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MASTER COURSE IN PLANT PROTECTION

ASSESSMENT OF FALL ARMYWORM BEHAVIORAL RESPONSE ON THREE REPELLENT PLANTS FOR POTENTIAL INTEGRATION IN PUSH PULL TECHNOLOGY.

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Maputo, June 2026

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ABSTRACT

Maize (*Zea mays*) remain one of the important crop cultivated worldwide. In Mozambique, it is a staple food crop for the majority of the population. However, pests such as *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) threatens maize production with complete crop loss being reported. The use of insecticides remains common choice of FAW management coupled with human and environmental hazards leading to increasing concerns over their long-term sustainability. This highlights the need for shift of interest to Integrated Pest Management (IPM) practices among which are behavioral manipulation methods. A promising nature based FAW management technique within the scope of IPM is Push Pull technology which involve repelling (Push) FAW away from the economical crop using volatile stimuli and driving them towards attractive crop (pull). However, use of desmodium has limited adoption necessitating need of diversifying push plants. Basil (*Ocimum basilicum*), coriander (*Coriandrum sativum* L.) and mint (*Mentha* × *piperita*) are repellent intercrops, with food and direct economic value, may represent better options in place of desmodium and remain largely underexplored. This study assesses the behavior of FAW when exposed to basil, coriander and mint. Laboratory oviposition studies were conducted in no choice and two choice, extended also in semi field conditions. Additionally, FAW survival, development duration and reproductive parameters were estimated when reared on the test plants. In laboratory conditions a Y tube olfactometer was used to study behavioral responses to various stimuli. The no choice tests revealed high mean number of eggs (191.9 ± 35.4) and egg masses (1.6 ± 0.3) oviposited on basil, followed by coriander (103.7 ± 37.6; 1.1 ± 0.4), while mint had the least (46.1 ± 26.9; 0.5 ± 0.3). Two choice oviposition revealed high oviposition in basil (328 ± 33.9 eggs; 3.2 ± 0.3 egg masses) and coriander (222.8 ± 43.6; 2 ± 0.4), while mint showed oviposition mainly on cage walls (473 ± 64.8; 3.6 ± 0.3) and least on mint (136.6 ± 38.5; 1.5 ± 0.4). Semi field two choice experiment revealed high eggs (1237 ± 135) and egg masses (7.5 ± 0.5) on basil, while mint had the least (826 ± 25.0; 4.25 ± 0.25). Basil-fed larvae showed highest survival, shortest development, highest pupal weight, pupation rate, and highest fecundity in F_1 and F_2, followed by coriander, while mint caused total mortality. Y tube olfactometer response showed high attractiveness to basil (75%) and coriander (57.1%), while mint showed low relative olfactory selection rate (14.3%). The trial between test plants against maize showed selection rates of 30% for basil, 28.6% for coriander and 10% for mint. When combined with maize, basil showed highest preference (40%), followed by coriander (25%), while mint had the least (20%). Generally, mint exhibited potential repellent properties.

Key words: Fall armyworm, host plant adaptability, oviposition preference, relative olfactometer selection, repellent plant.

RESUMO

O milho (*Zea mays*) continua a ser uma das culturas mais importantes cultivadas a nível mundial. Em Moçambique, constitui um alimento básico para a maioria da população. No entanto, pragas como *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) ameaçam a produção de milho, tendo sido reportadas perdas totais da cultura. O uso de inseticidas continua a ser uma prática comum no controlo da lagarta do funil do milho (LFM), estando associado a riscos para a saúde humana e para o ambiente, o que levanta preocupações quanto à sua sustentabilidade a longo prazo. Isto evidencia a necessidade de uma mudança para práticas de Maneio Integrado de Pragas (MIP), incluindo métodos de manipulação comportamental. Uma técnica promissora para o controlo da LFM, no âmbito do MIP, é a tecnologia push–pull, que consiste em repelir (push) a praga da cultura principal através de estímulos voláteis e atraí-la (pull) para culturas atractivas. Contudo, o uso de desmodium tem tido uma adopção limitada, tornando necessária a diversificação das plantas repelentes. O manjericão (*Ocimum basilicum*), o coentro (*Coriandrum sativum* L.) e a hortelã (*Mentha × piperita*), com propriedades repelentes e valor alimentar e económico directo, podem constituir alternativas ao desmodium, embora ainda pouco exploradas. Este estudo avaliou o comportamento da LFM quando exposta a manjericão, coentro e hortelã. Foram realizados ensaios laboratoriais de oviposição em condições de não escolha e de dupla escolha, também em semi-campo. Adicionalmente, foram avaliadas a sobrevivência, a duração do desenvolvimento e os parâmetros reprodutivos quando criada nas plantas em estudo, e em laboratório utilizou-se também um olfatómetro em Y para estudar respostas comportamentais. Os ensaios de não escolha revelaram um elevado número médio de ovos (191,9 ± 35,4) e massas de ovos (1,6 ± 0,3) no manjericão, seguido do coentro (103,7 ± 37,6 e 1,1 ± 0,4), enquanto a hortelã apresentou os valores mais baixos (46,1 ± 26,9 e 0,5 ± 0,3). Nos ensaios de dupla escolha, verificou-se maior oviposição no manjericão (328 ± 33,9 e 3,2 ± 0,3) e no coentro (222,8 ± 43,6 e 2,0 ± 0,4), enquanto na hortelã as mariposas apresentaram maior oviposição nas paredes da gaiola (473 ± 64,8 e 3,6 ± 0,3) e menor na própria hortelã (136,6 ± 38,5 e 1,5 ± 0,4). O ensaio em semi-campo revelou valores mais elevados no manjericão (1237 ± 135 e 7,5 ± 0,5) e mais baixos na hortelã (826 ± 25,0 e 4,25 ± 0,25). As larvas alimentadas com manjericão apresentaram maior sobrevivência, menor duração, maior peso pupal, maior pupação e maior fecundidade nas gerações F_1 e F_2, seguidas pelas de coentro, enquanto a hortelã resultou em mortalidade total. O olfatómetro em Y revelou maior atratividade para o manjericão (75%) e coentro (57,1%), enquanto a hortelã apresentou menor selecção olfativa relativa (14,3%). Nos ensaios entre plantas de teste e milho, a selecção foi de 30% para manjericão, 28,6% para coentro e 10% para hortelã. Quando combinadas com milho, o manjericão apresentou maior preferência (40%), seguido do coentro (25%), enquanto a hortelã apresentou menor (20%). De forma geral, a hortelã demonstrou potencial como planta repelente.

Palavras-chave: lagarta do funil do milho, adaptabilidade à planta hospedeira, preferência de oviposição, seleção olfativa relativa, planta repelente.

DECLARATION

“I declare that this dissertation has never been submitted for the purpose of obtaining any degree or in any other field and that it is the result of my individual labor. This dissertation is presented in partial fulfillment of the requirements for obtaining the degree of master in plant protection, from the University of Eduardo Mondlane”.

STEPHEN THUKU GATHUNDIA

………………………………………………Date…………………………………………….

