	Collines	Cowpea	7.802783	2.271767
2	Tori	Thysanoptera	Benin	Atlantic	Cowpea	6.563450	2.133650
3	Za-kpota/Tindji	Thysanoptera	Benin	Zou	Cowpea	7.000717	1.958200

S/N	Localies	Insect familly	Country	Region	Host plant	Latitude(N)	Longitude(E)
4	Ouinhi	Thysanoptera	Benin	Oueme	Cowpea	7.104050	2.456950
5	Zangnanado	Thysanoptera	Benin	Zou	Cowpea	7.223717	2.464667
6	Zogbodomey	Thysanoptera	Benin	Zou	Cowpea	7.081467	2.109283
7	Oudeme/Glazoué	Thysanoptera	Benin	Collines	Cowpea	8.105000	2.129000

Source: Hospice TOSSOU

Table 3: List of cowpea accessions collected and used in this study

No	Accessions names	Origins	Resistance status
1	Adjagnikoun	Farmers	unkown
2	Akunnado	Farmers	unkown
3	Atchawékoun	Farmers	unkown
4	Awlétchi	Farmers	unkown
5	Awonlignikoun	Farmers	unkown
6	Djètoko	Farmers	unkown
7	Elisabeth	Farmers	unkown
8	Gboto	IITA genbank	unkown
9	Gléssissaffodo	Farmers	unkown
10	IT06K-242-3	IITA genbank	unkown
11	IT07K-188-49	IITA genbank	unkown
12	IT07K211-1-8	IITA genbank	unkown
13	IT07K-243-1-10	IITA genbank	unkown
14	IT07K318-33	IITA genbank	unkown
15	IT83S-742-2	IITA genbank	unkown
16	IT84D-449	IITA genbank	unkown
17	IT84E-124	IITA genbank	unkown
18	IT84S-2246-4	IITA genbank	unkown
19	IT86D-1033	IITA genbank	unkown
20	IT86D-1038	IITA genbank	unkown
21	IT86D-1057	IITA genbank	unkown
22	IT86D-888	IITA genbank	unkown
23	IT87S-1390	IITA genbank	unkown
24	IT93K-452-1	IITA genbank	unkown

No	Accessions names	Origins	Resistance status
25	IT97K-449-35	IITA genbank	unkown
26	IT97K-556-6	IITA genbank	unkown
27	Kaki	IITA genbank	unkown
28	Kaki gros grains	Farmers	unkown
29	Kaki petit grains	Farmers	unkown
30	Kodobobo	Farmers	unkown
31	Komcallé	IITA genbank	unkown
32	Kpègnikoun	Farmers	unkown
33	Kplobè	IITA genbank	unkown
34	Kplobè-Wéwé	Farmers	unkown
35	Kpodjiguèguè	Farmers	unkown
36	Kumassi	IITA genbank	unkown
37	Mawougbadonou	Farmers	unkown
38	Mawounan	Farmers	unkown
39	Moussa	IITA genbank	unkown
40	Nontché-Wagbèhamin	Farmers	unkown
41	Sanzibanili	IITA genbank	unkown
42	Sèwé	IITA genbank	Resistant check
43	Tawa	IITA genbank	unkown
44	Tiligré	IITA genbank	unkown
45	Tola	Farmers	unkown
46	Tonton	Farmers	unkown
47	Vidégnikoun	Farmers	unkown
48	Vita7	IITA genbank	Susceptible check

3.2. Mass rearing and morphological identification of flower bud thrips in the laboratory

3.2.1. Mass rearing of flower bud thrips in laboratory

The Plexiglas cylindrical boxes (cylindrical oviposition tubes) were washed with soapy water and dried with toilet paper (Alabi *et al.*, 2004). Scissors were used to cut small pieces of paper towel 3.5 cm side and stapled by their center. These papers were then introduced into the plexiglass cylindrical boxes of 4 cm in diameter and 11 cm in height to reduce the internal humidity of the boxes. The peduncles, cowpea pods were rinsed with tap water and then cut into 8 cm segments. The cut ends of these peduncles were then sealed with parafilm to prevent early drying and the risk of rot and were placed in the plexiglass boxes (Figure 6). The stalks used here were very fresh to facilitate the feeding of female thrips and allow them to lay eggs in mass. Then, about 70 adult reproductive thrips were sucked off using a pooter and introduced into each box containing the peduncles. The boxes were then closed with a stopper pierced in the middle and mat of small meshes not allowing flower bud thrips to escape but assume the air-breathing of the insects. The boxes thus prepared are called oviposition boxes. After 72 hours, the eggs were laid on the peduncles. Thus, adult thrips and peduncles were removed from the boxes. The stalks were then placed on paper towels and debris and live or dead insects were removed with a brush. The boxes were cleaned and disinfected with paper towels slightly moistened with 70% ethyl alcohol, and the peduncles were reintroduced into the boxes. Fresh (soft) cowpea pods were taken from the field then cleaned to remove all eggs they may carry. Thus treated pods were introduced into the boxes containing the peduncles. A few hours later, the eggs hatched and emerged larvae migrated on the pods to feed on it. Subsequently, new soft cowpea pods were introduced and the plexiglass cleaned up twice a week and for about three weeks. The rearing lab displayed 27 ± 2°C and 65-70% of relative humidity and 12:12 D/N photoperiod.

Figure 7 : Photos of tubes containing chopped cowpea peduncles. Source: H. TOSSOU

Legend: 7A-collection of cowpea flowers containing flower thrips in farms; 7B-shopped peduncle of cowpea; 7C-reaing of different samples collected

3.2.2. Morphological identification of the thrips

In the International Institute of Tropical Agriculture (IITA-Benin) Entomological Laboratory, the different species of flower bud thrips were identified using morphological methods (Palmer, 1990). Samples were taken from the first progeny that came from each reared local population and identified. The identification was done by the student under supervision of the head of the entomological laboratory (Dr George GOERGEN, a Taxonomits at IITA-Benin) based on a specific keys. Flower bud thrips were transferred in 2-ml Eppendorf tubes containing 1ml of

70% ethyl alcohol using a small paintbrush to place them onto microscope slides for identification. Adult thrips were identified using the keys of Mound & Marullo (1996) and Palmer (1990).

3.3. Treatment, purification of collected germplasms

Collected cowpea seeds were first dried up at about 12 % of moisture content and then treated with fungicide, packed in envelope bags and conserved in the fridge at four (4°C) degree Celsius. The fungicide used was a mixture of Maneb 63% and Carbendazime 50% at the rate of 10g per 1 kg of seeds (Dossou et *al*., 2016).

3.4. Identification of the most damaging local population of flower bud thrips among the samples collected under artificial conditions

3.4.1. Experimental design

The cowpea cultivars Vita7 and Sewe were grown in pots containing sterilized soil in the greenhouse. Sewe and Vita7 served as resistant and susceptible checks, respectively (Alabi *et al.,* 2004). Each of these cultivars was sown in three pots with three seeds per pot, and the pots arranged in a Completely Randomized Design with three replications. In this experiment, the local populations of thrips collected were used as treatments. Ten days after sowing, seedlings of cowpea were thinned out to one plant per pot. Two weeks after planting, the plants were sprayed with Lambda cyhalothrin (as Karate 2.5 EC) applied at the rate of 2.5 g (a.i.) ha^{-1} using a CP-15 knapsack sprayer. The plants were irrigated as needed. Three weeks after planting, each plant was covered with a mesh sleeve cage. Infestation was done at 30 days after planting by putting the reared thrips on cowpea plants at the rate of 15 larvae (6-7 days after hatching) per plant (Figure 7). The infestation took place for a week before the rating started. The mesh sleeves used was to avoid thrips migration. The scoring was done successively at 37, 44, 51 and 58 days after planting (DAP).

(A: seedling of cowpae) ***(B: Artificial infestation of cowpea)***

Figure 8 : Photograh of plants infested by thrips enclosed in much sleeve. Source: H. TOSSOU

3.4.2. Data collection

Data were taken at weekly intervals, from the 4th to the 8th week after sowing. Data were recorded on each infested plant including the rating of damage, number of thrips per flower, the total number of flowers made along the phenology of the plants and the number of aborted flowers. The accessions were evaluated using the protocol of Jackai and Singh (1988) 1-9 scale. The rating was based on a combination of different thrips intensities causing browning of the stipulations and floral buds, non-peduncle elongation, and abscission of the floral buds (Jackai and Singh, 1988) (Table 4). At each rating date, thrip populations were predicted by randomly selecting 2 flowers per plant. The flowers were put in glass pipes containing 70% ethanol solution and then dissected and counted as the number of thrips (Abudulai *et al.*, 2006).

Table 4: Scoring scale of Jackai and Singh (1988)

Scope	Scoring scale of Jackai and Singh (1988) is illustrated as follow:
1	no browning/drying (i.e scaling) of stipules, leaf or flower buds; no bud abscission
3	initiation of browning of stipules, leaf or flower buds; no bud abscission
5	distinct browning/drying of stipules and leaf or flower buds; some bud abscission
7	serious bud abscission accompanied by browning/drying of stipules and buds; non elongation of peduncles
9	Very severe bud abscission, heavy browning, drying of stipules and buds; distinct no elongation of (most or all) peduncles.

3.4.3. Data analysis

Variance analysis was conducted on data gathered on thrips harm and yield parameters (Felipe, 2009). The mixed linear model used to perform the analysis of variance is presented below:

$$y_{ij} = \mu + \rho_i + r_j + \varepsilon_{ij},$$

Where

y_{ij} is the observed value for the i^{th} accession from j^{th} replication,

μ is the general mean effect;

ρ_i is the i^{th} accession effect (considered as fixed effect);

r_j is the j^{th} replication effect (considered as random effect); and

ε_{ij} is the experimental error considered as random.

The means were segregated using the Lesser Significant Difference Protected Fischer (LSD) test at 0.05 significant level. The local populations of thrips were classified based on the means damage displayed by the susceptible accession (vita7): 1-3 = weak, 4-6 = damaging and 7-9 = most damaging. A correlation analysis was performed to compare the relationship between thrips damages caused by local populations. The different analyses were performed in the R3.6.0 software environment (R Core Team, 2019).

3.5. Determination of the reaction of cowpea accessions to flower bud thrips under greenhouse conditions

3.5.1. Planting and experimental design.

The seeds of the 48 cowpea accessions collected were planted in the greenhouse at IITA-Benin station in pots filled with sterilized soil mixed with fertilizer NPK (15-15-15) at a dose of 0.50g/pot. The pots were cleaned and the greenhouse sprayed with Lambda cyhalothrin (as Karate 2.5 EC) using a CP-15 knapsack sprayer applied at a dose of 2.5 g (a.i.) ha^{-1}. The 48 accessions were sowed in a Completely Randomized Design with three replicates. The accessions were sown in pots at the rate of three seeds per pot. The pots were watered every 3 days through the experiment. At 10 days after planting, seedlings were thinned at 1 plant per pot. In each replication or block, each accession was sowed in four (4) pots. Sewe and Vita7 were used as resistant and susceptible checks respectively in the experiment (Alabi *et al.,* 2004), respectively. At two weeks old (15DAP) and 60 DAP, the plants were then sprayed with Lambda cyhalothrin.

3.5.2. Artificial infestation

The infestation of the different plants was performed manually using 1.5 Eppendorf tubes. At about four weeks old, the various accessions were artificially infested. A total of 25 larvae at 6 to 7 days after hatching were placed in single plant using Eppendorf tubes. These tubes were transferred to the greenhouse early in the morning from 7 to 9 am. The Eppendorf were delicately opened and placed on the plant liana on each plant.

3.5.3. Assessment of the different accessions resistances

The scoring scale of Jackai and Singh (1988) (Table 4) was used to evaluate the accessions. A week after the infestation of the test accessions, thrips had spread and symptom began to show on the most susceptible onces. The data collection started from the 5th week (37 days after planting). A visual rating of thrips damage was done every week. Plants were marked and data collected on them along the phenology of the accessions. Data collected included (1): the rating of thrips damage, (2): number of thrips per flower (3): number of peduncles per plant and (5): number of pods per peduncle, (6): number of days to 50% flowering and maturity. The total number of pods per plant was calculated from the number of pods per peduncle and the number of peduncles per plant. The accessions were scored for damage on a scale of 1-9 from 37 to 58 days after planting. Scoring of damages observed was based on a combination of varying intensities of browning of the stipules and flower buds, non-elongation of peduncles and flower bud abscission. For each accession, population density of thrips was estimated at each scoring date. Two flowers per plant were randomly taken and placed in a vital glass containing 70% of ethanol solution (Abudulai *et al.*, 2006; Agbahoungba *et al.*, 2017). Once in the laboratory, these tubes were shaken, then flowers were washed and poured into a petri-dish of 90mm diameter and dissected under a microscope (Wild M38, HEERBRUGG SWITZERLAND)., Thrips were observed at 6.4X magnification and counted using a tally counter. Four weeks (37, 44, 51 and 58) after planting during plant phenology, the population density of thrips was evaluated at a weekly interval.

3.5.4. Data analysis

The damage scores, Thrips counts per flower and the number of pods per plant were subjected to the analysis of variance using R3.6.0 software environment (R Core Team, 2019).

To determine if there were significant differences among the cowpea accessions. The analysis of variance followed the mixed linear below:

$$y_{ij} = \mu + \rho_i + r_j + \varepsilon_{ij},$$

The means were separated using Fischer protected least significant difference (LSD) test at 0.05 significance level. After assessment, accessions were grouped according to the average score (thrips damage score) displayed across the experiment: 1-3 = resistant, 4-6 = moderately resistant and 7-9 = very susceptible.

3.6. Identification of the sources of resistance to flower bud thrips among Benin cowpea accessions in field conditions.

3.6.1. Experimental design

This experiment was conducted under field conditions at IITA-Benin (Abomey-Calavi), at Zapkota and Gbaffo (Dassa-Zoume). The screening experiments were done during the minor rainy season from septembre to octobre. Many documents reported that thrips population density and damage is remarkable in the minor season due to weak intensity of rain. During the major season, strong rain washes them off and hence impede on their damage on cowpea. In each location, one farm was selected for the experiments.

Forty-eight (48) accessions of cowpea were evaluated using alpha lattice design (8 blocks x 6 accessions per block) with three replications. The experiments were set up in the fields from July 2018 to January 2019. Each accession was planted in three row-plots of 5 m long on 3m wide with an inter-row space of 0.75 m between rows, and 0.3 m between plants on the row with two plants per hill and 1.5 m between adjacent plots. The cultivar Sewe was used as the resistant control and Vita 7 as the susceptible control in the study (Alabi *et al.*, 2004). Susceptible check (Vita7) was planted as spreader rows in a checkerboard designed two weeks before planting of the experimental accessions. The spreader rows were removed and placed between the test plots at the fourth week after planting (Abudulai *et al.*, 2006). When the test accessions were at two weeks old, sprayed Lambda cyhalothrin (as Karate 2.5 EC) was carefully applied at the rate of 2.5 g (a.i.) ha^{-1} 60 DAP, against pod-sucking bugs (PSBs) to eliminate the confounding effects of *Aphis craccivora* and *Clavigralla tomentosicollis* in identifying thrips resistant cultivars (Agbahoungba *et al.*, 2017). Two weedings were performed manually using traditional hoes.

3.6.2. Data collection

The visual scoring of thrips damage was used to rate the test accessions in the fields. Along the phenology of the test accessions, plants were scored four times: 37, 44, 51 and 58 DAP. The scoring scale of Jackai and Singh, (1988) was used (Table 4). Data was recorded on the thrips damage, thrips population density per accession along the phenology of accessions from 30 days after planting; and subsequently at weekly intervals, for five weeks. Scores were defined as: 1-3 = resistant, 5= moderately susceptible and 7-9 = very susceptible. Rating was based on a combination of varying intensities of thrips induced browning of the stipules and flower buds, non-elongation of peduncles, and flower bud abscission (Table 4) (Jackai and Singh, 1988). Number of thrips per flower (adult as well as larvae) was estimated from 10 flowers, randomly picked in a plot.

Data related to yield and yield components were also collected during the trials. These parameters include the number of days to 50 % flowering; number of days to 50 % maturity; number of pods per peduncle; number of peduncles per plant; number of seeds per plot; grain weight per plot (g). At the maturity, the pods were harvested two times and the yield estimated (kg ha^{-1}) from the total dried grain weight per plot. Per plot, ten (10) plant were chosen on the middle lines of the plots and marked with a yellow cord attached to the plant lianas. Data were recorded on those plants during the scoring period in such a way that each of them was followed. Randomly, 2 flowers per marked plant were picked at weekly interval (Figure 8). The samples were taken once a week, in the mornings, between 07:00 - 09:00 am. The flowers were preserved in a glass bottle containing 70% ethanol before extracting the thrips.

Sample collected were then brought to the laboratory. Flowers were thereafter stripped and thrips counted using microscope as shown the picture as attached.

Figure 9 : Photo of flowers infested with thrips. Source: H. TOSSOU

Once in the laboratory, the vial glasses containing samples of flowers in alcohol, are agitated vigorously and emptied in a petri dish of 90 mm of diameter. With the aid of tweezers and brush, the flowers were then stripped of thrips. Another petri dish of the same size is drawn with lines forming small lockers on the lower face of the box. This box is placed, the face drawn up under the binocular loop (Figure 10). In the end, the petri dish containing thrips is placed on the other superset beneath the binocular. Thrips were observed at 6.4X magnification with a Wild M38, Heerbrugg Switzerland type and Thrips were counted using a hand machine**.**

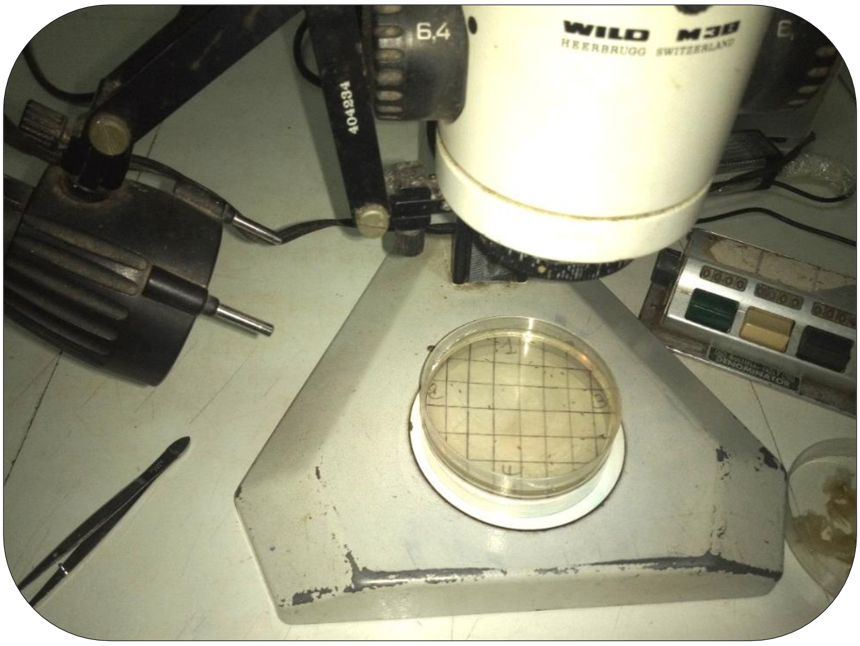

Figure 10 : Mounting and thrips countin. Source: H. TOSSOU

3.6.3. Statistical analysis

All collected data were analyzed using R3.6.0 software environment (R Core Team, 2019). The analysis of variance ANOVA across locations was performed using the mixed linear model below (Smith *et al.*, 2005; Agbahoungba *et al.*, 2018)

$$y_{ijlm} = \mu + \rho_i + \iota_j + r_l + b_{m(l)} + \rho\iota_{ji} + \varepsilon_{ijlm} ,$$

Where

y_{ijlm} is the observed value for the i^{th} accession from j^{th} location,

m^{th} block nested within the l^{th} replication;

μ is the general mean effect;

ρ_i is the i^{th} accession effect (considered as fixed effect);

ι_j is the j^{th} location effect (considered as fixed effect);

r_l is the l^{th} replication effect (considered as random effect);

$b_{m(l)}$ is the effect of m^{th} replicated nested within the l^{th} replication (considered as random);

$\rho\iota_{ji}$ is the interaction effect of j^{th} location and i^{th} accession (considered as random);

ε_{ijlm} is the experimental error considered as random.