I confirm that the work reported in this dissertation was carried out under my supervision.

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DEDICATION

I dedicate this work to my lovely parents Antony Gathundia Thuku and Teresiah Wanjira Gathundia for their moral support in my studies and my sisters.

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LIST OF ABBREVIATION

ANOVA	Analysis of Variance
CABI	Centre for Agriculture and Biosciences International archives
CNS	Central Nervous System
DBM	Diamondback Moth
EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agricultural Organization
FAW	Fall Armyworm
ICIPE	International Centre of Insect Physiology and Ecology
IPM	Integrated Pest Management
ISAAA	International Service for the Acquisition of Agri-biotech Applications
MM	Millimeter
PPT	Push Pull Technology
TLD	Total Larval Development
USA	United States of America
USD	United States Dollar
VOC	Volatile Organic Compound

1.0 INTRODUCTION

1.1 Contextualization

Maize, also referred to as corn, is one of the most important crops cultivated. Originating from the ancient civilizations of Central America worldwide maize has become a global crop (Ferreira *et al.,* 2024). Under human selection, maize has undergone rapid development, leading to significant phenotypic changes and environmental adaptations. Genetic drift, natural selection, and breeding activities have contributed to the current diversity of maize (Kong *et al.,* 2020).

Maize adaptability to various climates and soil types (Stitzer & Ross-Ibarra, 2018). Its high yield potential and diverse applications as food, feed, and industrial products, has compounded its status as a staple crop (Grote *et al.,* 2021; Khan *et al.,* 2018; Ranum *et al.,* 2014). Globally, maize is one of the most important cereal crops, providing food and livelihoods for an estimated 300 million people. (Hatfield *et al.,* 2011). According to Integrated Agricultural Survey – Ministry of Agriculture, Environment and Fisheries, (2025) reports maize is produced on 82.8% of farms in Mozambique. About 46% of rural households in Mozambique utilize maize flour in their diets, making it the most produced and desired cereal for human consumption (Sanchez *et al.,* 2011).

Historically, maize production has been inhibited by key abiotic factors such as climate change (Cairns *et al.,* 2013) and biotic factors, among them pests such as fall armyworm (Nonci & Muis, 2022) (FAW) *Spodoptera frugiperda* (J. E. Smith), confirmed in Mozambique in 2017 (Cugala *et al.,* 2017). Additional reports by FAO (2018) indicates high FAW prevalence in northern and central regions of Mozambique.

FAW larvae affect over 350 plants (Montezano *et al.,* 2018), among them, maize (*Zea mays* L.), is preferred causing up to 88% yield losses depending on environmental conditions (Day *et al.,* 2017; Prasanna *et al.,* 2018). Fall armyworm has much affinity in maize in all phenological stages, however, there is a marked preference of the larvae for younger plants (V1-V4) (FAO, 2020; Mungofa, 2016).

To date there are biological, cultural, chemical and mechanical management methods reported against FAW in the world to reduce losses (Harrison *et al.,*2019; Midega *et al.,* 2018).

Pyke *et al.* (1987) introduced the push–pull strategy as a behavioral pest management approach in cotton, where repellents were used to repel *Heliothis* moths away from the main crop while attractive trap crops such as maize and pigeon pea were used to lure them. The study showed that combining neem-based repellents (push) with trap crops (pull) reduced pest oviposition and infestation more effectively than using either method alone. This pioneering work established the foundation of modern push–pull technology.

In search and selection of suitable host for habitat, food and oviposition, Lepidoptera insects rely on chemical cues emitted by host plants (Carrasco *et al.*, 2015; Cunningham *et al.,* 2014; Tanga *et al.*, 2013). This strategy is based on plant and pest interactions, manipulating the distribution and abundance of a pest and/or beneficial insects through the use of behavior-modifying stimuli. Use of trap plants like napier (*Pennisetum purpureum* Schumach) or brachiaria (*Brachiaria cv mulato* II) to lure pests and repellent inter crops like desmodium (*Desmodium intortum*) to push them away has achieved significant success in control of fall armyworm in East Africa (Midega *et al.,* 2018; Pickett *et al.,* 2014; Hassanali *et al.,* 2008). It is based on FAW manipulation by volatile organic compounds. PPT relies on natural processes rather than synthetic chemicals (Midega *et al.,* 2018). As a part of IPM it aim to reduce FAW abundance below economic threshold level (Zairy *et al.,* 2023).

1.2 Problem Statement

Fall armyworm is not new to scientific community but a highly destructive pest accidentally introduced into Africa (Padhee *et al.,* 2019; Goergen *et al.*, 2016). It poses a severe threat to food security (CABI, 2018.) . It has been reported to damage 1.5 million hectares of maize in Africa (Padhee *et al.*, 2019). Further reports state it can cause 45-67% annual maize loss worth $ 6.2 billion per year (Timilsena *et al.*, 2022).

The use of synthetic insecticides remains the primary strategy in FAW management (Rajashekhar *et al.,* 2024; Caniço *et al.*, 2021). This approach while common option, is associated with externalities to human health, environmental degradation, pest resistance, harmful on natural enemies, uneconomical and low efficacy (Prasanna *et al.*, 2018; Midega *et al.,* 2018; Pickett *et al.*, 2014; Khan *et al.*, 2001; Clark *et al.*, 1995). This highlights the need for shift of interest to sustainable integrated pest management practices among which are behavioral manipulation methods (Szendrei & Rodriguez-Saona, 2010).

A promising nature based FAW management technique within the scope of IPM is Push Pull technology (PPT) which involve repelling (Push) FAW away from the economical crop using volatile stimuli and driving them towards attractive crop (pull) (Khan *et al.*, 2012; Cook *et al.*, 2007).

Despite substantial success of PPT its adoption still remains low and discontinuation is evident by 19% in Uganda and 40% in Kenya (Sileshi *et al.,* 2025; Waiswa *et al.,* 2025; Laetitia *et al.*, 2021). Latest reports among 18 countries (ICIPE, 2025) reports 350,298 households have adopted PPT since its deployment which is below one million household target. Many studies have used desmodium in PPT, besides being a potential source of quality livestock feed (Hassanali *et al.,* 2008), it is not an edible plant for humans and seed availability is also a challenge (Embid *et al.,* 2023). This is one of the bottlenecks hindering adoption and limited replication of PPT elsewhere. Other repellent intercrops, especially those with food and direct economic value, may represent complementary option for desmodium and remain largely underexplored as well diversify choice of repellent plants.

This propose necessity for exploiting novel plants to repel and expand the scope of PPT. Aromatic crops like basil (*Ocimum basilicum*), coriander (*Coriandrum sativum*) and mint (*Mentha × piperita*) are known for their volatile's insecticidal properties (Al-Khayri *et al.*, 2023; Renkema *et al.,* 2020; Siddhartha *et al.*, 2019; Kirtikar & Basu, 1975). The choice of this plants is based on reported bioactive repellent compounds (Beizhou *et al.,* 2012) and yet their role as intercrops in control of FAW in PPT remains insufficiently researched.