The means were separated using Least Significance Difference (LSD).

Data collected on thrips parameters and yield components were also subjected to correlation analyses to determine the association between the different parameters used to assess cultivar resistance to the pest. SNK grouping analysis was performed. The resistance identified in the field and greenhouse trials were compared, and the cross-resistant accessions sorted out.

Six most resistant accessions were selected across locations and used to construct the trend of thrips population per flower, and thrips damage over time for each location.

The adaptability and stability of the tested accessions to different environments were established using additive main effects and the multiplicative interaction (AMMI) and the accession plus accession by environment (GGE) biplot analysis. The above analysis were performed on thrips damage scores and grain yield from different locations. AMMI is an approach that fits the additive effects of accessions and the environments by the usual analysis of variance and then describes the non-additive parts by principal component analysis fitted to the AMMI model according to the following equation (Gauch and Zobel, 1996):

$$Y_{ger} = \mu + \alpha_g + \beta_e + \Sigma\lambda_n \tilde{a}_{gn}\delta_{en} + \theta_{ge} + \varepsilon_{ger},$$

Where

Y_{ger} = Thrips damage score/yield of accession g in environment e for replication r,

μ =grand mean;

α_g=mean deviation of the accession g (accession mean minus grand mean);

β_e=mean deviation of environment mean;

λ_n=the eigenvalue of the principal component (IPCA) axis n;

$\tilde{a}_{gn}$= the accession g eigenvector value for IPCA axis n;

δ_{en}= the environment e eigenvector value for IPCA axis n;

θ_{ge}= the residual;

ε_{ger}= the random error (Zobel *et al.*, 1988).

The thrips damage scores were transformed using inverse function plus one in the GGE biplot analysis to fit the biplot interpretation as the lowest thrips damage scores were allocated to the resistant accessions the highest ones to the susceptible accessions (Yan *et al.*, 2007). To evaluate the degree of connection between the parameters, Pearson's correlation assessment was conducted between thrips parameters (damage scores and counts) and yield and yield elements. ANOVA was performed for each location, to reveal the significances among accessions in the same environment.

CHAPTER FOUR

4. RESULTS

4.1. Morphological identification of flower bud thrips

After identification of the different population collected in different areas, *Megalurothrips sjostedti* Trybom was found in Gbaffo, Tori, Tindji, Zangnanado and zogbodomey. *Sericothrips occipitalis* was found in Oudèmè/Glazoué. The species *Megalurothrips sjostedti* Trybom is the most dominant and hence, was present in six sites out of seven who were surveyed. The names of the thrips identified in the different locations are presented in Table 5

Table 5: Liste of identified thrips species and locations in Benin

Scope	Locality	Insect species	Region	Host plant	Latitude (N)	Longitude (E)
1	Gbaffo	*Megalurothrips sjostedti*	Collines	Cowpea	7.802783	2.271767
2	Tori	*Megalurothrips sjostedti*	Atlantic	Cowpea	6.56345	2.133650
3	Tindji	*Megalurothrips sjostedti*	Zou	Cowpea	7.000717	1.958200
4	Ouinhi	*Megalurothrips sjostedti*	Oueme	Cowpea	7.10405	2.456950
5	Zangnanado	*Megalurothrips sjostedti*	Zou	Cowpea	7.223717	2.464667
6	Zogbodomey	*Megalurothrips sjostedti*	Zou	Cowpea	7.081467	2.109283
7	Oudeme/Glazoué	*Sericothrips occipitalis*	Collines	Cowpea	8.105000	2.129000

4.2. Selection of the most damaging local populations of flower bud thrips among collected diversity

The characterization of thrips showed non significant difference among the damages caused by the various population of thrips at 5% signifance level (Table 6). Thrips populations from Gbaffo and Ouinhi got the same average damage to cowpea (6.5) based on the visual rating on a 1-9 scale, while populations from Tori, Za-kpota/Tindji, Zangnanado and Zogbodomey caused less damge (5.9) on the susceptible checks. The different local populations of thrips caused almost the same level of damage to cowpea regardless of the agro-ecological zones they belong to. Based on the damage induced, they were considered as belonging to only one group. Thrips were then mixed and used for the greenhouse screening of cowpea accessions.

Table 6: Means squares for thrips damage scores on the cultivars Vita 7 and Sewe

Source of variation	Degree of freedom	Summe of square	Mean square for thrips damages scores
Varieties	1	413.44	413.44***
Locality	6	3.2	0.64^{ns}
Replication	2	13.97	6.98^{ns}
Varieties x Locality	5	0.52	0.1^{ns}
Varieties x Rep	2	2.06	1.03^{ns}
Locality x Rep	10	13.25	1.33^{ns}
Varieties x Locality x Rep	10	7.09	0.71^{ns}
Residuals	108	451.06	4.18

***: significant at P<0.001, ns = non significant at P = 0.05

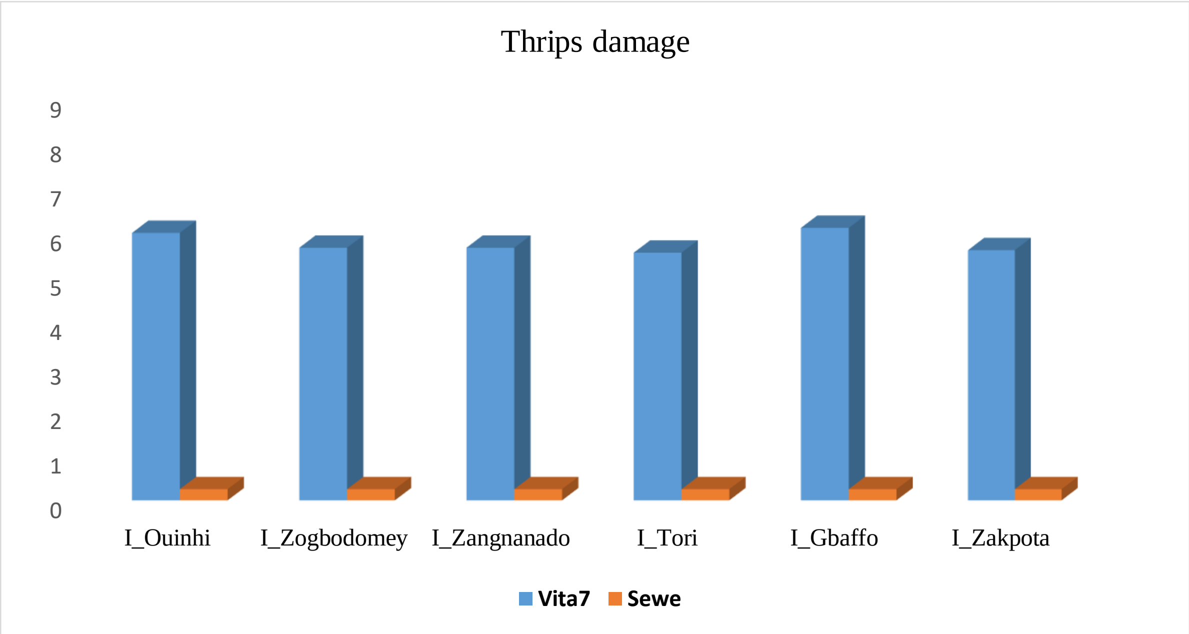

Figure 11 : Graphs showing the damage caused by flower thrips on cowpea accessions

4.3. Determination of the reaction of cowpea accessions to flower bud thrips under greenhouse conditions

4.3.1. Variation in thrips damages and thrips counts in flowers

The results of analysis of variance on thrips damages and thrips counts in flowers for the greenhouse screening are presented in Table 7. The results showed significant differences ($P<0,001$) among accessions for the thrips damage scores and the number of adult thrips at 37 DAP and not significant for subsequent dates, while the number of larvae per flower was significant from 37 to 51 DAP. Replication influenced at different dates thrips counts and damage in flowers.

4.3.2. Variations in cowpea grain yield and yield components under greenhouse conditions

The results of analysis of variance on cowpea grain yield and yield components are presented in Table 8. For all-grain yield and yield components, there were significant differences among the accessions.

High variations were observed for the numbers of pod per plant and peduncle as shown by the values of the coefficient of variation recorded (CV= 89.84, 83.33, respectively). Similar observations were made for yield and total grain weight. Low variation in the number of days to 50% flowering as well as the number of days to 50% maturity (CV=22.59, 21.85%, respectively) (Table 8).

Table 7: Means squares for thrips damage and count in greenhouse

Source of variation	Df	Thrips damage scores				Number of adults thrips per flower				Number of larvae thrips per flower			
		37DAP	44DAP	51DAP	58DAP	37DAP	44DAP	51DAP	58DAP	37DAP	44DAP	51DAP	58DAP
Accessions	47	0.97***	1.85 ns	2.76 ns	5.12 ns	2.66**	4.4 ns	9.37 ns	14.73 ns	40.29***	60.59***	58.96*	46.69 ns
Rep	2	0.028 ns	9.63*	1.94 ns	0.25 ns	2.78 ns	132.52***	65.144***	62.27**	27.03 ns	550.30***	460.08***	457.09 ns
Residuals	95	0.46 ns	2.13 ns	4.67 ns	5.58 ns	1.43 ns	3.57 ns	8.54 ns	11.02 ns	10.8 ns	21.47 ns	35.84 ns	48.76 ns

****, **, * = Significant at P<0.001; 0.01 and at 0.05, respectively and ns = non-significant at P=0.05.*

Table 8: Means squares for grain yield and yield components under greenhouse conditions

	Df	Yield	NPPl	NPodPl	TGW	NDF	100GW	NPodP	NDM
Accessions	47	7328.3***	21.52**	133.19**	17.58**	250.821***	57.82***	1.94**	437.57***
Residuals	96	1485.1	9.20	64.19	3.56	12.201	7.650	1.01	12.48
Range		40-217	3-13	1-36	2-11	40-50	6-23	0-3	1-8
CV		59.73	51.64	89.84	59.70	22.59	31.46	83.33	21.85

***, **, * = Significant at P<0.001; 0.01 and at 0.05 respectively and ns = non-significant at p = 0.05
NPodPl=Number of pods per plant, NPPl=Number of peduncles per plant, TGW = Total grains weight (g), NDF= Number of days to 50% flowering, NPodP=Number of pods per peduncles, NDM= Number of days to 50% maturity, 100GW=100 grains weight (g), Yield (kg/ha).

4.3.3. Classification of the accessions based on resistance status to thrips

In the greenhouse, 14 resistant accessions came out of 48. Among these, IT07K-243-1-10 revealed high resistance and scored (1). Nontché-Wagbèhamin and Sèwé showed a score of 2. Eleven (11) accessions were also resistant and presented a score of 3. These accessions include Awlétchi, Awonlignikoun, Gléssissaffodo, IT83S-742-2, IT86D-888, Kpègnikoun, Kpodjiguèguè, Kumassi, Moussa, Sanzibanili and Tiligré. Kaki, Kplobè-Wéwé, Mawounan, and IT84S-2246-4 were moderately resistant. The rest of the accessions were moderately susceptible (Adjagnikoun, Akunnado, Atchawékoun, Djètoko, Elisabeth, Gboto, IT06K-242-3, IT07K-188-49, IT07K318-33, IT84D-449, IT84E-124, IT86D-1033, IT86D-1038, IT86D-1057, IT87S-1390, IT93K-452-1, IT97K-449-35, IT97K-556-6, Kaki gros grains, Kaki petit grains, Komcallé, Kplobè, Mawougbadonou, Tola, Tonton and Vidégnikoun), susceptible and very susceptible (IT07K211-1-8; Tawa and Vita7; respectively) (Table 9). Kodobobo and Djètoko did not germinate in greenhouse.

Table 9: Resistance status of the 48 accessions tested in greenhouse conditions

S/N	Accessions	Thrips damage scores	Status	S/N	Accessions	Thrips damage scores	Status
1	IT07K-243-1-10	1	R	25	Gboto	6	MS
2	Nontché-Wagbèhamin	2	R	26	IT06K-242-3	6	MS
3	Sèwé	2	R	27	IT07K-188-49	6	MS
4	Awlétchi	3	R	28	IT07K318-33	6	MS
5	Awonlignikoun	3	R	29	IT84D-449	6	MS
6	Gléssissaffodo	3	R	30	IT84E-124	6	MS
7	IT83S-742-2	3	R	31	IT86D-1033	6	MS
8	IT86D-888	3	R	32	IT86D-1038	6	MS
9	Kodobobo	N/A	N/A	33	IT86D-1057	6	MS
10	Kpègnikoun	3	R	34	IT87S-1390	6	MS
11	Kpodjiguèguè	3	R	35	IT93K-452-1	6	MS
12	Kumassi	3	R	36	IT97K-449-35	6	MS
13	Moussa	3	R	37	IT97K-556-6	6	MS
14	Sanzibanili	3	R	38	Kaki gros grains	6	MS

S/N	Accessions	Thrips damage scores	Status
15	Tiligré	3	R
16	Kaki	4	MR
17	Kplobè-Wéwé	4	MR
18	Mawounan	4	MR
19	IT84S-2246-4	5	MR
20	Adjagnikoun	6	MS
21	Akunnado	6	MS
22	Atchawékoun	6	MS
23	Djètoko	N/A	N/A
24	Elisabeth	6	MS
39	Kaki petit grains	6	MS
40	Komcallé	6	MS
41	Kplobè	6	MS
42	Mawougbadonou	6	MS
43	Tola	6	MS
44	Tonton	6	MS
45	Vidégnikoun	6	MS
46	IT07K211-1-8	7	VS
47	Tawa	7	VS
48	Vita7	8	VS

R; MR; MS; S; VS= Resistant, Moderately reistant, moderately susceptible; susceptible and very susceptible, respectively.

4.3.4. Trends in thrips damage scores, thrips counts in flowers and yield components

Figures 11 A, B and C show the trends in thrips damage results and thrips counts. The trend in thrips damage increased in the accessions Awonlignikoun, Kplobe wewe, and IT83S-742-2 and reached the peak at a value of 4 at 44 days, 5 at 51 days and stayed constant at 58 DAP. On the other hand, the accessions Awtchi, Kpodjiguegue, and IT84E-124 grew up to reach the maximum peak of damage of 6 at 51 DAP and thereafter decreased to 58 DAP (Figure 11-A).

The number of adults per flower increased for Kplobe-wewe and IT84E-124 from 1 to 3 at 44 DAP while the number of adults thrips per flower increased for Kplobe wewe at 51 DAP and stayed constant at 5 at 58 DAP. The accession IT84E-124 decreased from 3 to 1 at 51 DAP and thereafter grew up to 58 DAP where the maximum number of adult thrips was 4. The higher infestation was observed at 37 DAP followed by a continuous decrease across dates for Awonlignikoun (Figure 11-B). IT83S-742-2 increased in thrips number from 37 to 42 DAP, and dropdown to 58 DAP. With regards to Awletchi and Kpodjiguegue, thrips adult’s number decreased from 1 at 37 DAP to 0 at 44 DAP where they built up in population to the end and reached 3 adults per flower (Figure 11-B).

The trend in thrips larvae per flower for the cultivars Kplobe Wewe, IT84E-124 and IT83S-742-2 increased from 37 to 44 DAP and reached the maximum at a value of 10; and 5 larvae per flower respectively at 44 DAP. From 44 DAP larvae count has inceased to 12 at 51 DAP before decreasing at 58 DAP in Kplobe wewe (Figure 11-A). In IT84E-124, the number of larvae increased to 5 at 44 DAP then decreased to 4 at 51 DAP and thereafter increased to 6 at 58 DAP, while it decreased (18 to 6 larvae) in IT83S-742-2 at 44 DAP, from 6 to 0 at 51 and stayed constant to the end. Awletchi and Kpodjiguegue followed the same trend and were constant in thrips larvae number from 37 to 44 DAP, increased later at 51 DAP and stayed constant at 58 DAP. Highly infested Awonlignikoun at 37 DAP, dropdown in number of thrips larvae (17-0) from 37 to 51 DAP where it maintained population at 0 to 58 DAP (Figure 11-C).

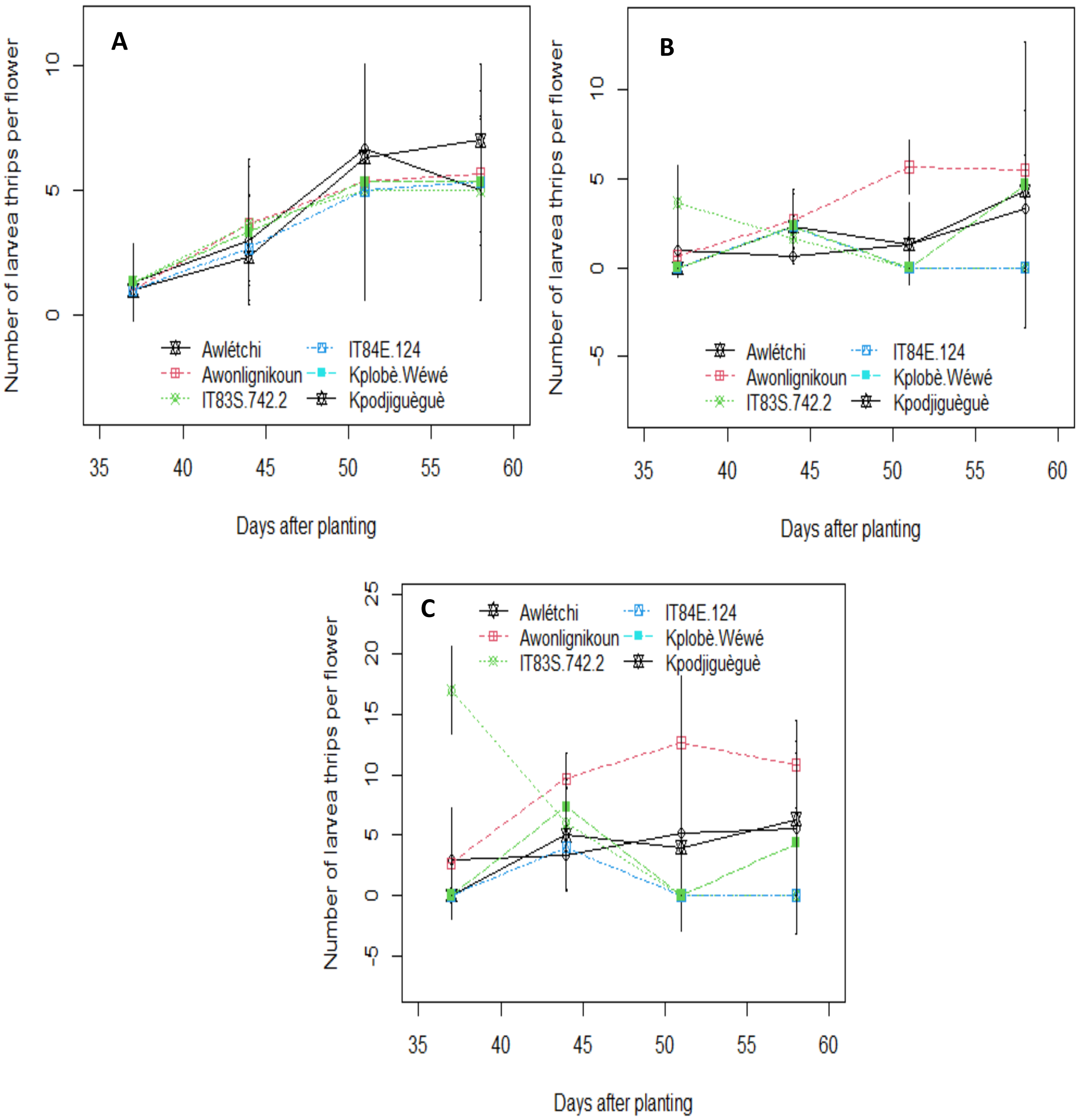

Figure 12 : Trends in thrips damages and thrips counts over time for selected six cowpea accessions in greenhouse

The variations in the yield components are presented in Table 10. The number of days to 50% flowering fluctuated between 40 days in Kumassi and IT07K211-1-8 and 50 days in IT97K-449-35 and Sanzibanili. The number of days to 50% maturity varied from 55 days in Kumassi and IT07K211-1-8 to 65 days in IT97K-449-35. Yield ranged from 40.8 kg.ha^{-1} in Kpègnikoun and Sanzibanili to 217.0 kg.ha^{-1} in IT86D-888. The 100 grains weight varied from 6.03g in Vita7 to 23.30 g in IT93K-452-1. The number of peduncles per plant was from 3 in IT97K-449-35 and Kpodjiguèguè to 13 in Vita7. The number of pods per peduncle varied from 0 in IT86D-

1038, IT06K-242-3, IT84E-124, IT86D-1057, IT97K-449-35, Mawougbadonou and Vidégnikoun to 3 in Tawa, Mawounan, Kaki petit grains, and Sèwé. The number of pod per plant ranged from 0 in IT86D-1038 to 36 in Sèwé.

Table 10: Means of thrips and plant parameters on 48 cowpea accessions in greenhouse

	Yield	NDF	NDM	NPPl	NPodP	NPodPl	TGW	100GW	NATF	NLTF	DMS
Adjagnikoun	47.6	43.0	58.0	8.33	0.66	7.00	2.33	12.4	2.66	5.33	6.00
Akunnado	81.6	40.6	55.6	8.00	1.66	13.0	4.00	16.4	2.33	5.33	6.00
Atchawékoun	115.	46.0	60.6	8.00	1.00	8.00	5.66	16.0	2.00	5.33	6.00
Awlétchi	61.2	43.0	58.0	8.66	1.66	17.6	3.00	17.1	1.66	4.66	3.33
Awonlignikoun	47.6	44.6	59.6	7.00	1.66	12.3	2.33	15.3	2.00	4.00	2.50
Djètoko	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Elisabeth	81.6	44.6	59.6	7.00	2.00	15.6	4.00	22.6	1.66	5.33	6.00
Gboto	156.	44.0	59.0	6.33	2.33	13.0	7.66	16.6	1.00	3.00	6.16
Gléssissaffodo	74.8	45.6	60.0	10.0	1.33	11.6	3.66	12.6	3.00	6.00	2.66
IT06K-242-3	129.	43.0	58.0	10.6	0.33	5.33	6.33	18.2	2.33	8.00	6.00
IT07K-188-49	74.8	44.6	59.6	10.6	2.00	17.6	3.66	13.7	2.00	5.66	6.16
IT07K211-1-8	149.	40.0	55.3	8.00	2.00	16.3	7.33	19.0	3.66	7.33	6.50
IT07K-243-1-10	142.	44.0	59.0	7.66	1.33	11.3	7.00	22.0	2.33	3.66	1.00
IT07K318-33	95.2	40.6	56.0	5.33	2.00	10.3	4.66	20.0	2.00	5.00	6.00

	Yield	NDF	NDM	NPPl	NPodP	NPodPl	TGW	100GW	NATF	NLTF	DMS
IT83S-742-2	115.	42.0	57.0	8.00	1.66	15.6	5.66	15.5	3.66	9.00	3.16
IT84D-449	47.6	44.0	58.3	6.33	0.66	5.00	2.33	14.5	3.33	6.66	6.33
IT84E-124	95.2	44.0	59.0	6.33	0.33	4.00	4.66	16.6	1.33	6.00	6.00
IT84S-2246-4	156.	43.0	57.3	6.66	2.00	12.6	7.66	17.7	2.66	13.0	5.00
IT86D-1033	108.	45.6	60.6	7.33	1.00	4.00	5.33	16.6	2.33	5.33	6.00
IT86D-1038	95.2	44.0	59.0	5.00	0.00	0.00	4.66	18.6	2.33	6.00	6.33
IT86D-1057	95.2	40.6	56.0	5.66	0.33	3.66	4.66	16.6	2.66	6.00	6.00
IT86D-888	217.	44.0	59.0	5.33	1.66	9.00	10.6	18.2	1.00	3.00	3.00
IT87S-1390	68.0	44.0	59.0	4.66	2.00	8.00	3.33	13.7	2.33	9.66	6.00
IT93K-452-1	95.2	45.0	60.0	8.33	2.00	17.0	4.66	23.3	2.00	5.00	6.00
IT97K-449-35	210.	50.0	65.3	2.66	0.33	1.00	10.3	17.3	2.33	5.66	6.00
IT97K-556-6	47.6	46.6	61.6	5.66	1.66	9.00	2.33	15.2	3.33	4.66	6.16
Kaki	54.4	45.0	60.0	6.00	1.66	7.33	2.66	18.0	3.00	9.66	3.50
Kaki gros grains	88.4	48.6	63.3	8.00	1.00	7.33	4.33	18.9	1.66	5.33	6.16
Kaki petit grains	54.4	43.0	58.0	5.66	3.00	18.3	2.66	15.0	2.00	5.66	6.00

	Yield	NDF	NDM	NPPl	NPodP	NPodPl	TGW	100GW	NATF	NLTF	DMS
Kodobobo	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Komcallé	170.00	43.00	58.00	6.66	2.00	13.30	8.33	14.90	6.00	16.6	6.16
Kpègnikoun	40.80	45.00	60.00	7.00	1.66	13.30	2.00	17.90	2.66	6.66	2.83
Kplobè	68.00	46.00	61.00	6.66	2.00	15.00	3.33	12.60	2.00	4.00	6.00
Kplobè-Wéwé	176.00	44.00	59.00	11.30	1.00	11.30	8.66	15.30	0.66	1.33	3.50
Kpodjiguègué	68.00	42.00	57.00	3.33	0.66	3.33	3.33	17.30	2.00	3.00	2.66
Kumassi	95.20	39.60	54.60	10.00	1.00	9.00	4.66	14.40	1.66	5.00	3.00
Mawougbadonou	54.400	41.60	56.60	4.00	0.33	1.00	2.66	17.30	1.33	3.66	6.16
Mawounan	149.00	42.00	57.00	7.00	2.66	19.00	7.33	15.60	2.33	5.00	3.66
Moussa	142.00	43.00	58.00	11.30	1.33	14.6	7.00	11.20	1.00	3.00	3.00
Nontché-Wagbèhamin	95.20	43.00	58.00	4.66	2.00	11.6	4.66	13.90	2.00	4.66	2.16
Sanzibanili	40.80	50.00	64.00	7.33	1.00	8.00	2.00	16.50	1.66	3.66	3.16
Sèwé	190.00	43.00	58.00	12.30	3.00	35.6	9.33	15.30	1.66	3.00	2.33
Tawa	115.00	44.00	59.00	6.66	3.00	21.0	5.66	14.60	4.00	10.00	6.50
Tiligré	115.00	43.00	58.00	9.33	1.33	7.66	5.66	14.60	2.66	7.66	2.66

	Yield	NDF	NDM	NPPl	NPodP	NPodPl	TGW	100GW	NATF	NLTF	DMS
Tola	105.00	44.00	59.00	6.33	0.66	4.00	5.16	19.20	3.00	7.33	6.00
Tonton	108.00	44.00	59.00	7.33	1.66	11.0	5.33	17.3	1.33	4.66	6.00
Vidégnikoun	81.60	46.30	61.3	6.33	0.33	4.66	4.00	16.4	4.33	9.66	6.00
Vita7	61.20	45.60	60.00	13.30	1.00	13.00	3.00	6.03	7.33	9.33	7.83
Mean	97.71	42.15	56.45	7.05	1.37	10.37	4.79	15.62	2.34	5.78	4.89
LSD	62.45	5.66	5.73	4.92	1.63	12.98	3.06	4.48	2.42	5.05	0.70

NPodPl=Number of pods per plant, NPPl=Number of peduncles per plant, TGW = Total grains weight (g), NDF= Number of days to 50% flowering, NPodP=Number of pods per peduncles, NDM= Number of days to 50% maturity, 100GW=100 grains weight (g), DMS=Damage Median Score, NATF= Number of adults thrips per flower, NLTF= Number of larvae thrips per flower.

4.3.5. Relationship between thrips and plant parameters under greenhouse conditions

Analysis of the correlation between thrips and parameters of plant is shown in Table 11. The number of peduncle and pod per plant were significant $p < 0.001$ and positively correlated r = 0.46. The number of pod per peduncle and plant also showed a positive correlation r = 0.82 with a high significance of $p < 0.001$. Number of larvae of thrips per flower showed a positive correlation r = 0.24 with thrips damage, number of day to 50% flowering r = 0.24, number of day to 50% maturity r = 0.26 and 100 grain weight r = 0.10. The number of pod per plant was correlated positively r = 0.17 with number of day to 50% flowering, number of day to 50% maturity r = 0.19 and 100 grain weight r = 0.12 and significant at $p < 0.05$ of significance level. Number of peduncle per plant, number of day to 50% flowering and number of day to 50% maturity were correlated r = 0.36; r = 0.37 respectively and highly significant $p < 0.001$. the number of adult Thips per flower was only correlated with number of day to 50% flowering and number of day to 50% maturity r = 0.24; r = 0.26 respectively and significant $p < 0.005$. We observed that the number of day to 50% maturity was highly significant $p < 0.001$ and correlated positively with 100 grain weight r = 0.63, total grain weight as well as yield r = 0.33. The same correlation coefficient r = 0.29 was found between 100 grain weight, total grain weight, and yield as well. Total grain weight and yield are higly correlated r = 1.00 while damage and 100 grain weight as well as total grain weight were negatively correlated r = -0.01 and r = -0.10 respectely and significant $p < 0.01$.

Table 11: Correlation coefficents between thrips parameters and yield components

	NPPl	NPodP	NPodPl	NATF	NLTF	DMS	NDF	NDM	100GW	TGW	Yield
NPPl	-	-	-	-	-	-	-	-	-	-	-
NPodP	0.07^{ns}	-	-	-	-	-	-	-	-	-	-
NPodPl	0.46***	0.82***	-	-	-	-	-	-	-	-	-
NATF	0.17^{ns}	0.08^{ns}	0.11^{ns}	-	-	-	-	-	-	-	-
NLTF	0.09^{ns}	0.10^{ns}	0.05^{ns}	0.74^{ns}	-	-	-	-	-	-	-
DMS	-0.06^{ns}	-0.07^{ns}	-0.12^{ns}	0.22^{ns}	0.24***	-	-	-	-	-	-
NDF	0.36***	0.20^{ns}	0.17*	0.24*	0.24**	0.04 ^{ns}	-	-	-	-	-
NDM	0.37***	0.21^{ns}	0.19*	0.26*	0.26**	0.04	0.99 ns	-	-	-	-
100GW	0.08^{ns}	0.20^{ns}	0.12*	0.02^{ns}	0.10**	-0.01**	0.60 ns	0.63***	-	-	-
TGW	0.15^{ns}	0.13^{ns}	0.15^{ns}	0.06^{ns}	0.12^{ns}	-0.10**	0.31 ns	0.33***	0.29***	-	-
Yield	0.15^{ns}	0.13^{ns}	0.15^{ns}	0.06^{ns}	0.12^{ns}	-0.10 ns	0.31 ns	0.33***	0.29***	1.00***	-

****, **,* = significant at P<0.001; 0.01 and at 0.05 respectively and ns = non-significant at 0.05. NPodPl=Number of pods per plant, NPPl=Number of peduncles per plant, TGW = Total grains weight (g), NDF= Number of days to 50% flowering, NPodP=Number of pods per peduncles, NDM= Number of days to 50% maturity, 100GW=100 grains weight (g), Yield (kg/ha), NATF= Number of adults thrips per flower, NLTF= Number of larvae thrips per flower, DMS=Damage Median Score.*

4.4. Determination of the reaction of cowpea accessions to flower bud thrips in field conditions

4.4.1. Variations in thrips damage scores and thrips counts within and across locations

The results of analysis of variance within locations are presented in Table 12. In Abomey-Calavi, there were significant differences among the accessions for thrips damage scores, number of adult thrips per flower and number of larvae thrips per flower. The significant difference was observed at all scoring dates except for 58 DAP where thrips damage and the number of adult thrips were not significant. The replication was significant for thrips damage score at 44 and 51 DAP as well as the number of adults thrips per flower and number of larvae thrips per flower at 51 and 37 DAP, respectively (Table 12).

In Gbaffo, there were significant differences among the accessions for thrips damage scores at 37 DAP. The number of adult thrips per flower and number of larvae thrips per flower were also significant at 58DAP for accessions. Blocks effects were also significant for thrips damage scores at 37 and 51 DAP and the number of adult thrips per flower at 58 DAP. The effects of replication and blocks were also significant only for the number of larvae thrips per flower at 58DAP (Table 12).

In Zakpota, there were significant differences among the accessions at the all scoring dates for thrips damage as well as for thrips counts. The effects of replications were significant for thrips damage scores at all dates except for 58 DAP. The replications effects were only significant for the number of larva thrips per flower at 58DAP. In contrast, the blocks effcts were not significant for all the parameters at all the dates (Table 12).

Table 12: Means squares for thrips damage scores and thrips counts in cowpea accessions in Abomey-Calavi, Gbaffo and Zakpota

		Thrips damage scores				Number of adults thrips per flower				number of larvae thrips per flower			
Abomey-Calavi													
Source of variation	Df	37DAP	44DAP	51DAP	58DAP	37DAP	44DAP	51DAP	58DAP	37DAP	44DAP	51DAP	58DAP
Accessions	47	1.47***	4.90***	11.15***	14.19^{ns}	91.69***	207.75***	166.99***	417.47^{ns}	263.08***	207.75***	914.95***	555.65**
Rep	2	0.18^{ns}	9.63***	1.94*	0.25^{ns}	21.246^{ns}	25.664^{ns}	118.37**	204.08^{ns}	148.82*	25.664^{ns}	291.45^{ns}	104.40^{ns}
Rep/Blocks	14	0.19^{ns}	0.52^{ns}	0.34^{ns}	0.89^{ns}	12.91^{ns}	6.12^{ns}	31.85^{ns}	97.57^{ns}	24.98^{ns}	6.12^{ns}	105.27^{ns}	277.36^{ns}
Residuals	73	0.19^{ns}	0.63^{ns}	0.55^{ns}	1.13^{ns}	22.413^{ns}	23.25^{ns}	23.72^{ns}	263.79^{ns}	39.32^{ns}	23.25^{ns}	145.69^{ns}	246.28^{ns}
Gbaffo													
		Thrips damage scores				Number of adults thrips per flower				number of larvae thrips per flower			
Source of variation	Df	37DAP	44DAP	51DAP	58DAP	37DAP	44DAP	51DAP	58DAP	37DAP	44DAP	51DAP	58DAP
Accessions	47	8.05*	3.47^{ns}	4.14^{ns}	2.55^{ns}	0.06^{ns}	0.06^{ns}	0.44^{ns}	25.63***	2.01^{ns}	0.44^{ns}	0.17^{ns}	822.37***
Rep	2	30.36**	4.11^{ns}	30.53**	1.44^{ns}	0.06^{ns}	0.06^{ns}	0.44^{ns}	50 3.32***	2.01^{ns}	0.44^{ns}	0.17^{ns}	566.17^{ns}
Rep/Blocks	14	5.09^{ns}	2.08^{ns}	4.94^{ns}	2.1^{ns}	0.09^{ns}	0.093^{ns}	0.66^{ns}	15.95^{ns}	3.01^{ns}	0.67^{ns}	0.26^{ns}	390.67*
Residuals	73	5.09^{ns}	2.68^{ns}	5.88^{ns}	2.99^{ns}	0.06^{ns}	0.06^{ns}	0.44^{ns}	8.80^{ns}	2.01^{ns}	0.44^{ns}	0.17^{ns}	198.66^{ns}
Zakpota													
		Thrips damage scores				Number of adults thrips per flower				number of larvae thrips per flower			
Source of variation	Df	37DAP	44DAP	51DAP	58DAP	37DAP	44DAP	51DAP	58DAP	37DAP	44DAP	51DAP	58DAP
Accessions	47	2.23*	1.91***	3.35**	3.77***	26.27***	64.67***	50.41***	124.97*	71.26***	132.56***	259.34***	379.16***
Rep	2	7.75**	6.44***	8.25**	0.47^{ns}	4.64^{ns}	3.6^{ns}	18.18^{ns}	142.66^{ns}	26.9^{ns}	20.91^{ns}	41.6^{ns}	656.60*
Rep/Blocks	14	1.47^{ns}	0.61^{ns}	1.43^{ns}	0.72^{ns}	3.79^{ns}	0.71^{ns}	9.91^{ns}	57.98^{ns}	7.79^{ns}	4.95^{ns}	28.43^{ns}	238.09^{ns}
Residuals	73	1.27^{ns}	0.83^{ns}	1.64^{ns}	1.09^{ns}	6.18^{ns}	7.12^{ns}	6.31^{ns}	68.32^{ns}	12.61^{ns}	11.18^{ns}	36.55^{ns}	145.55^{ns}

****, **, * = Significant at P<0.001; 0.01 and at 0.05 respectively and ns = non-significant at 0.05.*
DMS=Damages Median Scores, NATF= Number of adults thrips per flower, NLTF= Number of larvae thrips per flower
Within location analysis was performed for each location. Data on thrips damage and thrips

4.4.2. Means of thrips damage scores and counts, yield and yield components of cowpea accessions at Abomey-Calavi

The variations in the thrips damage scores and counts, yield and yield components of cowpea accessions at Abomey-Calavi are presented in appendix 1. The number of peduncles per plant was from 0.00 in Djètoko to 49.33 in Kaki petit grain. The number of pods per peduncle varied from 0.33 in Awonlignikoun, Djètoko and Gboto to 4 in Kpègnikoun. The number of pod per plant ranged from 0.00 in Djètoko to 194.67 in Kpègnikoun. The number of adult thrips per flower varied from 5.67 in Djètoko to 26.00 in IT97K-449-35, and that of the larvae varied from 7.33 in Djètoko to 37.67 in Tiligré. The thrips damage median score ranged from 0.70 in Djètoko to 5.92 in Vita7, while the number of days to 50% flowering fluctuated between 35.67 days in Elisabeth to 46.33 days in Atchawékoun. However, the number of days to 50% maturity varied from 52.67 days in IT86D-888 to 60.33 days in Atchawékoun. In the meantime, 100 grains weight ranged from 10.35g in Kplobè to 76.39g in Awonlignikoun, while, the total grains weight varied from 19.10g in IT07K211-1-8 to 498.50 g in Gboto.

4.4.3. Means of thrips damage scores and counts, yield and yield components of cowpea accessions at Gbaffo

The variations in the thrips damage scores and counts, yield and yield components of cowpea accessions at Gbaffo are presented in appendix 2. The number of peduncles per plant was from 2.33 in Kodobobo to 13.67 in Tola. The number of pods per peduncle varied from 0.33 in Kaki petit grains to 1.33 in Nontché-Wagbèhamin and Awlétchi. The number of pod per plant ranged from 1.00 in IT83S-742-2 to 16.33 in Sèwé. The number of Adult thrips per flower varied from 11.33 in Kplobè to 79.33 in Komcallé, and that of the larvae varied from 12 in Vita7 to 187.33 in Tiligré. The thrips damage median score ranged from 4.67 in IT07K318-33 to 7.67 in IT07K-188-49 and Mawounan, while the number of days to 50% flowering fluctuated between 35.00

days in Elisabeth to 51.37 days in Djètoko. However, the number of days to 50% maturity varied from 51.33 days in Kodobobo and IT84D-449 to 66.33 days in Djètoko. In the meantime, 100 grains weight ranged from 5.23g in Kodobobo to 29.13g in Atchawékoun, while, the total grains weight varied from 6.37g in IT07K211-1-8 to 179.67g in Sèwé.