To successfully develop repellency study of biology, ecology and FAW interactions with proposed repellent are crucial in development of management approach (Montezano *et al.*, 2018). There is need of testing interaction with basil, coriander and mint as repellent candidates to the pest, to understand their suitability and how the proposed plants influence oviposition behavior, survival and development duration and olfactory interactions of the FAW (Wang *et al.*, 2020; Alkema *et al.,* 2019). Additionally, the ability of FAW to utilize basil, coriander and mint as host remain unknown.

This study aimed to evaluate these additional proposed companion crop employed against fall armyworm to fill the underexploited potential.

1.3 Objectives

1.3.1 General objective

- To assess FAW behavioral response into basil, coriander and mint as potential repellent plants for Push pull technology for fall armyworm management.

1.3.2 Specific objectives

i. To estimate number of FAW eggs and egg masses oviposited on basil, coriander and mint in laboratory and semi-field conditions;
ii. To estimate the development duration and survival rate of FAW on basil, coriander and mint;
iii. To determine the olfactory selection rate of female FAW when exposed to basil, coriander and mint in laboratory conditions.

1.4 Hypothesis

i. There is a difference in the estimated number of eggs and egg masses oviposited on basil, coriander and mint in the laboratory and semi- field conditions;
ii. There is a difference in development duration and survival rate of FAW when fed on basil, coriander and mint;
iii. The female FAW olfactory selection rate would be different in basil, coriander and mint.

2.0 LITERATURE REVIEW

2.1 Introduction and spread of fall armyworm in Africa

The fall armyworm is one of the most significant pests globally causing substantial yield losses in maize (Goergen *et al.,* 2016). FAW belong to the family Noctuidae within the order Lepidoptera (Pashley *et al.,* 1992). It was first documented as a destructive pest native to tropical and subtropical regions of America in 1797 (Abbas *et al.,* 2022; Barros, Torres, & Bueno, 2010; Barros, Torres, Ruberson, *et al.,* 2010; Fernandes *et al.,* 2019; Luginbill, 1928). FAW received much attention as a serious pest of grains when damage was observed in corn and rice in western Florida (Sparks, 1979).

In Africa maize strain haplotype fall armyworm was first reported initially from West Africa São Tomé, Nigeria, Benin and Togo (Abbas *et al.,* 2022; Goergen *et al.,* 2016), based on 2018 report showed that it spread in Africa across 28 sub Saharan countries (Sisay *et al.,* 2019). Later FAW spread from the Americas to more than 80 countries and more than 48 in Africa (FAO, 2019; EPPO, 2025) (Figure 1).

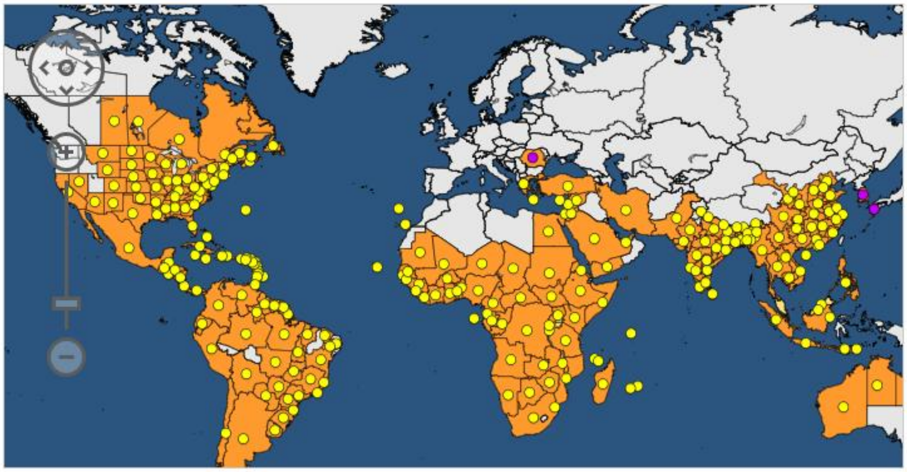

Figure 1. Current spread and distribution of Fall Armyworm worldwide.
Source: (EPP0, 2025).

Before becoming widely dispersed by the wind, fall armyworm found in the America may have invaded Africa as stowaways on commercial flights, either in cargo containers or airplane holds

(Cock *et al.,* 2017; Johnson, 1987). The likelihood that the characterized Florida strain of fall armyworm, which is limited to the eastern seaboard of the United States and the Caribbean islands, introduced the insect to Africa is strong (>90%) (Tepa-Yotto *et al.,* 2022; Johnson, 1987)

2.2 Fall armyworm damage and economic significance

Based on surveys, the initial study of fall armyworm in Africa it was determined that, if uncontrolled, FAW may reduce maize yields by 8.3 to 20.6 million tons annually, or 21–53% of production, 2.5-6.2 billion USD and affect 40.8 to 101 million people (Day *et al.,* 2017). According to farmers' estimates, a study reported that FAW infestation rates were 47% and yield of 1381 kg/ha in Kenya and 32% and yield of 934 kg/ha in Ethiopia (Kumela *et al.,* 2019). A case study by Baudron *et al.,* (2019) in Zimbabwe, the FAW accounted losses of 11.6% in 2018. In India it is reported to affect 170,000 hectares (Sangomla & Kukreti, 2019).

According to a study by De Groote *et al.* (2020) in Kenya, during the 2017 long rainy season, losses in the high-potential areas resulted in an estimated overall loss of 34%. The low and medium potential production areas also suffered the greatest losses, with total losses exceeding 50%. The yield lost to FAW was reported to be worth US$300 million annually, with epidemic years reporting yield losses of at least USD 500 million (Day *et al.,* 2017).

FAO (2018) reported in Mozambique, an estimated 49,000 tons of maize were believed to have been lost as a direct result of the FAW attack a year after its discovery. Additionally, Mozambique yield and area harvested data from year 2017-2023 shows substantial fluctuation in corn yield production (FAOSTAT, 2024) (Figure 2).

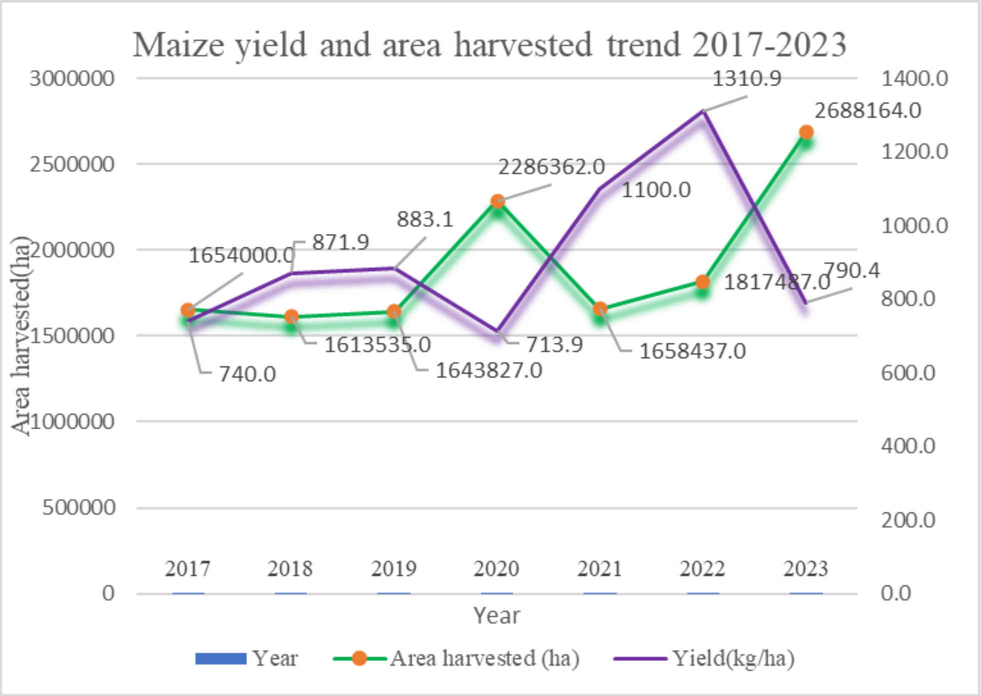

Figure 2. Maize Yield (kg/ha) and Area harvested variation over the last 7 years from year 2016 to 2023

(FAO, 2024).

The latest 39.74% decline in yield despite substantial 47.9% increase in area harvested from year 2022 to 2023 is represents yield reduction but negative economic implication in increased production cost and low farmers income and warrant further exploration.

2.3 Life cycle of fall armyworm

Fall armyworm has four life stages egg, six larval instars, pupae and adults (Sharma *et al.*, 2022). Navasero & Navasero (2020) reveals eggs to be the first life stage which is characterized to be domed and dorso-ventrally flattened. The egg is white to yellow in color and is laid mass or cluster, and in many layers, stacked on top of each other. Eggs that are about to hatch turn dark or black. They are laid underneath the leaves and a female can lay up to 1000 eggs (Overton *et al.*, 2021). They have incubation of 2-4 days in 21^0C-27^0C (FAO, 2020; Sparks, 1979). The eggs measure 0.4 mm in diameter and 0.3 mm in length (Prasanna *et al.*, 2018).

According to Kasige *et al.* (2022) and Prasanna *et al.* (2018), the larvae are reported to have six instars which are characterized by distinct body sizes and have a common white inverted “Y” mark (Figure 3).

Figure 3. First to sixth larvae instars of FAW: (a) first instar, (b) second instar, (c) third instar, (d) fourth instar (e) fifth instar and (f) sixth instar.
Source: Kasige *et al.* (2022).

The head capsule of instar one to instar six varies, respectively, between 0.35-0.39 millimeter (mm), 0.45-0.90mm and 1.0-1.3mm, 1.5-2.0mm,1.8-2.4mm and 2.6-3.1mm while the length varies from 0.9-1.8mm, 2.0-4.3mm, 5.1-7.8mm, 9.0-15.7mm,17.1-24.00mm and 23.5-36 mm. (Kasige *et al.,* 2022). The first and second is green, third and sixth is brown and has four squared spots (Abrahams *et al.*, 2017). The duration of the larvae development is 14 to 22 days (Sanjeewa *et al.,* 2021; FAO, 2020). The larvae are the main causes of damage especially during the third and fourth instar through extensive feeding corn whorl, stalk, and ear (Hruska, 2019).

The pupae is the third stage of fall armyworm development stage (CABI 2023) reports development of pupae or pupation to occur in the soil 2cm to 8cm enclosed in a woven silk, this takes 8-30 days (FAO, 2020)They are red-brown color and elliptical in shape (Abrahams *et al.*, 2017). The pupae measures 15mm to 30mm in length and diameter respectively. The male and female pupa have distinct characteristic where by male pupa have a shorter distance between the genital and the anus slit while female have longer distance (Navasero & Navasero, 2020) (Figure 4).

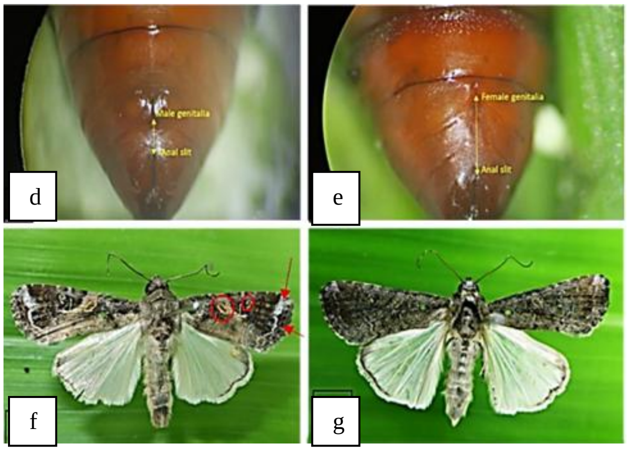

Figure 4. FAW male and female pupa (d, e) and male and female (f, g) adult.

Source: Navasero & Navasero (2020).

The adult moth is the last stage of fall armyworm development and lives between 10- 21 days, spots of light brown and grey tone are visible on the male moth’s forewings while female is reported to have light-colored forewings. The life cycle takes 30 days to complete in the summer, 60 days in the spring and fall, and 80–90 days to complete in the winter (Akeme *et al.*, 2021) moths are nocturnal and multivoltine, complete generations ranging from two to eleven in the Americas (CABI, 2023).

2.4 Host plant selection and oviposition behavior of FAW

Insect-plant interactions is common ecological phenomena that influence survival and development of insects particularly polyphagous insects (Awmack & Leather, 2002). Adult insects are responsible in locating suitable ecological settings for oviposition, food and habitat (Cunningham *et al.*,2014.). Therefore, the selection of oviposition sites and host selection of Lepidoptera insect is paramount to maximize survival and continuity of the progeny.

Renwick & Chew (1994) describes Lepidoptera oviposition and host selection is guided by a series of sensory mediated activities. This includes searching, orientation, encounter, landing, contact evaluation and acceptance or rejection of the host guided by sensory and visual cues Renwick, (1989). This stimuli's prompt receptors to produce sensory signals causing adaptive responses (Heard, 1999). Additionally, Carrasco *et al.* (2015) states that host selection is achieved in two stages which are selection and location. In location selection Carrasco *et al.* (2015) agrees with Renwick & Chew (1994) in utility of sensory cues, while selection involves physical interaction with the host physically leading to host acceptance or rejection. This host selection and oviposition behavior is consistent with preference–performance hypothesis (PPH) or optimal oviposition theory (Gripenberg *et al.,* 2010).

Despite acceptance of the PPH (Heisswolf *et al.,* 2005; Mayhew, 2001; Thompson & Pellmyr, 1991; Craig *et al.,* 1989) other studies demonstrated weak association between the adult choice and sibling performance and adults making poor and inconsistent choices (Scheirs *et al.,* 2004; Rausher, 1979). The "bad motherhood" involves poor host selection in oviposition by adults is resulted by several factors like priority of adult nutritional needs, presence of predators which can limit survival of the offsprings and polyphagous insects are well known to be affected when subjected to an array of chemical cues (Bernays, 2001; Scheirs *et al.,* 2000; Denno *et al.,* 1990).