4.4.4. Means of thrips damage scores and counts, yield and yield components of cowpea accessions at Zakpota

The variations in the thrips damage scores and counts, yield and yield components of cowpea accessions at Zakpota are presented in appendix 3. The number of peduncles per plant was from 1.63 in Moussa to 12.97 in Tola. The number of pods per peduncle varied from 0.33 in Kaki petit grains to 1.33 in Nontché-Wagbèhamin and Tola. The number of pod per plant ranged from 3.36 in IT83S-742-2 to 18.69 in Sèwé. The number of adult thrips per flower varied from 2.62 in Kpègnikoun to 77.28 in Komcallé, and that of the larvae varied from 8 in Kpègnikoun to 188.36 in Tiligré. The thrips damage median score ranged from 4.67 in IT07K318-33 to 7.67 in IT07K-188-49 IT86D-1033, Kumassi and Mawounan, while the number of days to 50% flowering fluctuated between 35.00 days in Elisabeth to 52.00 days in Djètoko. However, the number of days to 50% maturity varied from 50.00 days in Elisabeth to 67.34 days in Djètoko. In the meantime, 100 grains weight ranged from 6.46g in Kodobobo to 30.36g in Atchawékoun, while, the total grains weight varied from 6.46g in IT07K211-1-8 to 181.68g in Sèwé.

The results of the analysis of variance for thrips damage and thrips count across locations are presented in Table 13. Significant differences were observed among the accessions for the three parameters. Location effects were highly significantly ($P<0.001$) for thrips damage, adult flower thrips and larvae flower thrips on cowpea. The effects of the interaction between location and accessions are not significant for all traits (Table 13).

Table 13: Mean squares for thrips damages scores and thrips population/flower across locations

Source of variation	Degree of freedom	Damage Score	Adults thrips flowers	larvae thrips flower
Location	2	756.25***	4237.8***	3655.8*
Rep (Location)	6	2.73^{ns}	54.1^{ns}	421.2*
Accession	47	16.98***	153.9***	726.2***
Location x Accession	94	7.74^{ns}	55.6^{ns}	187.8^{ns}
Residuals	1518	8.19	63.9	189.6

The trends in the thrips damage scores, the number of adult thrips per flower and the number of larvae thrips per flower over time (37-58 days after planting) per location are presented in Figures 12, 13 and 14. The trends in thrips damage increased in all the selected cultivars and reached the peak of 5 at 44 days after planting for IT84E-124 variety at Abomey-Calavi (Figure 12-A). The highest damages peak for other varieties were observed at 51 days after planting with upgrowth damage of Kplobe-wewe (7). The number of adults and larvae thrips per flower decreased at 44 days after planting, then increased and reached the peak of 48 adults and 62 larvae at 51 days after planting except for the variety IT84E-124 which presented the opposite effect from the beginning at 44 days after planting at Abomey-calavi (Figure 12-B).

In Zapotoa the trends in thrips damage scores and thrips counts are presented in Figure 13 A-B and C). In Zakpota, thrips damage increase for all accessions from 44 to 58 DAP and reached the maximum of 8 except for Awletchi where damage reduced from 8 to 6 from 51 to 58DAP (Figure 13-A). Kpodjiguegue did not follow the same trend but reduced earlier in damage from 44 to 51 DAP before an increase to reach 6 at 58 DAP. Adult thrips count increased for all the genotypes from 7 at 37 to 28 at 44 DAP, then dropped down to 4 at 58 DAP but Awletchi and Kpodjguegue did not follow this trend (Figure 13-B). From 51 DAP, Awletchi reduced in the number of adult thrips to 4. Concerning Kpodjguegue, it decreased in adult thrips number from 37 to 44DAP (12 to 8) and increased up to 13 adults thrips at 51DAP and thereafter decreased to 9 adults per flower at 58 DAP (Figure 12- B). For thrips larvae counts, the number increased for all accessions and varied between 8 and 25 per flower at 58 DAP, apart Awonlignikoun where the number high increased for 51 to 58 DAP and reached pick of 61 larvae par flower, while IT84E-124 reduced in number of larvae to 10 at 51DAP before building population up to 25 larvae per flower at 58 DAP (Figure 13-C).

At Gbaffo, the trends in thrips damage scores, the number of adult trips in all the accessions increased and reached their maximum peaks of 8, respectively at about 44 and 51 days after planting with a slight fall at 51 days for IT84E-124 and Kpodjiguegue (Figure 14-A, C). A decrease in the number of trips larvae was observed up to 51 days after planting for all the selected cultivars with exponential growth from 51 to reach the maximum peak of 60 at 58 days after planting (Figure 14-C).

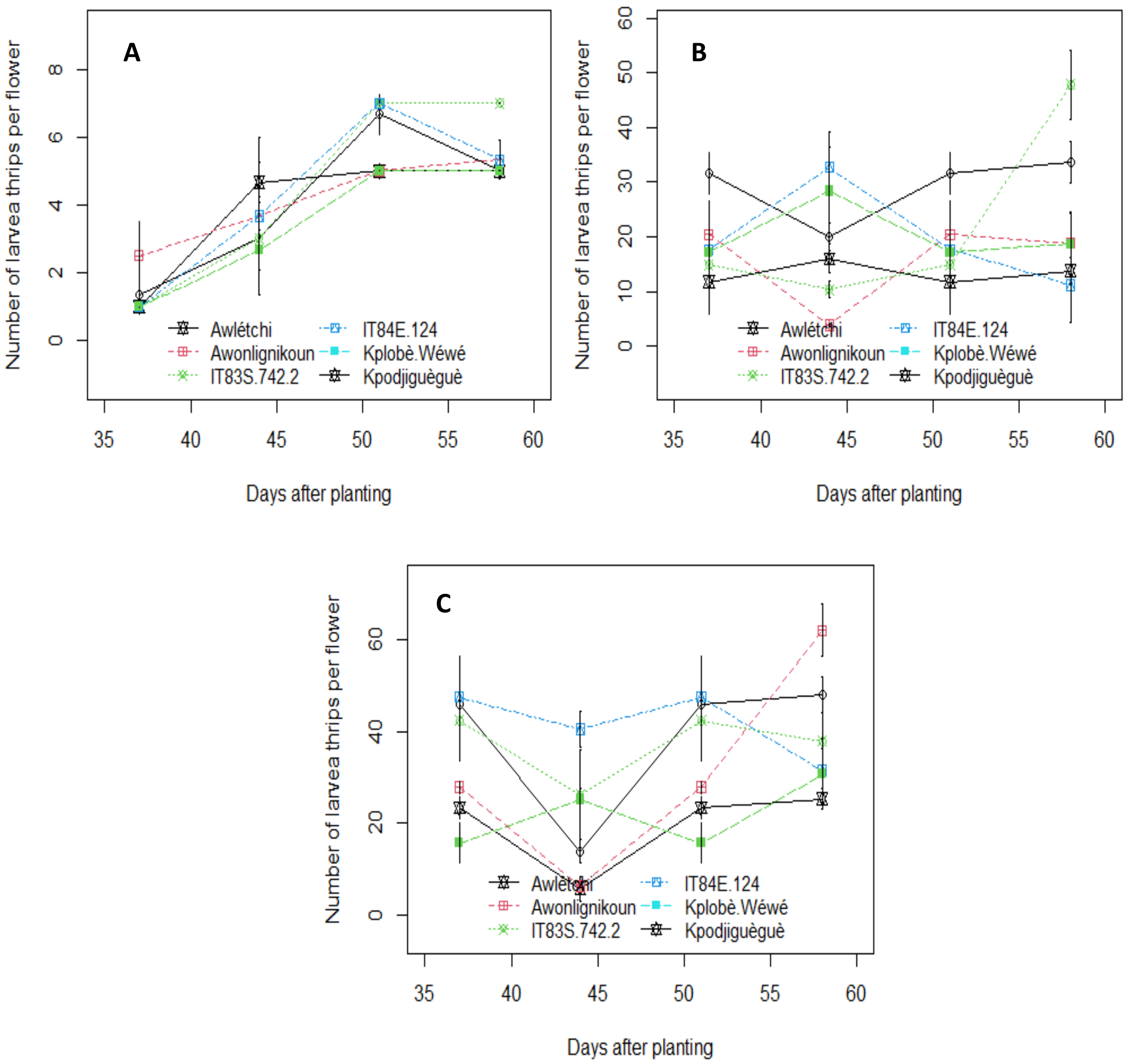

Figure 13 : Trends in thrips damage scores and thrips counts in Abomey-Calavi for six selected accessions

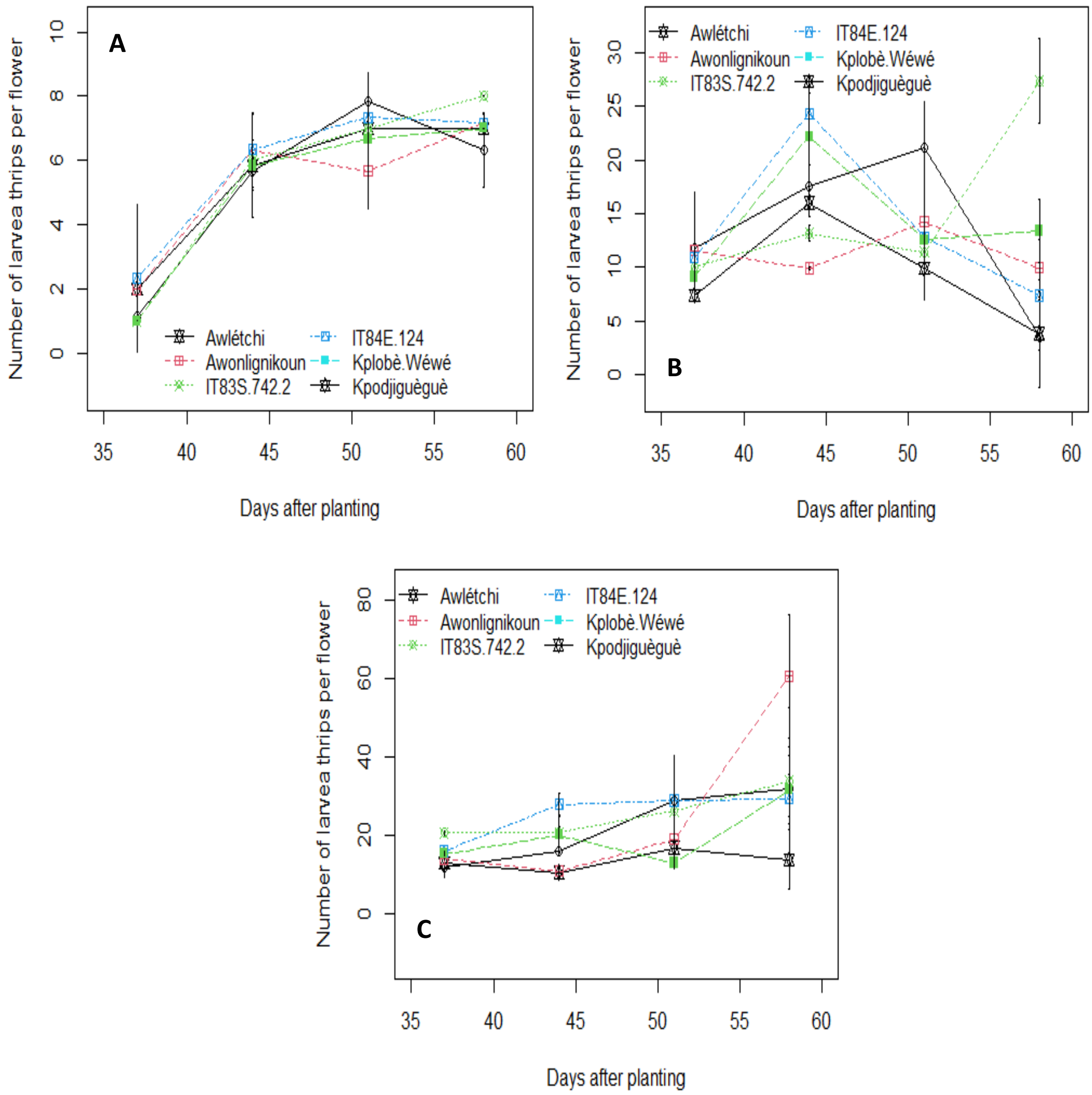

Figure 14 : Trends in thrips damage and thrips count over time for selected six accessions in Zakpota for six selected accessions

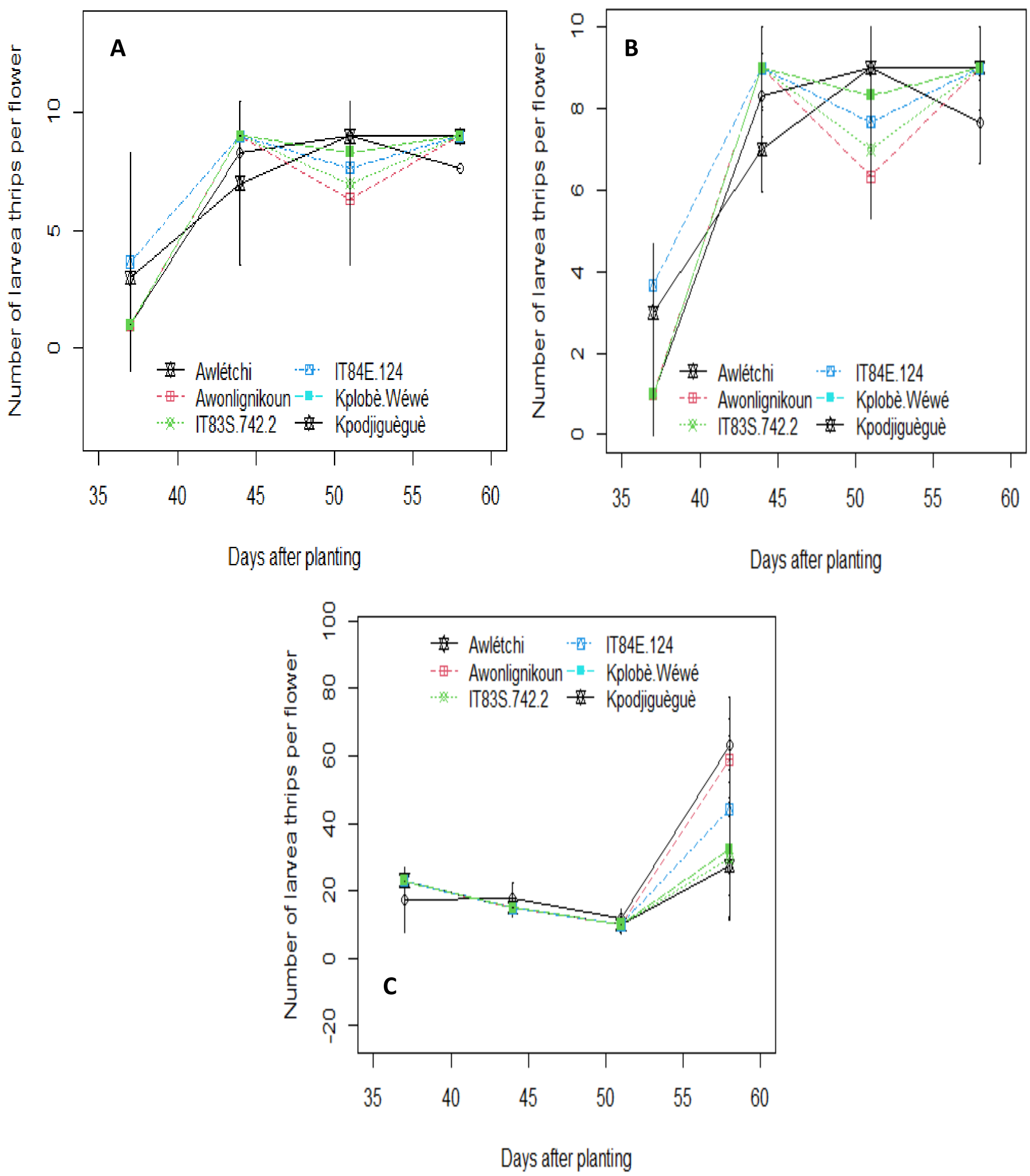

Figure 15 : Trends in thrips damage scores and thrips counts in Gbaffo for six selected accessions

4.4.5. Variations in grain yield and yield components across locations

The results from the analysis of variance on the grain yield and yield components across the locations are presented in Table 14. The results showed that there were highly significant differences among the accessions for cowpea yield components. The effects of the environment on the cowpea yield components was highly significant except for NDF, NPodP, NDM and 100GW. High locations and accessions interactions effects were recorded for all the cowpea yield components (Table 14).

Table 14: Means squares for yield and yield components across locations

Source of variation	Df	Means squares										
		Yield	**NPodPl**	**NPPl**	**TGW**	**NDF**	**NPodP**	**NDM**	**100GW**	**NLTF**	**NATF**	**DMS**
Location	2	373384**	134050**	28082.0**	1473873 **	22.780^{ns}	42.072^{ns}	67.50^{ns}	109.087^{ns}	54483***	9314.3***	147.02***
ReP (Location)	6	29181***	9455***	1265.9***	65429***	51.269***	17.141***	59.22***	94.451^{ns}	285ns	308.8*	1.52^{ns}
Accession	47	16969***	1971***	200.4***	35840***	215.763***	1.872***	366.01***	184.167*	2827***	738.9***	4.94***
Loc.accession	92	7871***	1798***	141.9^{ns}	16892ns	94.481***	1.532**	159.00***	136.759^{ns}	614^{ns}	198.4*	2.05***
Residuals	284	6990	1025	66.5	15463	8.744	0.951	9.60	114.549	543	139.3	0.91
Range	0-862	8-240	1-100	1-34	8-48	19-48	0-2	26-63	8-48	11-113	8-49	4-7
CV	124.34	141.72	84.51	124.34	12.44	81.09	11.41	11.41	72.45	76.94	69.45	26.32

***, **, * = Significant at P<0.001; 0.01 and at 0.05 respectively and ns = non-significant at 0.05 NPodPL=Number of pods per plant, NPPL=Number of peduncles per plant, TGW = Total grains weight (g), NDF= Number of days to 50% flowering, NPodP=Number of pods per peduncles, NDM= Number of days to 50% maturity, 100GW=100 grains weight (g), Yield (kg/ha), DMS=Damages Median Scores, NATF= Number of adults thrips per flower, NLTF= Number of larvae thrips per flower

Table 15: Means of thrips and plant parameters across locations

	Yield	NDF	NDM	NPPl	NPodP	NPodPl	TGW	100GW	NATF	NLTF	DMS
Adjagnikoun (G1)	14.84	42,00	56,00	15.17	1.44	29.50	22.26	20.25	25.84	24.13	6.17
Akunnado (G2)	110.22	44.50	58.67	19.83	1.42	27.98	165.33	12.91	18.69	35.01	6.33
Atchawékoun (G3)	132.90	46.83	60.17	21.96	1.64	45.17	199.33	20.70	17.11	31.14	5.91
Awlétchi (G4)	45.33	40.50	54.83	17.13	1.16	8.63	68,00	12.31	39.33	54.32	5.25
Awonlignikoun (G5)	108.06	41.17	56.17	21.10	0.70	6.32	162.09	48.19	17.34	30.32	5.92
Djètoko (G6)	62.80	48.33	62.67	1.66	0.49	1.50	94.20	19.49	12.65	25.32	3.67
Elisabeth (G7)	124.67	35.33	49.33	22.17	1.69	45.17	187,00	13.02	21.83	60.21	4.42
Gboto (G8)	221.55	42.50	56.50	8.93	0.68	4.36	332.33	15.05	15.13	57.52	5.58
Gléssissaffodo (G9)	174.26	42.50	56.50	26.76	2.19	85.64	261.40	14.27	13.84	28.72	5.58
IT06K-242-3 (G10)	90.89	40.17	54.17	22.53	1.80	39.34	136.33	13.37	10.32	26.67	5.92
IT07K-188-49 (G11)	61.99	44.00	58,00	16.97	0.99	18.95	93,00	14.95	26.66	37.13	5.83
IT07K211-1-8 (G12)	8.48	42.00	56.00	21.12	1.01	22.63	12.73	17.24	26.99	45.02	5.92
IT07K-243-1-10 (G13)	54.67	40.00	54.00	19.64	2.30	58.70	82.00	18.60	16.00	35.85	5.75
IT07K318-33 (G14)	125.07	43.50	57.50	15.79	1.47	26.15	187.60	23.63	17.96	65.81	5.17