Plants are also adapted to deploy defense mechanisms which limit oviposition and host selection (Dudareva *et al.,* 2006). The defense mechanisms may work also through volatile organic compounds which can repel insects or even deter oviposition (Finch *et al.,* 2012). Therefore, through leveraging plant defense mechanisms and exploiting the chemical ecology enhances integrated pest management.

FAW is a Lepidoptera polyphagous pest which also rely on chemical and visual cues in host selection as well as oviposition (Liu *et al.,* 2024). The utility of olfactory cues in repellency of FAW or and attraction of natural enemies has been utilized in FAW management (Sobhy *et al.,* 2023). Specifically, β-caryophyllene indole linalool, and E)-β-farnesene are main volatile organic compound (VOC) that have been leveraged in oviposition deterrence. Additionally, β-caryophyllene and linalool have been reported to repel FAW and also attract natural enemies (Wang *et al.,* 2025).

2.5 Methods of fall armyworm control

2.5.1 Cultural methods

Gebreziher (2020) states that a sustainable management approach to effectively control fall armyworm starts with preventive measures against the invasive pest. Recommended measures like early planting use of high-quality certified seeds crop rotation, intercropping, weeding, field sanitation, and improving of soil fertility to reduce the damage caused by fall armyworm (Nget *et al.,* 2024; Baudron *et al.,* 2019; Firake *et al.*, 2019; Altieri, 1980).

2.5.2 Regular monitoring

Occasional scouting after planting is a effective monitoring tool on fall armyworm. When deciding the remedial control measures, scouting of maize is crucial to determine the extent of FAW infestation (McGrath *et al.,* 2018).

Firake *et al.* (2019) further propose "W" scouting model at 3-4 weeks after emergence. If 5% of the maize plants are with egg masses, then management practices are recommended. If 10% of the plants shows signs of damage chemical control should be applied. Although, at silking and post silking stage insecticide application is not recommended but if 10% of the ear are damaged its prudent to apply judiciously.

This practice makes it possible to accurately diagnose the agro-ecosystem in terms of the quantity and distribution of pests, the extent of harm, and the type of damage produced.

2.5.3 Genetically modified crops

International Service for the Acquisition of Agri-biotech Applications (ISAAA; 2017) suggests that in developed nations (USA, Brazil, and Argentina), FAW is frequently managed in the by the use of genetically modified maize, which contains genes that express toxins that are fatal to FAW.

Bacillus thuringiensis Berliner (Bt) has also been exploited as a transgenic management tactic against FAW (Guo *et al.*, 2021; Okumura *et al.*, 2013). However, there is less adoption of the Bt especially in Sub Saharan Africa (Botha *et al.*, 2019).

2.5.4 Biological control method

To manage fall armyworm in maize farms *Telenomus remus* Nixon (Hymenoptera: Scelionidae) has been significant in parasitism for FAW biological control which is already present in Africa FAW eggs (Colmenarez *et al.,* 2022). Ferrer (2001) reports 50% to 80% decrease in pesticide application as a result of use of *T. remus*.

Sisay *et al.* (2018) study on FAW parasitism discovered that *Cotesia icipe* Fernandez-Triana & Fiaboe (Hymenoptera: Braconidae), and *Coccygidium luteum* Brullé (Hymenoptera: Braconidae) were the predominant larval parasitoid in Ethiopia, with parasitism ranging from 33.8% to 45.3%, whereas the tachinid fly, *Palexorista zonata*, was the main parasitoid in Kenya, with parasitism of 12.5%.

In the Americas, particularly in Brazil, *Trichogramma pretaliosum* have also been tested as part of biological control against FAW achieving egg mass parasitism of up to 79% (De Lourdes Corrêa Figueiredo *et al.*, 2015). However, Beserra & Parra (2005) cites because females can only access the top layer of the egg masses. It is difficult to oviposit through the hairs and scales when this layer is too thick, FAW is typically thought to be difficult to manage using *Trichogramma spp* alone.

In a study by Akutse *et al.* (2019) evaluated the effectiveness of entomopathogenic fungi on eggs and second-instar larvae, reporting that the Beauveria treatment affected 30% of second-instar larvae, and Metarhizium caused 87% egg mortality and 96.5% mortality of neonatal larvae. Entomopathogenic nematodes also has been potential to parasitize FAW.

2.5.5 Use of chemical control

This entirely involves the use of synthetic pesticides to spray against fall armyworm (Chhetri & Acharya, 2019). Emamectin benzoate, Cypermethrin; Spinosad, Indoxacarb, Chlorantraniliprole , Infenuron, Cyantraniprol, Chlorfenapyr, Malathion, Flubendiamide, Deltamethrin, Fipronil and Carbofuran are among of the potential chemicals reported to manage FAW (Zairy *et al.*, 2023). In Mozambique Abamectin 18 gr/l, *Bacillus Thuringiensis* (Bt), *Beauveria bassiana*, Beta-Cyfluthrin, Flubendiamide 480 gr/l, Thiamethoxan 250 g/kg Lufenuron EC are among insecticide that are registered and recommended. Akeme *et al.* (2021) categorize this method as the last control strategy eyeing from integrated pest management perspective.

Hurska *et al*. (2019) recommend chemical use extremely severe, if 75% of the plants have whorl feeding damage. Though it's still a required alternative in cases of severe infestations, its status as a last resort indicates a desire for more environmentally friendly approaches(Pretty, 2012).

2.5.6 Use of botanical plant extracts

Insecticides made from plants extracts have been widely marketed as appealing substitutes for synthetic chemical insecticides in pest management scenarios (Khater, 2012). Botanical pesticides have been used as alternatives and are safer, less expensive, and more environmentally friendly than chemical pesticides (Arya & Tiwari, 2013).

Ginger extract have demonstrated insecticidal properties, a study done by Liu *et al.* (2022) reports mortality on sorghum aphids where at 12 and 24 hours after treatment caused 39.15% and 66.14% respectively. A study conducted by Maredia *et al.*, (1992) found that neem oil and neem seed and leaf powder had a 70% mortality of fall armyworm larvae at concentrations of 0.13% and 0.25% respectively. Yield on maize plots treated with China berry and garlic extracts are reported to be 4.3 tonnes and 4.9 tonnes respectively compared to untreated plot (Siazemo, 2020).

Phambala *et al.* (2020) contact toxicity testing revealed that *Nicotiana tabacum* and *Lippia javanica* had the highest larval mortality rates each at 66%. Salinas-Sánchez *et al.* (2012) also reported that *Tagetes erecta* extracts in hexane, acetone, and ethanol killed 48%, 60%, and 72% of FAW larvae, respectively.

Stevenson *et al.* (2017) reviewed the state of botanically active substance research and use in Africa, they discovered numerous promise for their application in the continent's pest control efforts. Although the scalability and consistency of botanical extracts in field circumstances may differ, they interact well with frameworks for sustainable pest management.

2.5.7 Use of plant repellant

Companion planting and intercropping generate biological interaction, it can greatly lessen insect and disease pressures (Brennan, 2016; Tukahirwa & Coaker, 1982). Plants interact with foraging lepidopterans through semiochemicals (Landolt, 1993). Visual and olfactory cues enable host preference, host location, non-host and determine oviposition preferences (Thompson & Pellmyr, 1991).

Chemical cues result in attraction of natural enemies to specific plants (Bernasconi *et al.,* 1998). In comparison to solitary cropping, intercropping offers a significant yield benefit under conservation agriculture (Awal *et al.,* 2006; Vandermeer, 1989; Ofori & Stern, 1987). Certain intercrops emit VOCs that have the ability to draw in and repel insect pests (Miller & Cowles, 1990). Diversity of chemical compounds affect olfactory reception by insects reducing or increasing attractiveness capabilities (Stamps *et al.,* 2005).

In maize production a variety of known repellent crops have been well documented and proven effective in management of FAW. Use of greenleaf desmodium (*Desmodium intortum*) and silverleaf desmodium (*Desmodium uncinatum*) as a repellent plant has been widely studied and deemed effective (Midega *et al.,* 2018, 2015; Cook *et al.,* 2007; Khan *et al.,* 2000). Additionally, to the diversify push pull technology, laboratory studies demostrated oviposition deterrence by the female FAW and further field trials demostrated to be effective (Can *et al.,* 2024). Faba bean (*Vicia faba*) was also reported to be unsuitable for FAW growth and development and also had repellency on female FAW (Can *et al.,* 2024; Liu *et al.,* 2022). Mollases grass (*Melinis minutiflora*) was also evaluated and proposed as a potential repellent plant due to reduced attractiveness to FAW and reduced damage on maize (Can *et al.,* 2024). Additionally, molasses grass was part of the original push component established in management of stemborer (Khan *et al.,* 1997). (Guera *et al.,* 2021) also presents *Tagetes erecta* as a potential repellent to FAW and field trials revealed less infestation when used as an intercrop.

Basil (*Ocimum basilicum*), coriander (*Coriandrum sativum*) and mint (*Mentha × piperita*) were chosen for this study based on reported bioactive compounds relevant to pest management, specifically deterrence effect on oviposition, host finding and also insecticidal agent (Gu *et al.,* 2025; Nouioura *et al.,* 2024; Kačániová *et al.,* 2022; Brahmi *et al.,* 2017). Basil, coriander and mint secondary metabolites have been exploited due to their long term insecticidal, repellency and behavior manipulation characteristics against economically important pests such as *Tuta absoluta, Helicoverpa armigera, Amrasca biguttula, Aphis fabae, Batrocera dorsalis* (Gunaeni *et al.,* 2024; Boulamtat *et al.,* 2020; Yarou *et al.,* 2018; Sujayanand *et al.,* 2016). Their chemical profiles have been documented to have been modeled and validated consolidating suitable knowledge which can be applied in volatile mediated pest control strategies. Beyond their insecticidal efficacy, practical availability and adaptation has been reported by Sitoe & Van Wyk (2024), the crops have commercial and economical value to the farmers as main spices and further processing as culinary and medicinal uses, they can be cultivated as primary crop for commercial markets and relatively easy to cultivate making them feasible to implement. Below, a pictorial presentation of each plant in figure 5

Figure 5. Picture of basil (A), coriander (B) and mint (C).

2.5.7.1 Coriander (*Coriandrum sativum*)

Coriander (*Coriandrum sativum*) belonging to family Apiaceae have multiple biological properties among them is insecticidal properties (Al-Khayri *et al.*, 2023). Terpenoids is the most dominant volatile organic compound found in *C. sativum*. It exists as monoterpenes, sesquiterpenes and diterpenes (Knudsen *et al.*, 2006).

The primary functions of terpenoids are repelling of herbivorous and plant defense. Linalool is a terpenoid compound in the monoterpene class (YanHua *et al.*, 2004; Zheng *et al.*, 2010). It has demonstrated as a significant repulsion property to many insects including mosquitoes (*Aedes albopictus*, *Aedes aegypti*) (Dekker *et al.*, 2011; Kim *et al.*, 2020), *Anopheles gambiae* (Huff & Pitts, 2019), *Tribolium confusum* and *Tribolium castaneum* (Kheloul *et al.*, 2019; Pajaro-Castro *et al.*, 2017) rice weevils and black bean aphids (Fouad *et al.*, 2021; Webster *et al.*, 2008).

Other volatile organic compounds found in *C. sativum* include camphor, borneol, cineole, coriandrol, cymene, dipentene, geraniol, phellandrene terpineol, and terpinolene are the principal components which inhibit acetylcholinesterase, causes paralysis and death of insects (Al-Khayri *et al.*, 2023; Chahal *et al.*, 2017; Sahib *et al.*, 2013; Zheng *et al.*, 2010; Diederichsen & Hammer, 2003).

C. sativum compounds can mask attractive odors, making it difficult for insects to locate their targets. Additionally, some components can be toxic to certain insects, affecting their nervous systems and deterring them from feeding or breeding. Gunaeni *et al.* (2024) study shows significant reduction of *Bactrocera dorsalis* and *Helicoverpa armigera* on chilli intercropped with *C. sativum*.

2.5.7.2 Mint (*Mentha × piperita*)

Brickell & Cathey (2004) document genus Mentha (mint), one of the vital components of the Lamiaceae family, which has about 19 species including *Mentha × piperita* , *Mentha arvensis, Mentha aquatica, Mentha spicata, Mentha longifolia*, and *Mentha suaveolens* and 13 natural hybrids. They are fast growing and generally tolerate a wide range of agro-climatic conditions with distribution across Europe, Africa, Asia, Australia, and North America and highly produced (Dorman *et al.*, 2003; Tucker & Naczi, 2007).

A variety of substances have been found in species of the genus Mentha, including aglycon, glycoside or acylated flavonoids, cinnamic acids and steroidal glycosides (Afif, 2010). Pinene, Linalool, Mycrene, Limonene, Ocimene, Cineole, Menthone, Isomenthone, Terpinen-4-ol and Carvone are reported (Shahi *et al.*, 1999; Taneja & Chandra, 2012). These volatile combinations of various organic compounds, the majority are aromatic and have a unique odor. To reduce environmental impact from pesticides, mint has been explored as a bio pesticide. Santoro *et al.*, (2011) describe mint as an aromatic crop that produces large amounts of volatile organic compounds (VOCs), such as menthol suitable for use as essential oils and applied as bio pesticides (Catani *et al.,* 2022). The plant essential oils interfere with basic metabolic, biochemical, physiological and behavioral functions of insects. According to Plimmer (1982) repellent properties of essential oils and extracts from genus Mentha are well documented, however, most of these studies are concentrated on pests belonging to coleoptera and Diptera species.