	Yield	NDF	NDM	NPPl	NPodP	NPodPl	TGW	100GW	NATF	NLTF	DMS
IT83S-742-2 (G15)	19.90	42,00	56,00	10.45	1.83	28.17	29.87	14.13	30.52	37.31	5.50
IT84D-449 (G16)	119.78	38.17	52.17	13.11	1.99	32.94	179.67	12.28	18.99	42.81	6,00
IT84E-124 (G17)	17.43	41.83	56.17	14.42	1.32	17.85	26.13	14.47	22.31	60.16	5.67
IT84S-2246-4 (G18)	59.10	40,00	54,00	19.69	1.20	23.18	88.67	18.38	30.73	63.49	5.42
IT86D-1033 (G19)	64.87	42.25	56.25	17.72	0.97	14.89	97.30	14.31	33.18	50.17	6.25
IT86D-1057 (G21)	18.12	42.50	56.50	12.70	0.98	9.71	27.20	12.39	17.70	28.66	6.42
IT86D-_888 (G22)	40.10	38,00	52.33	18.95	1.48	38.71	60.13	16.62	25.48	52.68	4.92
IT87S-1390 (G23)	78.23	43.83	57.83	20.50	1.54	38.61	117.33	11.69	37.49	50.28	6.42
IT93K-452-1 (G24)	227.16	40.83	54.83	24.45	2.00	68.81	340.73	22.49	35.83	43.52	6.42
IT97K-449-35 (G25)	26.89	45.67	59.67	17.16	2.12	51.31	40.33	20.40	29.17	25.81	5.83
IT97K-556-6 (G26)	36.75	45.17	59.17	20.67	1.67	50.19	55.13	15.13	29.70	54.47	6.50
Kaki (G27)	66.75	45.17	59.17	11.79	1.29	18.84	100.13	28.61	15.03	28,00	6.75
Kaki gros grains (G28)	55.06	42.50	56.50	10.80	1.36	19.68	82.60	12.85	44.01	47.30	5.17
Kaki Petit grans (G29)	173.16	44.50	58.67	27.94	1.55	70.34	259.73	12.37	16.14	25.81	6.67
Kodobobo (G30)	41.52	18.67	25.67	1.20	0.32	1.03	62.30	7.59	11.33	10.5	3.50

	Yield	NDF	NDM	NPPl	NPodP	NPodPl	TGW	100GW	NATF	NLTF	DMS
Komcallé (G31)	33.18	43.00	57,00	23.64	1.12	30.97	49.75	24.64	48.58	53.14	5.42
Kpègnikoun (G32)	45.25	42.00	56,00	28.16	2.33	100.16	67.87	18.06	8.31	11.66	5.17
Kplobè (G33)	92.88	41.33	55.33	19.30	1.67	41.30	139.33	10.35	12.52	35.15	6.17
Kplobè-Wéwé (G34)	126.71	44.0	59.67	27.15	1.8	46.47	190.07	15.94	30.30	69.67	5.92
Kpodjiguèguè (G35)	186.35	42.00	56,00	26.37	1.70	55.88	279.53	11.20	27.16	48.87	5.67
Kumassi (G36)	221.11	42.50	56.50	13.84	0.85	9.96	331.67	16.47	17.38	50.16	6.50
Mawougbadonou (G37)	69.11	44,00	58,00	13,00	2.02	38.56	103.67	17.34	14.87	29.46	6.58
Mawounan (G38)	39.28	42.17	56.17	12.67	1.51	26.99	58.93	22.18	28.67	25.49	6.50
Moussa (G39)	110.67	42.00	56.00	22.81	1.46	44.16	166.00	14.47	17.18	32.62	5.42
Nontché-Wagbèhamin (G40)	194.30	43.00	57,00	23.15	1.68	34.90	291.47	15.59	17.12	35.99	5.167
Sanzibanili (G41)	23.51	41.50	55.50	19.76	1.67	48.35	35.27	12.23	19.32	51.87	4.58
Sèwé (G42)	239.56	42.50	56.50	25.86	2.27	50.80	359.33	16.67	29.49	51.67	4.75
Tawa (G43)	101.88	42.50	56.50	17.82	1.56	31.28	152.8	18.23	24.52	37.05	6.58
Tiligré (G414	75.33	41.67	55.67	18.60	1.20	31.45	113,00	22.88	25.56	112.52	5.33
Tola (G45)	160.48	46.17	61,00	33.84	1.104	25.03	240.67	13.59	17.66	48.14	5.50

	Yield	NDF	NDM	NPPl	NPodP	NPodPl	TGW	100GW	NATF	NLTF	DMS
Tonton (G46)	98.67	44.33	58.50	17.86	1.60	34.04	148,00	15.86	22.84	51.97	6.16
Vidégnikoun (G47)	40.00	42.5	56.33	10.91	1.33	14.70	60,00	14.87	17.84	26.67	5.50
Vita7 (G48)	73.60	41,00	55,00	14.42	1.15	15.95	110.40	21.4	26.49	20.01	6.67
Mean	91.19	41.98	55.92	18.32	1.45	33.34	136.79	16.96	23.26	42.09	5.72
LSD	92.85	3.22	3.93	13.82	1.06	41.57	139.27	10.43	13.23	26.80	1.29

NPodPl=Number of pods per plant, NPPl=Number of peduncles per plant, TGW = Total grains weight (g), NDF= Number of days to 50% flowering, NPodP=Number of pods per peduncles, NDM= Number of days to 50% maturity, 100GW=100 grains weight (g), DMS=Damage Median Score, NATF= Number of adults thrips per flower, NLTF= Number of larvae thrips per flower

4.4.6. Correlation coefficients among thrips parameters and yield components across the different locations

The results of the correlation analysis are presented in Table 16. The results showed that the number of peduncles per plant was positively ($p < 0.001$) correlated with the number of pods per peduncle, and per plant, the total grain weight and the yield (r = 0.28),

0.58, respectively).

The number of peduncle per plant was negatively correlated with number of adult thrips per flower r = -0.28, the number of larvae r = -0.31 and thrips damage r = -0.37, but positively correlated with total grain weight and yield r = 0.31. A high positive correlation existed between the number of pod per peduncle and the number of pod per plant r = 0. 83. At the same time, the number of pod per peduncle showed a positive correlation with total grain weight and yield r = 0.21, but was negatively associated to number of adult thrips per flower r = -0.13, number of larvae per flower r = -0.16 and thrips damage r = -0.19. Negative correlation was also found in the number of pod per plant and number of adult thrips r = -0.18, number of larvae r = -0.23 and thrips damage r = -0.32. The correlation coefficient was equal to r = 0.25 between the number pod per plant and total grain weight and number pod per plant and yield. The variation in adult thrips count was high $p < 0.001$, and was positively correlated with the number of larvae per flower r = 0.58 as well as thrips damage r = 0.32. Adult thrips count was negatively r = -0.17 associated to total grain weight as well as yield. Results showed that adult thrips and larvae influenced damage in cowpea. The number of larvae per flower was positively associated with thrips damage r = 0.27 and was highly significant $p < 0.001$. Low relationship exists between larvae count and the number of days to 50% maturity r = 0.11 and was significant $p < 0.005$. The total grain weight and yield were negatively associated with larvae count with a coefficient of correlation of r = -0.13. The number of day to 50% flowering and maturity were associated positively to thrips damage with correlation coefficient r = 0.28 and r = 0.30 respectively, this later was negatively associated to yield and total grain weight (r = -0.13). It was found that the number of days to 50% flowering and number of day to 50% maturity were intimately associated with r = 0.99. Result also revealed that yield depend on the total grain weight r = 1.00.

Table 16: Correlation coefficients among thrips parameters and yield components across the different locations

Traits	NPPl	NPodP	NPodPl	NATF	NLTF	DMS	NDF	NDM	100GW	TGW	Yield
NPPl	-	-	-	-	-	-	-	-	-	-	-
NPodP	0.28***	-	-	-	-	-	-	-	-	-	-
NPodPl	0.58***	0.83***	-	-	-	-	-	-	-	-	-
NATF	-0.28***	-0.13**	-0.18***	-	-	-	-	-	-	-	-
NLTF	-0.31***	-0.16***	-0.23***	0.58***	-	-	-	-	-	-	-
DMS	-0.37***	-0.19***	-0.32***	0.32***	0.27***	-	-	-	-	-	-
NDF	0.07^{ns}	0.08^{ns}	0.05^{ns}	0.08^{ns}	0.07^{ns}	0.28***	-	-	-	-	-
NDM	0.08^{ns}	0.09^{ns}	0.05^{ns}	0.11*	0.11*	0.30***	0.99***	-	-	-	-
100GW	-0.03^{ns}	-0.02^{ns}	-0.03^{ns}	0.00^{ns}	-0.02^{ns}	0.02^{ns}	0.00^{ns}	0.02	-	-	-
TGW	0.31***	0.21***	0.25***	-0.17***	-0.13**	-0.13**	0.07^{ns}	0.08	-0.03^{ns}	-	-
Yield	0.31***	0.21***	0.25***	-0.17***	-0.13**	-0.13**	0.07^{ns}	0.08	-0.03^{ns}	1.00***	-

NPodPl=Number of pods per plant, NPPl=Number of peduncles per plant, TGW = Total grains weight (g), NDF= Number of days to 50% flowering, NPodP=Number of pods per peduncles, NDM= Number of days to 50% maturity, 100GW=100 grains weight (g), DMS=Damage Median Score, NATF= Number of adults thrips per flower, NLTF= Number of larvae thrips per flower

4.4.7. Adaptability and stability of thrips damage scores and yield across locations

4.4.7.1. Adaptability and stability of accessions for thrips damage scores across locations

The results from the AMMI analysis of variance for the grains yield of the 48 accessions tested in three environments (three locations and one season) are presented in Table 17. It is showed that accessions, locations effects were highly significant (p < 0.001). The effects of the accessions by location interacatons were not significant. The first linear interaction term (IPCA1) of the AMMI analysis, accounted for 24.96 of the GxE sum of squares, and the second accounted for 0.043% using 48 and 46 degrees of freedom (*df*), respectively.

Table 17: AMMI analysis of variance for thrips damages scores of 48 cowpea lines

Source of variation	DF	Sum of square	Mean squares	% explained
Localition	2	1512.5	756.25***	9.36
Rep/Location	6	16.4	2.73^{ns}	0.10
Accession	47	797.8	16.98***	4.94
Location xAccession	94	727.5	7.74^{ns}	4.50
IPCA1	48	181.613987	3.78ns	24.96
IPCA2	46	0.309716	0.007^{ns}	0.043
Residuls	1518	12928.7	8.18	
Total	1761	16164.82	-	-

****: significant at P<0.001; and ns: non-significant at 0.05.*
IPCA: Interaction Principal Component Axis.

The results of the GGE biplots analysis showing the which-won-where pattern on the thrips damage scores are presented in Figure 15. The results revealed that the two first principal components explained 99.89 % of the total variation in the original data with the first component (PCA1) accounting for 75.33% while the second component (PCA2) accounted for 24.56%. Eight quadrants were obtained with the accessions and the locations falling in different quadrants. Experiments were conducted in three locations for one season and the megaenvironments could not be generated. However, it is showed that the accessions G1 (Adjagnikoun) and G19 (IT86D-1033) are the ones presenting the lowest thrips damage scores (the most resistant) in Gbaffo while the accessions G27 (Adjagnikoun), G28 (Kaki gros grains) and G36 (Kumassi) were the most resistant in Zakpota. In Abomey-Calavi, the accessions G21 (IT86D-1057), G29 (Kaki petit grains) and G45 (Tola) were the most resistance (Figure 15).

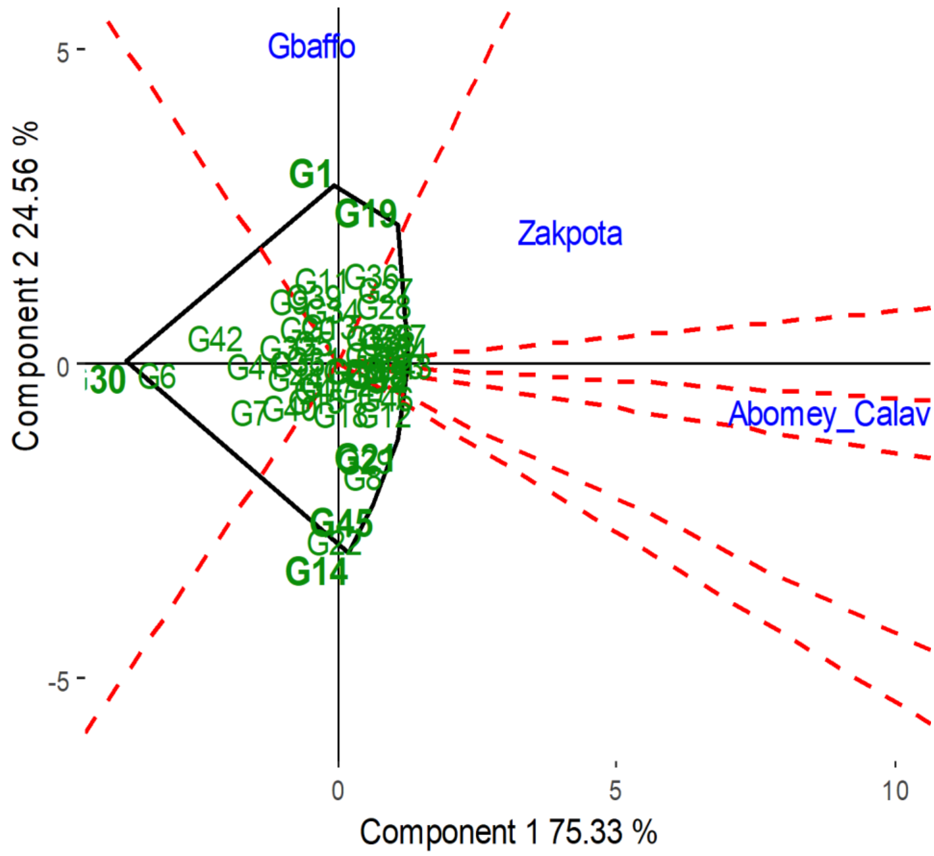

Figure 16 : GGE biplot showing the *"which-won-where" for thrips damage* scores in the 48 cowpea accessions evaluated.

Legend: *Adjagnikoun=G1; Akunnado =G2; Atchawékoun=G3; Awlétchi=G4; Awonlignikoun=G5; Djètoko=G6; Elisabeth=G7; Gboto=G8; Gléssissaffodo=G9; IT06K-242-3=G10; IT07K-188-49=G11; IT07K211-1-8=G12; IT07K-243-1-10=G13; IT07K318-33=G14; IT83S-742-2=G15; IT84D-449=G16; IT84E-124 =G17; IT84S-2246-4=G18; IT86D-1033=G19; IT86D-1038=G20; IT86D-1057=G21; IT86D-888=G22; IT87S-1390=G23; IT93K-452-1=G24; IT97K-449-35 =G25; IT97K-556-6=G26; Kaki=G27; Kaki gros grains =G28; Kaki petit grains =G29; Kodobobo=G30; Komcallé=G31; Kpègnikoun=G32; Kplobè=G33; Kplobè-Wéwé=G34; Kpodjiguèguè=G35; Kumassi=G36; Mawougbadonou=G37; Mawounan=G38; Moussa=G39; Nontché-Wagbèhamin=G40; Sanzibanili=G41; Sèwé=G42; Tawa =G43; Tiligré=G44; Tola=G45; Tonton=G46; Vidégnikoun=G47 and Vita7=G48*

In the biplot showing the ranking of the accessions and the ideal accessions (Figure 16), it was shown that the accessions G8 (Gboto), G37 (Elisabeth) were the ideal accessions with the ideal arrow oriented on them. The accessions G8 (Gboto), G18 (IT84S-2246-4), G37

(Mawougbadonou), G17 (IT84E-124), G14 (IT07K318-33), G24 (IT93K-452-1), G22 (IT86D-888), G45 (Tola), G29 (Kaki petit grains), G21 (IT86D-1057), G12 (IT07K211-1-8), and G46 (Tonton) concentrated at the right side of the PC1 are the most resistant across locations while the most reistant and stable across locations are G18 (IT84S-2246-4), G37 (Mawougbadonou), G17 (IT84E-124), G14 (IT07K318-33), and G24 (IT93K-452-1) located at the right side of the PC1 and near to the PC2 (considered as the stability axis). In addition, the location Zakpota was the ideal location and the ideal arrow was oriented on it. Zakpota was the mos discriminatory location for showing the resistsnce status of the cowpea accessions to flower bud thrips (Figure 16).

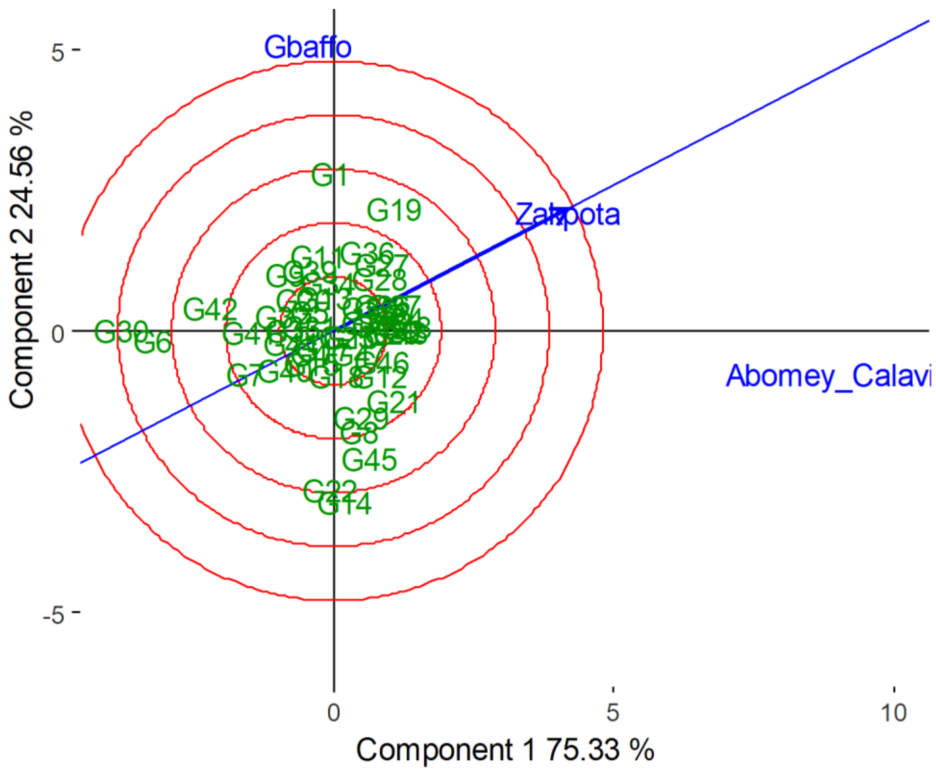

Figure 17 : A comparison GGE biplot in relation to the “ideal” accession for thrips damage scores on the 48 accessions

***Legend**: Adjagnikoun=G1; Akunnado =G2; Atchawékoun=G3; Awlétchi=G4; Awonlignikoun=G5; Djètoko=G6; Elisabeth=G7; Gboto=G8; Gléssissaffodo=G9; IT06K-242-3=G10; IT07K-188-49=G11; IT07K211-1-8=G12; IT07K-243-1-10=G13; IT07K318-33=G14; IT83S-742-2=G15; IT84D-449=G16; IT84E-124 =G17; IT84S-2246-4=G18; IT86D-1033=G19; IT86D-1038=G20; IT86D-1057=G21; IT86D-888=G22; IT87S-1390=G23; IT93K-452-1=G24; IT97K-449-35 =G25; IT97K-556-6=G26; Kaki=G27; Kaki gros grains =G28; Kaki petit grains =G29; Kodobobo=G30; Komcallé=G31; Kpègnikoun=G32; Kplobè=G33; Kplobè-Wéwé=G34; Kpodjiguèguè=G35; Kumassi=G36; Mawougbadonou=G37;*

Mawounan=G38; Moussa=G39; Nontché-Wagbèhamin=G40; Sanzibanili=G41; Sèwé=G42; Tawa =G43; Tiligré=G44; Tola=G45; Tonton=G46; Vidégnikoun=G47 and Vita7=G48

4.4.7.2.Adaptability and stability of the accessions for yield across locations

The results of the AMMI analysis performed on yield data for 48 cowpea genotypes evaluated in three environments (three locations and one season) are presented in Table 18. The results showed that locations effects was highly significant (P<0.001) while the location by accession interactions effects were not significant at 5% of the significance level. There were highly significant differences among the accessions for the yield of the 48 cowpea accessions. Most of the variation among the accessions were taken into account by the location effects (14.50%) and the location by accession interaction effects (14.06%). The first principal component interaction took into account most of the variation in the GxE effects. The two first principal components were enough to explain most of the variation in the original data (Table 18).

Table 18: AMMI analysis of variance for the yield of 48 cowpea accessions

Source of variation	Degree of freedom	Summe of square	Mean square	% explained
Location	2	746768	373384**	14.50
Rep/Location	6	175086	29181***	3.40
Accessions	47	797555	16969***	15.48
Location x accession	94	724115	7871^{ns}	14.06
IPCA1	48	675592.16	14074.84***	93.30
IPCA2	46	47235.86	1026.87^{ns}	6.52
Residuls	284	1985288	6990	
Total	527	5151640.02		

****; **: significant at P<0.001; and 0.01 respectively and ns: non-significant at 0.05. IPCA: Interaction Principal Component Axis.*

The results of the GGE biplot analysis performed on the yield of the cowpea accessions across locations are presented in Figures 17 and 18. The results showed that the two first principal components accounted for 98.35% of the GxE sum of squares with the first principal component explaining most of the variation. In the biplot showing the which-won-where pattern (Figure 17), the accession G22 (IT86D-888) was the high yielding accession in Zakpota with 40.1 kg.

ha^{-1}, G36 (Kumassi) and G45 (Tola) were the high yielding accessions in Gbaffo with yields of 221.11 kg.ha^{-1}, and 160.48 kg.ha^{-1}, respectively and the accession G42 (Sewe) was the high yielding in Abomey-Calavi with a yield of 239.56 kg.ha^{-1}.

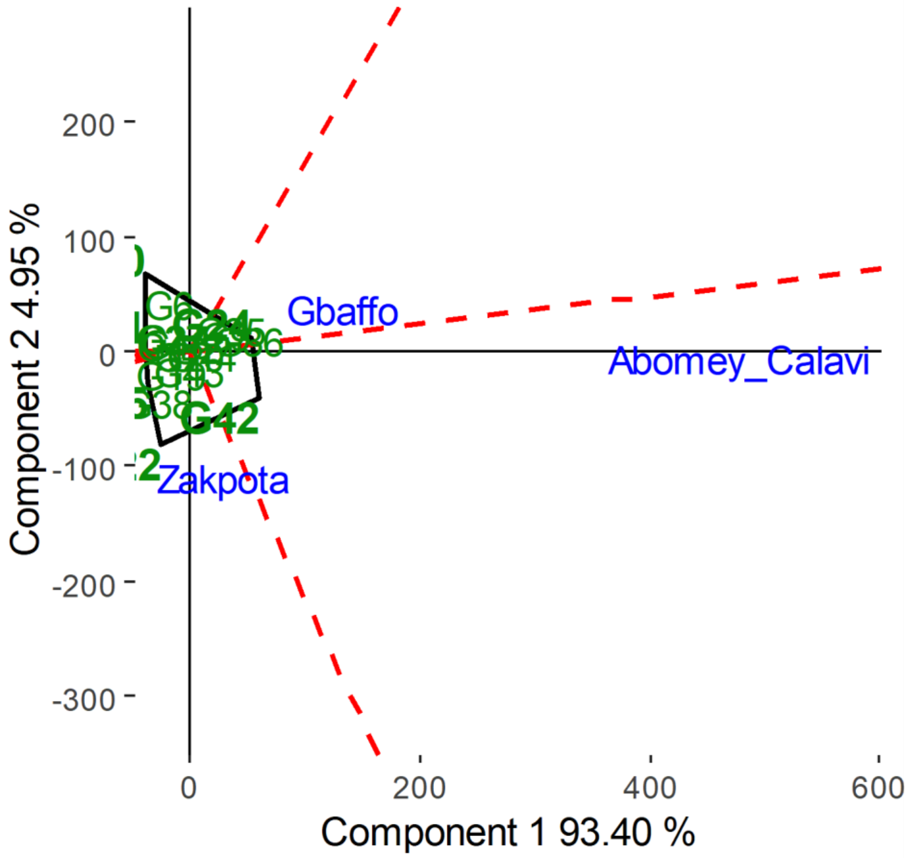

Figure 18 : GGE biplot showing the "which-won-where" for grain yield of the 48 cowpea accessions evaluated.

***Legend**: Adjagnikoun=G1; Akunnado =G2; Atchawékoun=G3; Awlétchi=G4; Awonlignikoun=G5; Djètoko=G6; Elisabeth=G7; Gboto=G8; Gléssissaffodo=G9; IT06K-242-3=G10; IT07K-188-49=G11; IT07K211-1-8=G12; IT07K-243-1-10=G13; IT07K318-33=G14; IT83S-742-2=G15; IT84D-449=G16; IT84E-124 =G17; IT84S-2246-4=G18; IT86D-1033=G19; IT86D-1038=G20; IT86D-1057=G21; IT86D-888=G22; IT87S-1390=G23; IT93K-452-1=G24; IT97K-449-35 =G25; IT97K-556-6=G26; Kaki=G27; Kaki gros grains =G28; Kaki petit grains =G29; Kodobobo=G30; Komcallé=G31; Kpègnikoun=G32; Kplobè=G33; Kplobè-Wéwé=G34; Kpodjiguègué=G35; Kumassi=G36; Mawougbadonou=G37; Mawounan=G38; Moussa=G39; Nontché-Wagbèhamin=G40; Sanzibanili=G41; Sèwé=G42; Tawa =G43; Tiligré=G44; Tola=G45; Tonton=G46; Vidégnikoun=G47 and Vita7=G48*

The biplot visualization presenting the comparison in relation to the ideal accession for Grain y ield obtained from the three locations is presented in Figure 18. The accessions G42 (Sewe), G 24 (IT93K-452-1), G36 (Kumassi), G35 Kpodjiguègué, G40 (Nontché-Wagbèhamin) and G45 (Tola) were the ideal accessions (Figure 17) with the ideal arrow oriented on them. The access ions G42 (Sewe), G9 (Gléssissaffodo), G35 (Kpodjiguègué), G36 (Kumassi), G24 (IT93K-452 -1), G44 (Tiligré), G37 (Mawougbadonou), G34 (Kplobè-Wéwé), G39 (Moussa), G33 (Kplob è), and G43 (Tawa) which concentrated at the right side of the PC1 were the most yielding acr oss locations while the most yielding and stable across locations are G43 (Tawa), G24 (IT93K -452-1) and G35 (Kpodjiguègué) located at the right side of the PC1 and near to the PC2 consi dered as the stability axis were positively correlated with the PC1 and were closer to the origin of the biplot. Those accessions were the high yielding and most stable across locations (Fig17) . In addition, the location Abomey-calavi was the ideal location and the ideal arrow was orient ed on it. Abomey-calavi was the most discriminatory location for showing the resistance status of the cowpea accessions to flower bud thrips (Figure 18).

The accessions G22 (IT86D-888) and G38 (Mawounan) were negatively correlated with the principal component PC1 and were the low yielding accessions. In the biplot showing the ranking of the accessions and the ideal accessions (Figure 18), it is showed that the accessions G42 (Sewe), G24 (IT93K-452-1) are the ideal accessions with the ideal arrow oriented on them.

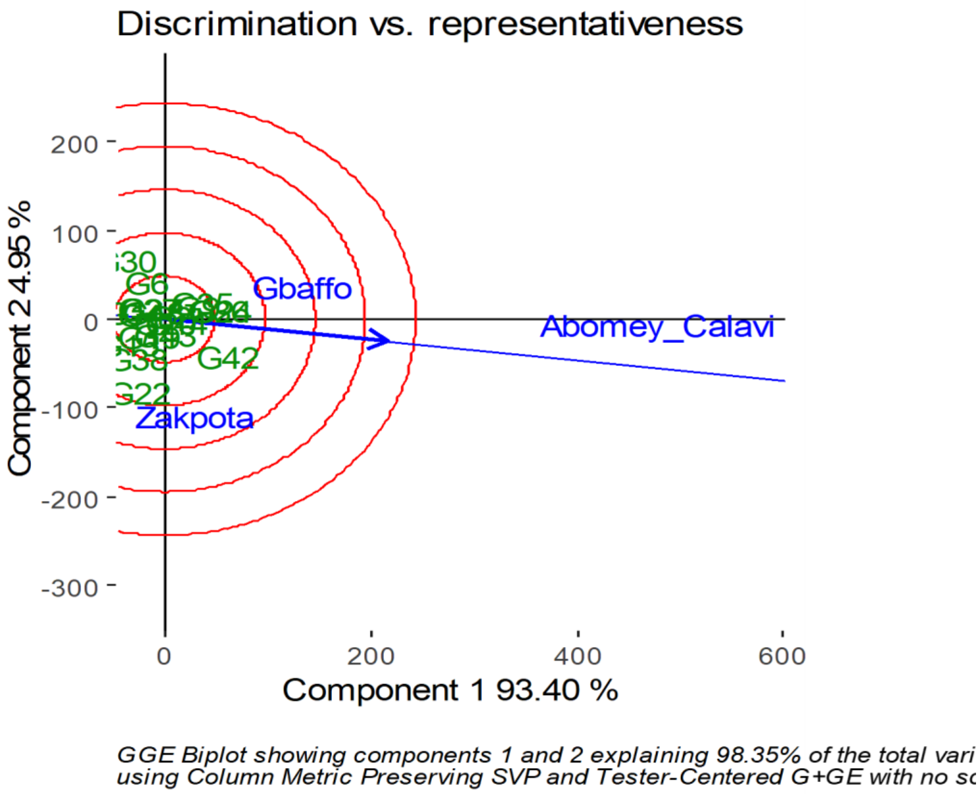

Figure 19 : A comparison GGE biplot in relation to the “ideal” accession for grain yield of the 48 accessions.

Legend: Adjagnikoun=G1; Akunnado =G2; Atchawékoun=G3; Awlétchi=G4; Awonlignikoun=G5; Djètoko=G6; Elisabeth=G7; Gboto=G8; Gléssissaffodo=G9; IT06K-242-3=G10; IT07K-188-49=G11; IT07K211-1-8=G12; IT07K-243-1-10=G13; IT07K318-33=G14; IT83S-742-2=G15; IT84D-449=G16; IT84E-124 =G17; IT84S-2246-4=G18; IT86D-1033=G19; IT86D-1038=G20; IT86D-1057=G21; IT86D-888=G22; IT87S-1390=G23; IT93K-452-1=G24; IT97K-449-35 =G25; IT97K-556-6=G26; Kaki=G27; Kaki gros grains =G28; Kaki petit grains =G29; Kodobobo=G30; Komcallé=G31; Kpègnikoun=G32; Kplobè=G33; Kplobè-Wéwé=G34; Kpodjiguèguè=G35; Kumassi=G36; Mawougbadonou=G37; Mawounan=G38; Moussa=G39; Nontché-Wagbèhamin=G40; Sanzibanili=G41; Sèwé=G42; Tawa=G43; Tiligré=G44; Tola=G45; Tonton=G46; Vidégnikoun=G47 and Vita7=G48

CHAPTER FIVE

5. DISCUSSION

The identification of the thrips species showed that there were two species of thrips *Megalurothrips sjostedti* Trybom and *Sericothrips occipitalis* that infested cowpea crop with *M. sjostedti* Trybom being the most popular and was found in six localities out of seven surveyed. This implied that *M. sjostedti* is the main cowpea thrips at flower stage. The same observation was made by many scientists in Uganda (Karungi *et al.*, 2000; Agbahoungba *et al.*, 2017); in Nigeria (Alabi *et al.*, 2003); in Ghana (Abudulai *et al.*, 2006); and in Cameroon (Ngakou *et al.*, 2008). Therefore, breeding for cowpea varieties resistant to flower bud thrips should target the insect species *M. sjostedti* to be more efficient in Benin conditions. Further, research could be initiated to identify the most damaging *M. sjostedti* among the male and female found in this study.

The characterization study showed that the various local populations of *M. sjostedti* Trybom caused the same level of damage to cowpea. This implied that in Benin, there is only one strain of *M. sjostedti* that attack cowpea accessions in the two agro-ececological zones. This could be because the two agro-ecological zones that hosted the experiments were production zones of cowpea in Benin, hence thrips hotspots, whose climatic conditions do not differ from each other. Climatic conditions have been reported to affect the biology of floral bud thrips and the appearance of new subspecies (Ekesi *et al.*, 1999). However, the inclusion of the extreme districts from the northern part of the country such Kandi, Marimama near the Republic of Niger and the districts from the eastern part of the country such as Pobè , Sakété, and Ifnagni near Nigeria which could have shown some new strains of flower bud thrips migrating from the surrounding countries.

Thrips count was only significant for adults at 37 DAP but not significant for subsequent dates, while the number of larvae per flower was significant from 37 to 51 DAP. The significance differences between adult thrips counts in flowers were reported in Uganda on the cowpea accessions (Agbahoungba *et al.,* 2017) indicating that 37 DAP constituted the appropriate time for spraying chemicals to reduce the economic injury level that could be caused by flower bud thrips on the varieties. In addition, the number of adult thrips released on the single infested plant can move to any other variety of choice and hence increase or reduce the infestation on that particular variety. That internal migration based on preference choice of adult thrips could explain the high variation observed at 37 DAP for the adults since the larvae are not mobile. Furthermore, the death overtime of adult thrips used to infest cowpea plants may explain the negative correlation that occurred for subsequent weeks since data were collected for 4 weeks but the entire life cycle of thrips is about three weeks at 25 degree Celsius.

In the greenhouse, climatic conditions were not the same as in the fields. High temperature and low relative humidity were recorded in the greenhouse. In addition, water was provided regularly as needed compared to the field where rain is sporadic. The variation of these abiotic factors could induce the late flowering and maturity period observed for some cowpea accessions. In addition, the plants in greenhouse were competing for light and this factor also could impact negatively on the development of cowpeas. This may cause the low variation observed in the number of days to 50% flowering as well as the number of days to 50% maturity (CV=22.59, 21.85%, respectively) in the greenhouse. The greenhouse conditions or research stations conditions have been reported to favor the varieties to express its yield potential (Ddamulira *et al.*, 2015) and any yield and yield components observed in the fields' conditions should be compared to the station yield. Therefore, the yield observed in the accessions IT86D-888 (217 kg.ha^{-1}); Sewe (190 kg.ha^{-1}), Gboto (156 kg.ha^{-1}) could be used as their potential yield since the environmental factors are controlled. The yield of the accessions in the present study may not be the genetic potential of the accessions since the plants have been stressed by flower thrips infestation in the greenhouse. Thus, the accessions that have been able to produce enough pods in spite of the presence of the high flower bud thrips population released in the greenhouse may have tolerance as a resistance mechanism against *M. sjostedti* damage. The high number of pods per plant observed on the accessions Sèwé, Moussa and Tawa demonstrated their tolerance mechanism of resistance to flower bud thrips. The accessions Sèwé and Moussou were reported in the previous search as resistant to *M. sjostedti* damage and presenting tolerance as a mechanism of resistance to flower bud thrips (Alabi *et al.*, 2004 and 2005; Abudulai *et al.*, 2006). These accessions could serve as parents in breeding programmes for the genetic improvement of cowpea for resistance to thrips.

The absence of significant accession and the highly significant location effects for thrips counts in flowers indicated that thrips population in flowers was more determined by the variations between locations than the variations among accessions. Thus, any study on flower bud thrips counts in cowpea should be performed in several locations to capture all the climatic variations as reported by Agbahoungba *et al.* (2017). A high number of thrips count was recorded in flowers at Abomey-Calavi and Zakpota than Gbaffo. This could be explained by the lower climatic variation between these three agro-ecological zones. Concerning thrips damage, the analysis of variance showed significant accession effects indicating the presence of genetic diversity among the evaluated accessions. In addition, thrips damage score ranged from 1 to 5, indicating the possibility of obtaining sources of thrips resistance among the evaluated accessions according to the guidelines of Jackai and Singh (1988).

The reduction in damage score observed in IT84E-124 across locations may be due to a resistance exhibited by the accession. In the same time, the thrips population decreased in that accession from 44 to 58DAP, meaning that it could have an antibiosis subtracts that impede on the development and buildup of thrips population. By contrast, we noted a high population over time for Awlétchi, Awonlignikoun, Kplobè-Wéwé, IT83S-742-2, and Kpodjiguèguè but the damage induced dropped regardless of the thrips population count. This showed that they have varying levels of resistance to thrips starting from 51DAP. This type of resistance could be explained by tolerance behavior. In the greenhouse condition, the high damage occurred at 51DAP for Awlétchi, Awonlignikoun, Kplobè-Wéwé, IT83S-742-2, Kpodjiguègué and thereafter decreased. IT84E-124 in the field developed early resistance compared to the greenhouse. This fact may be due to environmental changes and thrips population in flowers, meaning that the resistance in cowpea may depend on the level of infestation as well as climatic conditions.

The trend in thrips damage, as well as the thrips count (adult and larvae), were consistent for IT84E-124, Kplobè-Wéwé, Kpodjiguègué, IT83S-742-2 from 51 to 58 DAP. However, these accessions would have produced antibiosis compound that could impede on the multiplication and development of thrips. Hence, antibiosis mechanism of resistance could be checked in further studies on those accessions. The lines Tawa, IT93K-452-1 and Kpodjiguègué, exhibited the highest yield across locations with yield values of 101.88 Kg/ha^{-1}; 227.16 Kg/ha^{-1} and 186.35 Kg/ha^{-1}. The yield stability, however, was conferred by the second principal component (PC2); whereby accessions with PC2 scores close to zero (PC2~0) were the highly stable ones. IT84S-2246-4, Mawougbadonou, IT07K318-33, and IT93K-452-1 were the most resistant and stable lines across locations. G22 (IT86D-888) was the high yielding accession in Zakpota with 40.1 $kg.ha^{-1}$, G36 (Kumassi) and G45 (Tola) were the high yielding accessions in Gbaffo with yields of 221.11 $kg.ha^{-1}$, and 160.48 $kg.ha^{-1}$, respectively and the accession G42 (Sewe) was the high yielding in Abomey-Calavi with a yield of 239.56 $kg.ha^{-1}$. Based on the suitable environment analysis the highest and the most adapted accessions were Kplobè-Wéwé, Kumassi, Tola and Sewe with 126.71 $Kg.ha^{-1}$; 221.11 $Kg.ha^{-1}$, 160.48 $Kg.ha^{-1}$ and 239.56 $Kg.ha^{-1}$, respectively. Tawa, IT93K-452-1 and Kpodjiguègué displayed the most stable yield across locations.

The screening performed in the greenhouse identified fourteen accessions with different resistance level. Out of these, only Awlétchi, IT83S-742-2, Kpodjiguèguè stood outfrom both environment and kept the same level of resistance in the greenhouse as in the fields (score3). This result proved the resistant character suspected in those accessions. However, Awonlignikoun, Gléssissaffodo, IT86D-888, Kpègnikoun, Kumassi, Moussa, Nontché-Wagbèhami, Tiligré, IT07K-243-1-10, Sèwé, Sanzibanili, IT84E-124, Kplobè-Wéwé, Awonlignikoun have shown resistance based on environment and in one environment or other, there were susceptible or resistant accessions.

CHAPTER SIX

6. Conclusion and Recommendations

6.1. Conclusion

The study identified *Megalurithrips sjostedti* Trybom as the most dominant flower thrips in the majority of the main cowpea growing areas in Benin. The different biotypes of *M. sjostedti* from the sampling areas caused similar damage on the cowpea accessions. The most resistant and stable accessions are IT84S-2246-4, Mawougbadonou, IT07K318-33, and IT93K-452-1 whose resistance sources could be used to introgress resistance into other preferred elites lines susceptible to flower bud thrips. The accessions Tawa, IT93K-452-1 and Kpodjiguèguè were high yielding and the most stable accessions across environments. These accessions could be used as parents in breeding programmes for the improvement of cowpea yield.