Effect on okra intercropped with mint is reported to have significant effect on the abundance of *Amrasca biguttula* biguttula (leaf hoppers) (Sujayanand *et al.,* 2016).

Investigations demonstrated the potential of mentha oils as potent natural insecticides by using techniques like contact toxicity testing, bioassays in acetone solutions, and dipping larvae in oil.

2.5.7.3 Basil (*Ocimum basilicum*)

Lamiaceae family is among the species with potential insecticidal properties from above 150 species from genus Ocimum. Basil (*Ocimum basilicum*) is a herb known for its aromatic leaves and insecticidal properties (Ciriello *et al.,* 2022). Linalool, eugenol, methyl-eugenol, and 1,8-cineole, make up the functional compounds of its versatility (Comite *et al.,* 2021; Filip *et al.,* 2016; Pandey *et al.,* 2016).

Basil has been explored as an essential oil extract in fall armyworm by Siddhartha *et al.* (2019). At 1% concertation extract caused mean mortality of 36.58, 46.91 and 63.63 after 12, 24 and 36 hours respectively. Similarly, Huong *et al.* (2020) reports decrease in the abundance of Flea beetle (*Phyllotret alastriolata*), aphid (*Brevicoryne brassica*) Diamondback Moth (*Plutella xylostella*) Beet (*Spodoptera exigua*).

2.8 Push pull technology

Push pull became prominent in Africa after International Centre of Insect Physiology and Ecology (ICIPE) and partners developed the push-pull technology, a companion cropping system, which is one of the most effective ways to manage pests (Cook *et al.,* 2007).

In order to achieve integrated pest and weed management in farming systems, the “push–pull strategy” is based on a unique cropping system approach that manipulates the behavior of insect pests and their natural foes (Hassanali *et al.,* 2008).

Additionally, push-pull farming is cited specifically in fall armyworm as an intensifying strategy that uses a repellent intercrop (push), commonly *Desmodium spp*., to drive insect pests away from the main crop while attracting them with trap plants (pull), such as Brachiaria grass or Napier grass (*Penniselum purpureum*) (Mutyambai *et al.,* 2023). Push-pull is a useful intercropping technique intended not only to control fall armyworm but also to improve soil fertility and conserve biodiversity while managing weeds and major insect pests (Cook *et al.*, 2007).

3.0 MATERIALS AND METHODS

3.1 Study site description

The study was conducted in Entomology Laboratory of the Faculty of Agronomy and Forestry Engineering of Eduardo Mondlane University. The semi field bioassay was performed in field trial at the same faculty.

3.2 Experimental plant treatments and propagation

Maize was the positive control while the treatment plants examined as potential repellants were basil (*Ocimum basilicum*), coriander (*Coriandrum sativum*) and mint (*Mentha × piperita*). The plants were raised in black polyethene bags of 15cm of diameter and 20cm of height filled with substrate. Basil and mint were transplanted as seedlings while coriander and maize were planted as seeds and irrigated adequately. The seedlings were put in trial 1 month after transplanting and sowing for basil, mint and coriander due to slow growth rate while maize was 2 weeks old (Figure 6).

Figure 6. Experimental plant materials used in the study: (A) potted nursery medium in polythene, (B) basil plant, (C) mint plant, (D) coriander plant and (E) maize plant.

3.3 Fall armyworm colony

The fall armyworm larvae were initially collected from Boane- Maputo province in unsprayed field using plastic jars containing tender maize plants and taken to the Faculty of Agronomy and Forestry Engineering entomology laboratory for rearing. Each larva was put in a plastic flask of 25ml and capped under 27.8^{0}C-28.9^{0}C and 65-70 % relative humidity was measured using digital thermohygrometer. The FAW larvae were fed on fresh cut maize leaves until pupation. The pupae were transferred to oviposition cage until moth emergence (Perkins, 1979).

The moths were fed with honey 10% (w/v) solution soaked in a wad of cotton wool in petril dish 8cm diameter by 1.5 cm. Parchment papers were provided and hanged in the cage as oviposition substrate (Guo *et al.*, 2021). The eggs were collected and placed in a container with artificial diet for rearing again to get subsequent generations. The above methodology is represented in Figure 7 below.

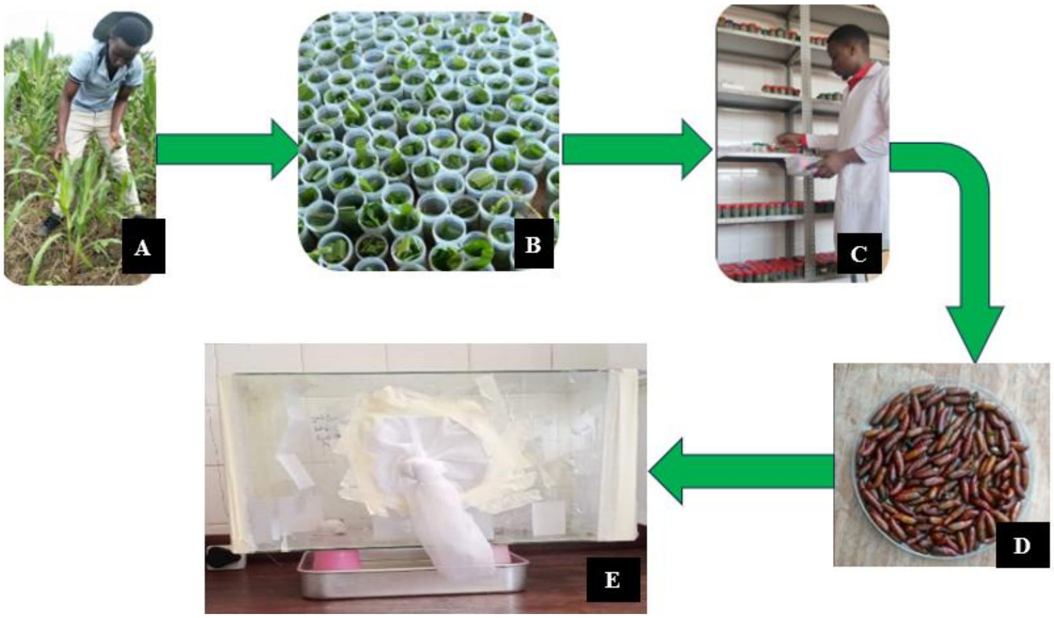

Figure 7. Collection and rearing of *S. frugiperda* in the laboratory: (A) collection of FAW larvae from unsprayed fields, (B) feeding of FAW with maize, (C) plastic flasks containing *S. frugiperda* in rack, (D) *S. frugiperda* pupa emerged and (E) adult oviposition cage.

3.4 Estimation of number of FAW eggs and egg masses in laboratory and semi- field conditions

The oviposition preference of the FAW was performed according to modified methodology by Guera *et al.,* (2020) and Can *et al.,* (2024) with fourth generation colony originally established in the laboratory. This was performed in: no choice and two choice experiments both conducted in a transparent plexiglass oviposition cage with sides of fine transparent net (in laboratory). The two choice experiment was additionally performed under semi field. The no choice and two choice experiments were arranged in completely randomized design with 10 replications. The semi- field experiments were done in randomized complete block design with 4 replications. Treatments included; basil, coriander, mint and maize.