6.2. Recommendations

At the end of this study some recommendations need to be made to researchers and farmers for the efficient use of Benin cowpea germplasm.

Further research should focus on:

1) The collection of the thrips populations across all the agroecological zones in Benin in order to discover other thrips biotypes in Benin.

2) Evaluation of the resistance mechanism of the identified resistant accessions;

2) Survey should be conducted on the farmer appreciation (taste) and fitness of the identified resistant lines.

3) Repetition of the present study in more locations for more seasons in order to determine the real stability of the resistance and the yield in more agroecological zones in Benin.

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APPENDIXES

Appendix 1 : Means of thrips damage scores and counts, yield and yield components of cowpea accessions at Abomey-Calavi

Accessions	NPPl	NPodP	NPodPl	NATF	NLTF	DMS	NDF	NDM	100GW (g)	TGW (g)
Adjagnikoun	23.67	2.00	53.33	18.33	20.67	5.15	42.00	56.00	16.51	33.40
Akunnado	34.33	2.00	51.00	19.67	16.67	5.80	44.00	58.33	12.71	248.00
Atchawékoun	39.00	2.33	85.00	9.67	16.33	5.07	46.33	60.33	12.26	299.00
Awlétchi	29.00	1.00	10.33	15.33	16.67	4.27	41.33	55.33	12.31	102.00
Awonlignikoun	37.00	0.33	5.00	7.33	8.00	4.23	40.67	54.67	76.39	243.13
Djètoko	0.00	0.33	0.00	5.67	7.33	0.70	45.00	59.00	18.62	141.30
Elisabeth	34.67	2.33	79.00	12.33	21.33	2.67	35.67	49.67	14.75	280.50
Gboto	11.33	0.33	1.67	10.67	25.00	5.38	43.00	57.00	14.91	498.50
Gléssissaffodo	48.67	3.67	168.00	14.67	23.00	3.38	43.00	57.00	14.91	392.10
IT06K-242-3	40.33	2.67	74.67	8.00	9.67	4.45	40.67	54.67	13.37	204.50
IT07K-188-49	23.67	1.33	31.00	6.33	17.00	4.38	45.00	59.00	14.10	139.50
IT07K-243-1-10	31.67	3.67	109.67	14.33	22.33	4.35	40.33	54.33	18.73	123.00
IT07K211-1-8	38.33	1.00	41.00	17.33	21.67	5.25	42.00	56.00	18.66	19.10
IT07K318-33	27.33	2.33	48.00	13.67	37.00	4.23	44.00	58.00	25.20	281.40
IT83S-742-2	20.00	2.67	55.33	13.67	21.67	4.24	42.00	56.00	13.47	44.80
IT84D-449	19.67	3.00	59.33	15.67	28.33	5.15	39.00	53.00	11.93	269.50
IT84E-124	22.33	1.67	28.33	18.33	31.00	4.92	40.67	54.67	17.28	39.20
IT84S-2246-4	32.67	1.33	37.67	19.00	23.67	3.82	40.33	54.33	18.38	133.00
IT86D-1033	30.00	0.83	24.33	18.50	26.00	4.74	42.50	56.50	13.79	145.95
IT86D-1057	22.00	1.00	16.67	12.00	20.00	5.25	43.00	57.00	13.59	40.80
IT86D-888	32.00	2.33	74.00	12.00	24.33	4.82	38.67	52.67	15.58	90.20

Accessions	NPPl	NPodP	NPodPl	NATF	NLTF	DMS	NDF	NDM	100GW (g)	TGW (g)
IT87S-1390	33.33	2.00	68.00	15.00	26.00	5.87	43.00	57.00	11.23	176.00
IT93K-452-1	45.00	3.00	134.00	21.33	31.67	5.78	42.00	56.00	22.69	511.10
IT97K-449-35	29.33	3.33	97.33	26.00	19.33	5.07	45.67	59.67	19.13	60.50
IT97K-556-6	33.33	2.67	94.00	17.67	25.33	5.55	45.67	59.67	14.56	82.70
Kaki	20.33	1.67	35.00	15.67	25.00	5.52	45.67	59.67	44.77	150.20
Kaki gros grains	17.67	1.67	35.00	20.00	32.00	5.55	43.00	57.00	14.27	123.90
Kaki petit grains	49.33	2.67	136.33	13.67	16.67	4.58	44.00	58.00	13.17	389.60
Kodobobo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Komcallé	43.67	1.67	59.00	18.00	30.33	4.03	44.00	58.00	22.21	78.83
Kpègnikoun	48.67	4.00	194.67	12.00	16.33	3.75	42.00	56.00	19.25	101.80
Kplobè	30.67	2.67	75.33	13.67	28.33	5.23	40.67	54.67	10.35	209.00
Kplobè-Wéwé	44.33	2.67	83.33	16.33	27.67	4.53	43.00	57.00	17.51	285.10
Kpodjiguèguè	46.67	2.67	105.33	14.67	22.67	4.13	42.00	56.00	10.67	419.30
Kumassi	22.33	0.67	14.33	14.67	34.00	5.02	43.00	57.00	12.75	497.50
Mawougbadonou	22.33	3.33	72.00	14.67	37.00	5.62	44.00	58.00	11.75	155.50
Mawounan	20.67	2.33	50.67	15.67	15.67	5.22	42.33	56.33	21.26	88.40
Moussa	43.33	2.00	86.33	15.33	21.00	4.08	42.00	56.00	17.47	249.00
Nontché-Wagbèhamin	42.00	2.00	64.67	14.00	19.33	3.77	43.00	57.00	14.86	437.20
Sanzibanili	36.33	2.67	93.33	14.00	20.00	2.78	40.67	54.67	12.27	52.90
Sèwé	41.67	2.67	85.33	24.00	28.67	2.53	43.00	57.00	12.08	539.00
Tawa	28.00	2.33	56.67	20.33	16.67	5.65	43.00	57.00	17.75	229.20
Tiligré	32.67	1.67	59.67	20.00	37.67	3.88	41.33	55.33	18.87	169.50
Tola	54.00	1.00	35.00	15.33	27.33	5.33	42.33	56.67	14.05	361.00
Tonton	28.33	2.33	62.67	10.33	23.33	5.55	44.00	58.00	14.67	222.00

Accessions	NPPl	NPodP	NPodPl	NATF	NLTF	DMS	NDF	NDM	100GW (g)	TGW (g)
Vidégnikoun	15.00	2.00	23.33	8.67	13.33	4.40	43.00	57.00	14.87	90.00
Vita7	16.33	1.33	20.33	38.33	28.00	5.92	42.33	56.33	19.42	165.60

NPodPl=Number of pods per plant, NPPl=Number of peduncles per plant, TGW = Total grains weight (g), NDF= Number of days to 50% flowering, NPodP=Number of pods per peduncles, NDM= Number of days to 50% maturity, 100GW=100 grains weight (g), DMS=Damage Median Score, NATF= Number of adults thrips per flower, NLTF= Number of larvae thrips per flower.

Appendix 2: Means of thrips damage scores and counts, yield and yield components of cowpea accessions at Gbaffo

Accessions	NPPl	NPodP	NPodPl	NATF	NLTF	DMS	NDF	NDM	100GW (g)	TGW (g)
Adjagnikoun	6.67	1.00	5.67	33.33	27.67	6.83	42.00	56.00	24.00	11.13
Akunnado	5.33	1.00	5.00	17.67	53.33	6.67	45.00	59.00	13.11	82.67
Atchawékoun	5.00	1.00	5.33	24.67	46.00	6.83	47.33	60.00	29.13	99.67
Awlétchi	5.33	1.33	7.00	63.33	92.00	6.50	39.67	54.33	12.31	34.00
Awonlignikoun	5.33	1.00	7.67	27.33	52.67	7.00	41.67	57.67	19.99	81.05
Djètoko	3.33	0.67	3.00	19.67	43.33	6.83	51.67	66.33	20.37	47.10

Accessions	**NPPl**	**NPodP**	**NPodPl**	**NATF**	**NLTF**	**DMS**	**NDF**	**NDM**	**100GW (g)**	**TGW (g)**
Elisabeth	9.67	1.00	11.33	31.33	99.00	6.33	35.00	49.00	11.29	93.50
Gboto	6.67	1.00	7.00	19.67	90.00	5.50	42.00	56.00	15.19	166.17
Gléssissaffodo	5.00	0.67	3.33	13.00	34.33	7.50	42.00	56.00	13.64	130.70
IT06K-242-3	4.67	1.00	4.00	12.67	43.67	6.67	39.67	53.67	13.37	68.17
IT07K-188-49	10.33	0.67	7.00	47.00	57.33	7.67	43.00	57.00	15.80	46.50
IT07K-243-1-10	7.67	1.00	7.67	17.67	49.33	7.17	39.67	53.67	18.46	41.00
IT07K211-1-8	4.00	1.00	4.33	36.67	68.33	6.50	42.00	56.00	15.83	6.37
IT07K318-33	4.33	0.67	4.33	22.33	94.67	4.67	43.00	57.00	22.07	93.80
IT83S-742-2	1.00	1.00	1.00	47.33	53.00	6.50	42.00	56.00	14.80	14.93
IT84D-449	6.67	1.00	6.67	22.33	57.33	6.83	37.33	51.33	12.63	89.83
IT84E-124	6.33	1.00	7.33	26.33	89.33	6.33	43.00	57.67	11.66	13.07

Accessions	**NPPl**	**NPodP**	**NPodPl**	**NATF**	**NLTF**	**DMS**	**NDF**	**NDM**	**100GW (g)**	**TGW (g)**
IT84S-2246-4	6.67	1.00	8.67	42.33	103.33	6.17	39.67	53.67	18.38	44.33
IT86D-1033	5.50	1.17	5.50	47.83	74.33	7.67	42.00	56.00	14.82	48.65
IT86D-1057	3.33	1.00	2.67	23.33	37.33	7.00	42.00	56.00	11.19	13.60
IT86D-888	6.00	0.67	3.33	39.00	81.00	4.83	37.33	52.00	17.67	30.07
IT87S-1390	7.67	1.00	9.33	60.00	74.67	6.67	44.67	58.67	12.15	58.67
IT93K-452-1	4.00	1.00	3.67	50.33	55.33	6.83	39.67	53.67	22.29	170.37
IT97K-449-35	5.00	1.00	5.33	32.33	32.33	6.67	45.67	59.67	21.67	20.17
IT97K-556-6	8.00	0.67	6.33	41.67	83.67	7.00	44.67	58.67	15.69	27.57
Kaki	3.33	1.00	2.67	14.33	31.00	7.50	44.67	58.67	12.44	50.07
Kaki gros grains	4.00	1.00	4.33	68.00	62.67	7.33	42.00	56.00	11.43	41.30
Kaki petit grains	6.67	0.33	4.33	18.67	35.00	5.67	45.00	59.33	11.57	129.87

Accessions	**NPPl**	**NPodP**	**NPodPl**	**NATF**	**NLTF**	**DMS**	**NDF**	**NDM**	**100GW (g)**	**TGW (g)**
Kodobobo	2.33	0.67	2.00	22.67	21.00	7.00	37.33	51.33	5.23	124.60
Komcallé	3.67	0.67	3.00	79.33	76.00	6.83	42.00	56.00	27.07	20.67
Kpègnikoun	7.67	0.67	5.67	4.67	7.00	7.00	42.00	56.00	16.87	33.93
Kplobè	8.00	0.67	7.33	11.33	42.00	7.00	42.00	56.00	10.35	69.67
Kplobè-Wéwé	10.00	1.00	9.67	44.33	111.67	7.33	45.00	62.33	14.37	95.03
Kpodjiguèguè	6.00	0.67	6.33	39.67	75.00	6.67	42.00	56.00	11.72	139.77
Kumassi	5.33	1.00	5.67	20.00	66.33	7.67	42.00	56.00	20.19	165.83
Mawougbadonou	3.67	0.67	5.00	15.00	22.00	7.00	44.00	58.00	22.93	51.83
Mawounan	4.67	0.67	3.33	41.67	35.33	7.67	42.00	56.00	23.10	29.47
Moussa	2.33	1.00	2.00	19.00	44.33	7.50	42.00	56.00	11.47	83.00
Nontché-Wagbèhamin	4.33	1.33	5.00	20.33	52.67	6.33	43.00	57.00	16.33	145.73

Accessions	**NPPl**	**NPodP**	**NPodPl**	**NATF**	**NLTF**	**DMS**	**NDF**	**NDM**	**100GW (g)**	**TGW (g)**
Sanzibanili	3.33	0.67	3.33	24.67	83.67	6.83	42.33	56.33	12.19	17.63
Sèwé	10.00	2.00	16.33	35.00	74.67	7.00	42.00	56.00	21.25	179.67
Tawa	7.67	1.00	6.00	28.67	57.33	6.67	42.00	56.00	18.71	76.40
Tiligré	4.67	0.67	3.33	31.00	187.33	6.67	42.00	56.00	26.88	56.50
Tola	13.67	1.33	15.00	20.00	69.00	5.17	50.00	65.33	13.13	120.33
Tonton	7.33	1.00	5.33	35.33	80.67	6.33	44.67	59.00	17.05	74.00
Vidégnikoun	7.00	0.67	6.00	27.00	40.00	6.50	42.00	55.67	14.87	30.00
Vita7	12.67	1.00	11.67	14.67	12.00	6.67	39.67	53.67	23.38	55.20

NPodPl=Number of pods per plant, NPPl=Number of peduncles per plant, TGW = Total grains weight (g), NDF= Number of days to 50% flowering, NPodP=Number of pods per peduncles, NDM= Number of days to 50% maturity, 100GW=100 grains weight (g), DMS=Damage Median Score, NATF= Number of adults thrips per flower, NLTF= Number of larvae thrips per flower.

Appendix 3: Means of thrips damage scores and counts, yield and yield components of cowpea accessions at Zakpota

Accessions	NP Pl	NPo dP	NPo dPl	NA TF	NL TF	D MS	ND F	ND M	100GW (g)	TGW (g)
Adjagnikoun	8.67	1.00	8.03	37.36	28.70	6.83	42.76	57.003	25.23	13.14
Akunnado	7.33	1.00	7.36	21.70	54.36	6.67	45.76	60.003	14.34	84.68
Atchawékoun	7.00	1.00	7.69	28.70	47.03	6.83	48.09	61.003	30.36	101.68
Awlétchi	7.33	1.33	9.36	67.36	93.03	6.50	40.43	55.336	13.54	36.01
Awonlignikoun	7.33	1.00	10.03	31.36	53.70	7.00	42.43	58.670	21.22	83.06
Djètoko	5.33	0.67	5.36	23.70	44.36	6.83	52.43	67.336	21.60	49.11
Elisabeth	11.67	1.00	13.69	35.36	100.03	6.33	35.76	50.003	12.52	95.51
Gboto	8.67	1.00	9.36	23.70	91.03	5.50	42.76	57.003	16.42	168.18
Gléssissaffodo	7.00	0.67	5.69	17.03	35.36	7.50	42.76	57.003	14.87	132.71
IT06K-242-3	6.67	1.00	6.36	16.70	44.70	6.67	40.43	54.670	14.60	70.18
IT07K-188-49	12.33	0.67	9.36	51.03	58.36	7.67	43.76	58.003	17.03	48.51
IT07K-243-1-10	9.67	1.00	10.03	21.70	50.36	7.17	40.43	54.670	19.69	43.01
IT07K211-1-8	6.00	1.00	6.69	40.70	69.36	6.50	42.76	57.003	17.06	8.38
IT07K318-33	5.63	0.67	6.69	26.36	95.70	4.67	43.76	58.003	23.30	95.81
IT83S-742-2	2.30	1.00	3.36	51.36	54.03	6.50	42.76	57.003	16.03	16.94
IT84D-449	7.97	1.00	9.03	26.36	58.36	6.83	38.09	52.336	13.86	91.84
IT84E-124	7.63	1.00	9.69	30.36	90.36	6.33	43.76	58.670	12.89	15.08
IT84S-2246-4	7.97	1.00	11.03	46.36	104.36	6.17	40.43	54.670	19.61	46.34
IT86D-1033	6.80	1.17	7.86	51.86	75.36	7.67	42.76	57.003	16.05	50.66
IT86D-1057	4.63	1.00	5.03	27.36	38.36	7.00	42.76	57.003	12.42	15.61
IT86D-888	7.30	0.67	5.69	43.03	82.03	4.83	38.09	53.003	18.90	32.08

Accessions	NPPl	NPodP	NPodPl	NATF	NLTF	DMS	NDF	NDM	100GW (g)	TGW (g)
IT87S-1390	8.97	1.00	11.69	64.03	75.70	6.67	45.43	59.670	13.38	60.68
IT93K-452-1	5.30	1.00	6.03	54.36	56.36	6.83	40.43	54.670	23.52	172.38
IT97K-449-35	6.30	1.00	7.69	36.36	33.36	6.67	46.43	60.670	22.90	22.18
IT97K-556-6	9.30	0.67	8.69	39.62	84.70	7.00	45.43	59.670	16.92	29.58
Kaki	4.63	1.00	5.03	12.28	32.03	7.50	45.43	59.670	13.67	52.08
Kaki gros grains	5.00	1.00	6.69	65.95	63.70	7.33	42.76	57.003	12.66	43.31
Kaki petit grains	7.67	0.33	6.69	16.62	36.03	5.67	45.76	60.336	12.80	131.88
Kodobobo	3.33	0.67	4.36	20.62	22.03	7.00	38.09	52.336	6.46	126.61
Komcallé	4.67	0.67	5.36	77.28	77.03	6.83	42.76	57.003	28.30	22.68
Kpègnikoun	8.67	0.67	8.03	2.62	8.03	7.00	42.76	57.003	18.10	35.94
Kplobè	9.00	0.67	9.69	9.28	43.03	7.00	42.76	57.003	11.58	71.68
Kplobè-Wéwé	11.00	1.00	12.03	42.28	112.70	7.33	45.76	63.336	15.60	97.04
Kpodjiguèguè	7.00	0.67	8.69	37.62	76.03	6.67	42.76	57.003	12.95	141.78
Kumassi	6.33	1.00	8.03	17.95	67.36	7.67	42.76	57.003	21.42	167.84
Mawougbadonou	4.67	0.67	7.36	12.95	23.03	7.00	44.76	59.003	24.16	53.84
Mawounan	3.97	0.67	5.69	43.07	36.36	7.67	42.76	57.003	24.33	31.48
Moussa	1.63	1.00	4.36	20.40	45.36	7.50	42.76	57.003	12.70	85.01
Nontché-Wagbèhamin	3.63	1.33	7.36	21.73	53.70	6.33	43.76	58.003	17.56	147.74
Sanzibanili	2.63	0.67	5.69	26.07	84.70	6.83	43.09	57.336	13.42	19.64
Sèwé	9.30	2.00	18.69	36.40	75.70	7.00	42.76	57.003	22.48	181.68
Tawa	6.97	1.00	8.36	30.07	58.36	6.67	42.76	57.003	19.94	78.41
Tiligré	3.97	0.67	5.69	32.40	188.36	6.67	42.76	57.003	28.11	58.51
Tola	12.97	1.33	17.36	21.40	70.03	5.17	50.76	66.336	14.36	122.34
Tonton	6.63	1.00	7.69	36.73	81.70	6.33	45.43	60.003	18.28	76.01

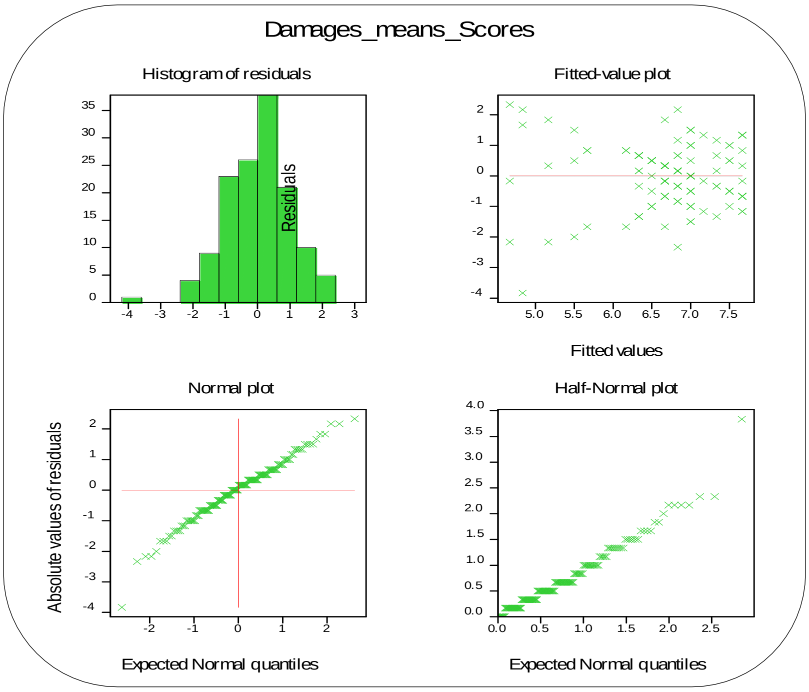
Accessions	**NPPl**	**NPodP**	**NPodPl**	**NATF**	**NLTF**	**DMS**	**NDF**	**NDM**	**100GW (g)**	**TGW (g)**
Vidégnikoun	6.30	0.67	8.36	28.40	41.03	6.50	42.76	56.670	16.10	32.01
Vita7	11.97	1.00	14.03	16.07	13.03	6.67	40.43	54.670	24.61	57.21

NPodPl=Number of pods per plant, NPPl=Number of peduncles per plant, TGW = Total grains weight (g), NDF= Number of days to 50% flowering, NPodP=Number of pods per peduncles, NDM= Number of days to 50% maturity, 100GW=100 grains weight (g), DMS=Damage Median Score, NATF= Number of adults thrips per flower, NLTF= Number of larvae thrips per flower.

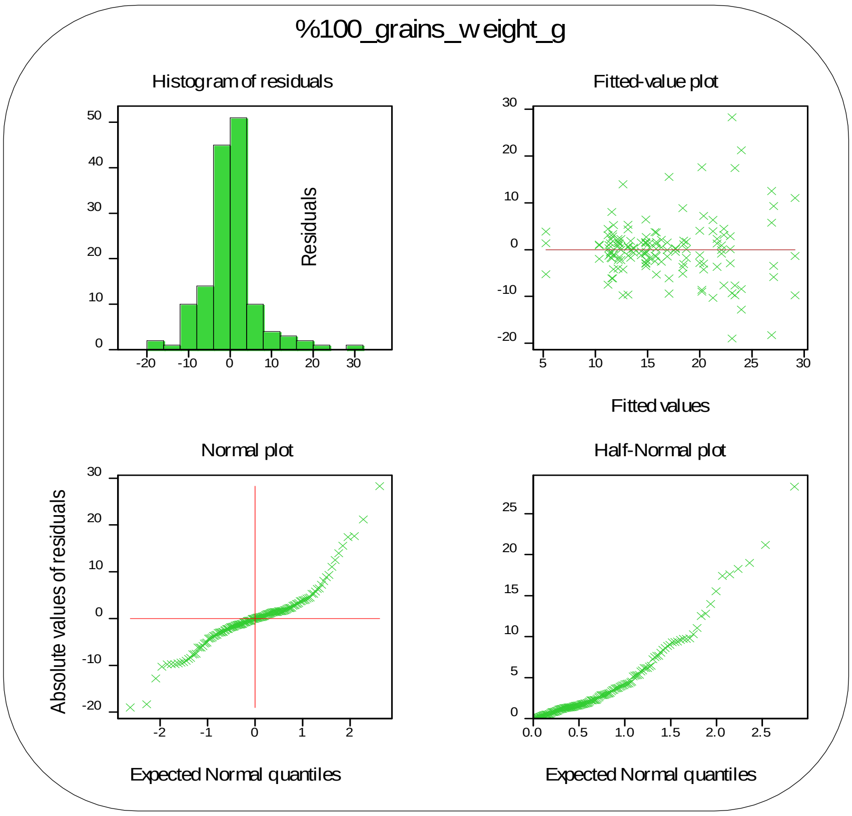
Appendix 4: list of tested varieties

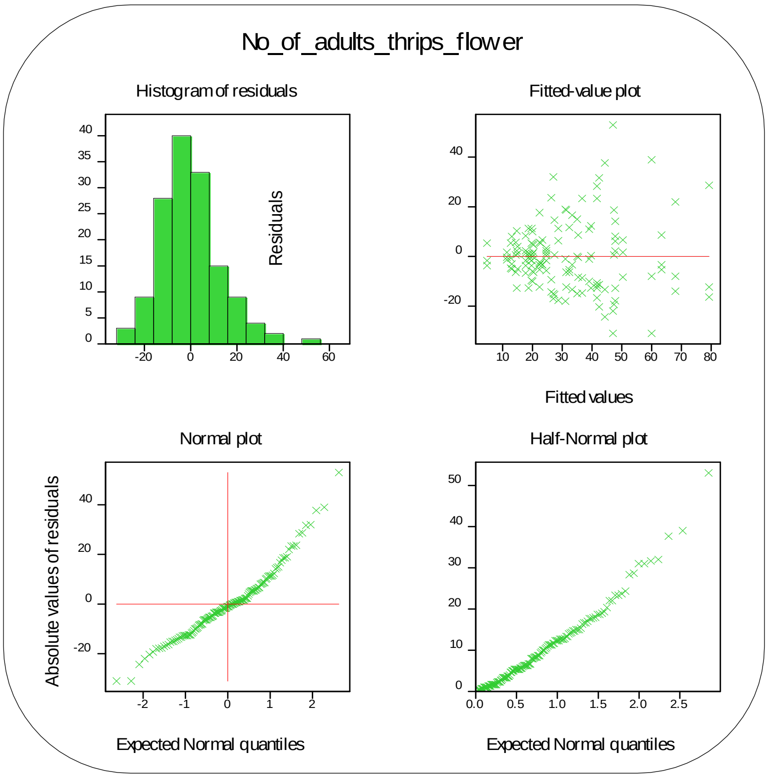
Accession	**Code**	**Accession**	**Code**
Adjagnikoun	G1	IT97K-449-35	G25
Akunnado	G2	IT97K-556-6	G26
Atchawékoun	G3	Kaki	G27
Awlétchi	G4	Kaki gros grains	G28
Awonlignikoun	G5	Kaki petit grains	G29
Djètoko	G6	Kodobobo	G30
Elisabeth	G7	Komcallé	G31
Gboto	G8	Kpègnikoun	G32
Gléssissaffodo	G9	Kplobè	G33
IT06K-242-3	G10	Kplobè-Wéwé	G34
IT07K-188-49	G11	Kpodjiguèguè	G35
IT07K211-1-8	G12	Kumassi	G36
IT07K-243-1-10	G13	Mawougbadonou	G37
IT07K318-33	G14	Mawounan	G38
IT83S-742-2	G15	Moussa	G39
IT84D-449	G16	Nontché-Wagbèhamin	G40
IT84E-124	G17	Sanzibanili	G41
IT84S-2246-4	G18	Sèwé	G42
IT86D-1033	G19	Tawa	G43
IT86D-1038	G20	Tiligré	G44
IT86D-1057	G21	Tola	G45
IT86D-888	G22	Tonton	G46
IT87S-1390	G23	Vidégnikoun	G47
IT93K-452-1	G24	Vita7	G48

Appendix 5: ANOVA assumption's verification for the thrips damage data

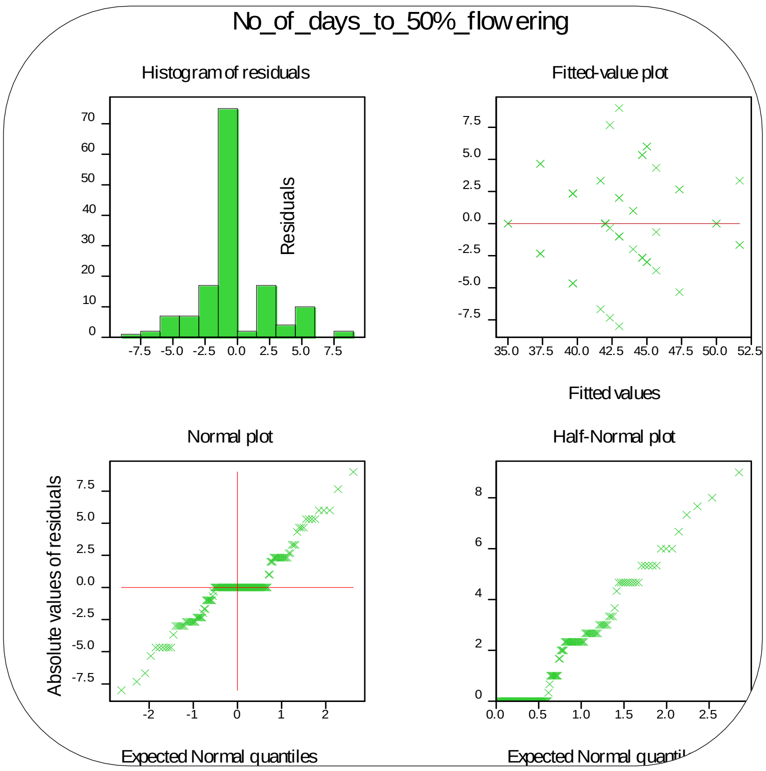


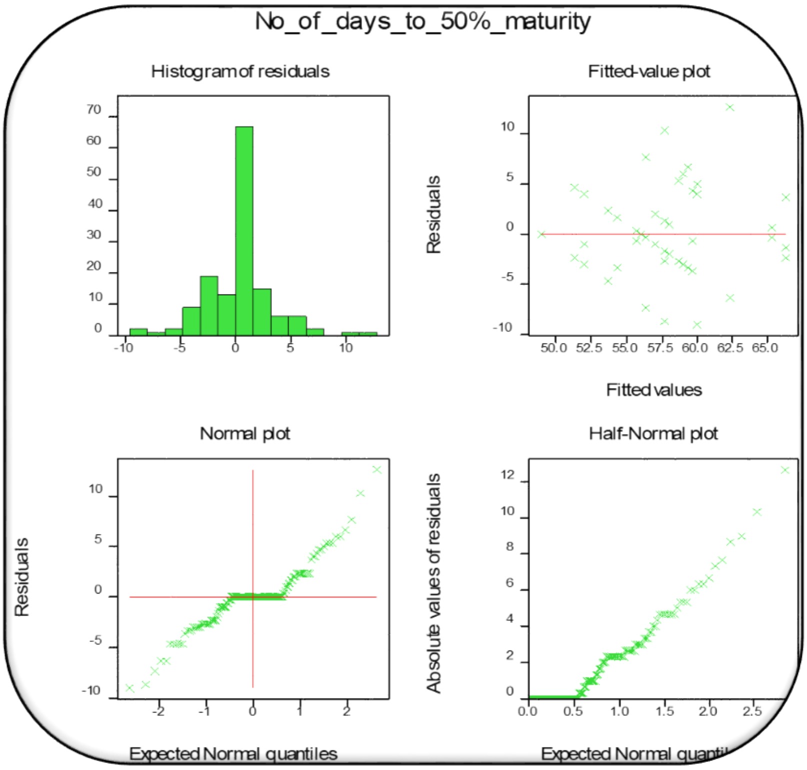
Appendix 6: ANOVA assumption's verification for the hundred grains weight data and the number of adult thrips per flower



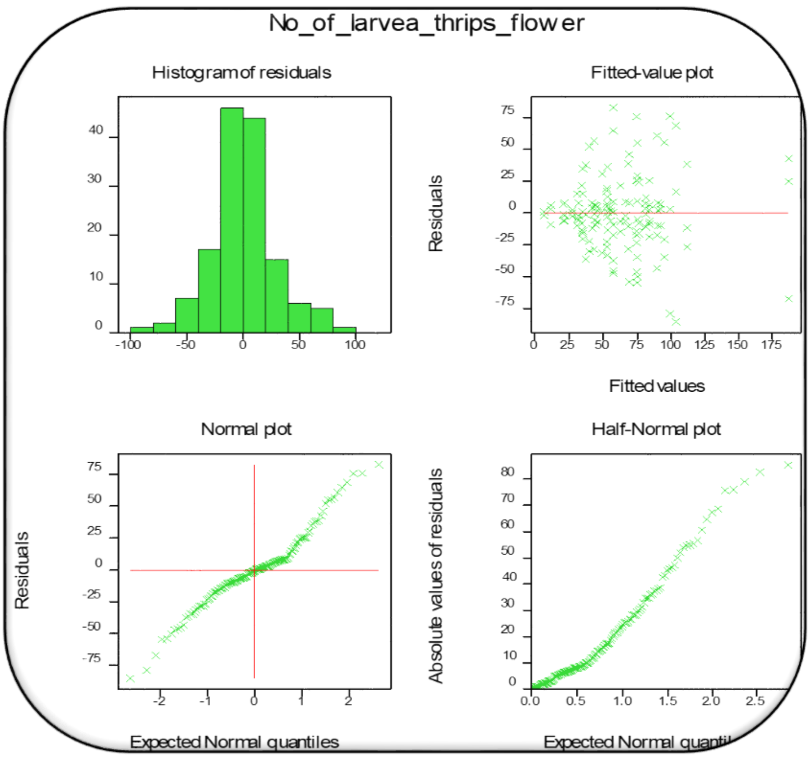


Appendix 7**:** ANOVA assumption's verification for the number of day to 50% flowering and maturity data

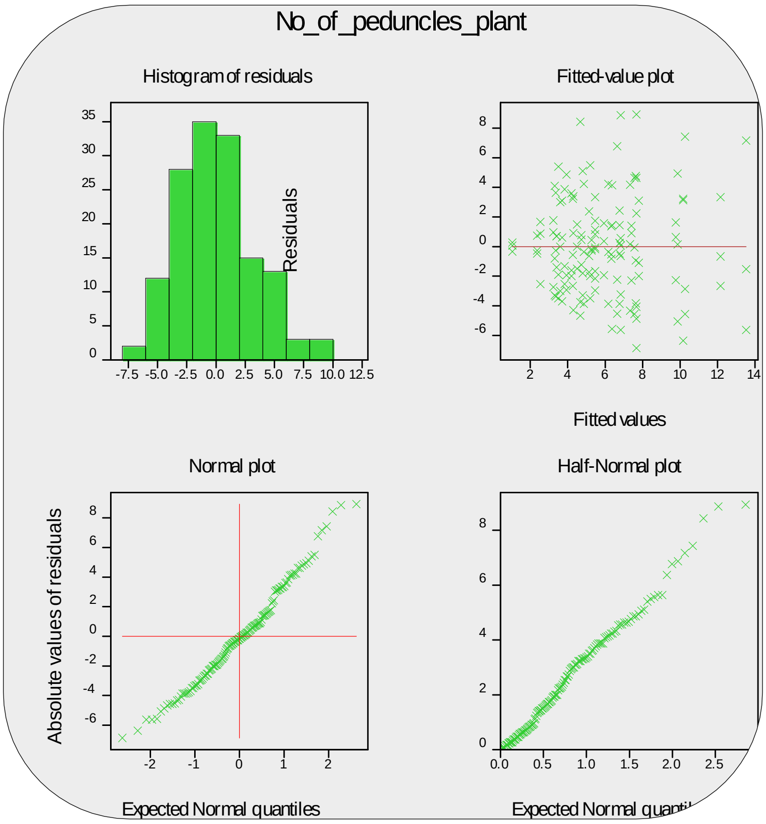




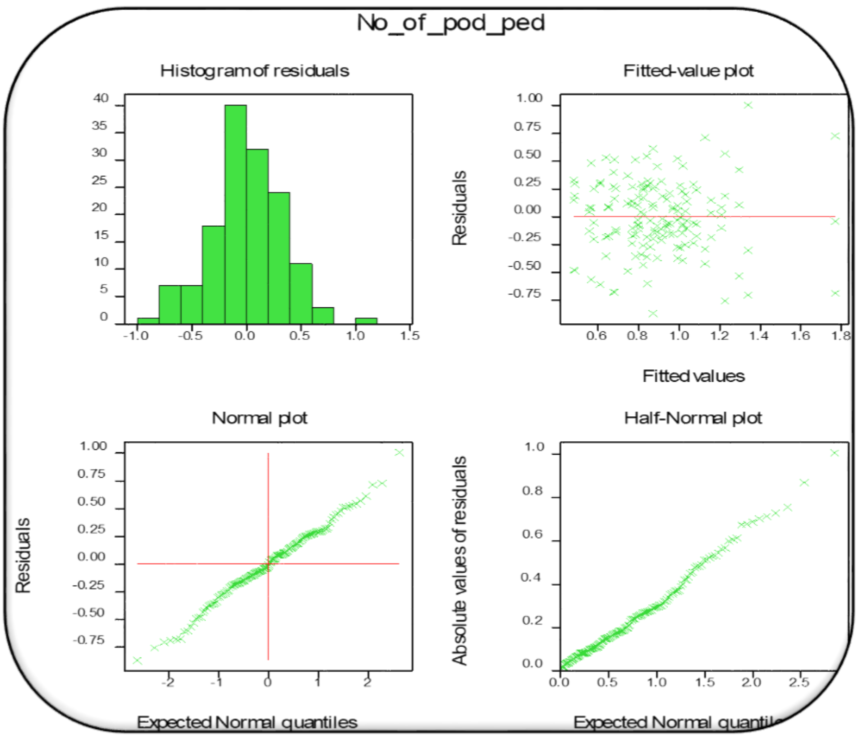
Appendix 8**:** ANOVA assumption's verification for the data on the number of larvae of thrips per flower



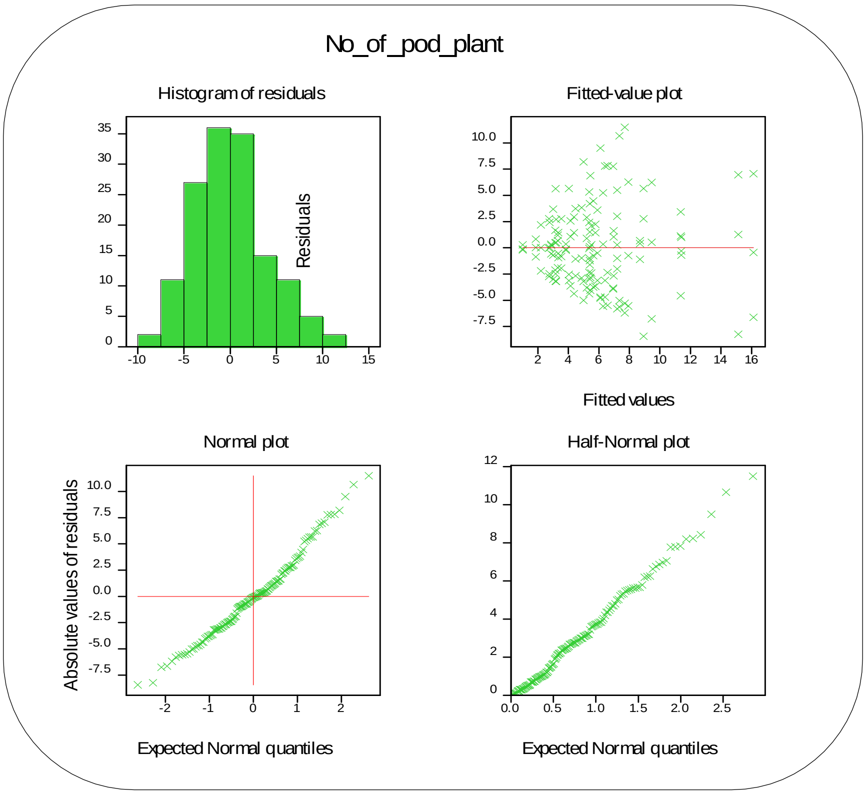
Appendix 9**:** ANOVA assumption's verification for data on the number of peduncle per plant



Appendix 10**:** ANOVA assumption's verification for data on the number of pod per peduncle



Appendix 11**:** ANOVA assumption's verification for data on the number of pod per plant



Appendix 12**:** ANOVA assumption's verification for data on the total grain weight per plot