3.4.1 No choice experiment in laboratory conditions

The no choice experiments were conducted following methodology by Can *et al.,* (2024) by subjecting adult FAW to one treatment (a treatment consisted of a plant species being evaluated) at time in each cage. For each replicate one month-old potted plant with 4-6 leaves of maize, basil, coriander and mint was introduced into the center of the transparent plexiglass cube glass measuring 20L×20W×40H centimeters (Figure 8).

Figure 8. FAW ovipostion in no choice test of basil, coriander and mint, respectively (A, B, C).

Then, two pairs of adults (2 females and 2 males) were introduced which formed one experimental unit. Four days old adults were allowed to mate before being used in the experiment. A cotton wool dipped in 10% (w/v) honey solution was presented as food supplement. The experiment was done under natural photoperiod. The aim of the no-choice bioassays was to examine the oviposition behavior of adult FAW under conditions in which they are limited to a single plant species. A total of 20 pairs of adults (40 adults) were used and 10 plants per treatment in the no choice experiment as summarized in table 1 below.

Table 1. Treatments in no choice experiment for *S. frugiperda* oviposition

Treatment code	**Treatment plant species**	**Number of replicates**	**Insects per replicate**
T1	Basil	10	2 males and 2 females
T2	Coriander	10	2 males and 2 females
T3	Mint	10	2 males and 2 females
T4	Maize	10	2 males and 2 females

The females were allowed to oviposit for 48hours (Zhang *et al.*, 2025). To avoid position bias, cages were repositioned after 24 hours. Number of egg masses were collected on the plants as well as on the walls of the cages. The cage walls were considered as an indication of plant avoidance in guidance of previous studies by Wang *et al.* (2023). The number of eggs oviposited were estimated using Leica EZ4 HD stereo microscope (Leica Microsystems, Wetzlar, Germany).

3.4.2 Two choice experiment in laboratory conditions

The two choice experiments were conducted by exposing one of the test plants (either basil, coriander and mint) and maize simultaneously positioned at opposite ends and adult FAW released at the center of the cage measuring 90L×40W×40H centimeters. A thirty days' plants of basil, coriander or mint were selected each combined with two weeks old maize and introduced into the cage (Figure 9).

Figure 9. FAW ovipostion in two choice test (D, E, F) in basil, coriander and mint combined with maize, respectively.

Afterwards four mated females and four males were introduced which formed one experimental unit. The females were allowed to oviposit for 48hours (Zhang *et al.*, 2025) under natural photoperiod. The two-choice bioassays were performed to gain further insights into the oviposition behavior of adult FAW when presented with two different plants while the preferred one is also one of choices. Forty (40) pairs of adults were used and twenty (20) pairs of plants per treatment in the two choice experiment as summarized in table 3 below.

Table 2. Treatments in Two choice experiment of *S. frugiperda*

Treatment code	**Treatment plant species**	**Number of replicates**	**Insects per replicate**
TC1	Basil + Maize	10	4 males and 4 females
TC2	Coriander + Maize	10	4 males and 4 females
TC3	Mint + Maize	10	4 males and 4 females

The plants were rotated and also cages repositioned to avoid position bias. Number of egg masses were collected on the plants as well as on the walls of the cages. The number of eggs oviposited were estimated using Leica EZ4 HD stereo microscope (Leica Microsystems, Wetzlar, Germany).

3.4.3 Two choice experiment in semi field conditions

The study also adopted semi field conditions experiments. The bioassays were done in a round net house of 2.8 meters of diameter and 2 meters' height allowing free host searching and expanded insect's movement Each net house was 1 meter away from the other.

This bioassay was done using modified methodology by Savadatti *et al.* (2024). Two weeks' maize plant and one-month old test plants potted in polythene bags were put in a 20cm-by-20cm plant to plant spacing and 75 cm row to row as shown in Figure 10 below.

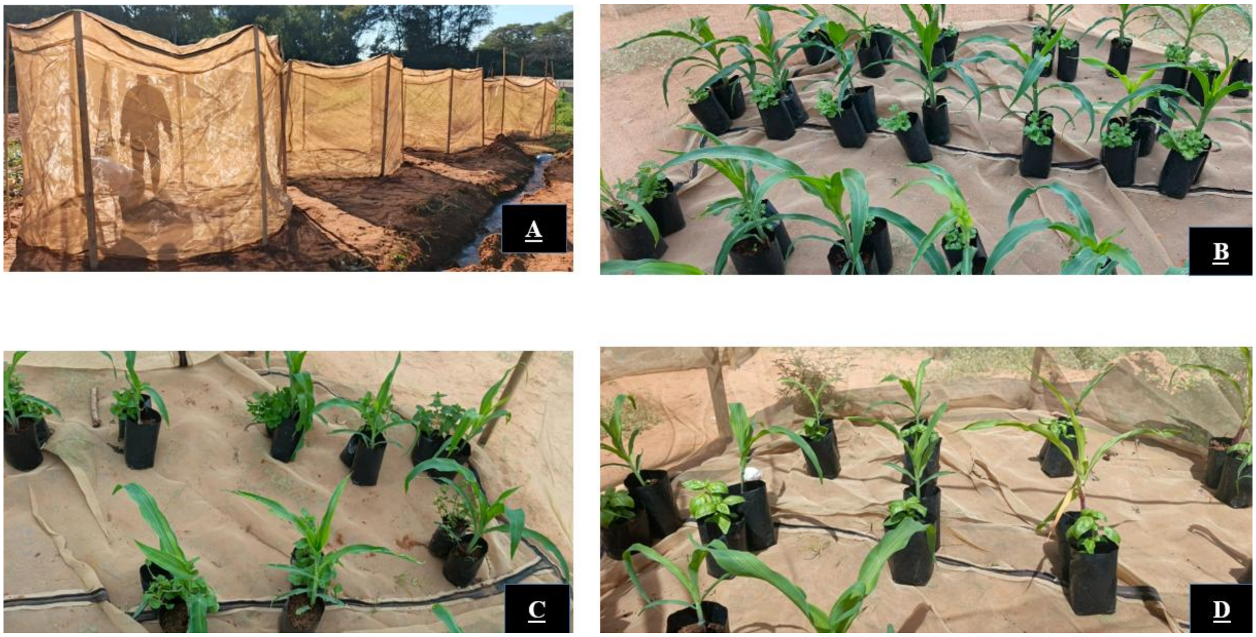

Figure 10. Set up of semi-field experiments: (A) rounded net cages, (B) coriander+maize trial, (C) mint+maize trial and (D) basil + maize trial.

Each net house composed 17 pairs of plants. Four days old 10 pairs of adults (10 males and 10 females) were released into the net houses. A cotton wool soaked in 10%(w/v) honey solution was put as food supplement. Collection of eggs happened after 48 hours (Zhang *et al.*, 2025) and recorded in maize, potential repellent plant, and the net walls in each assay. This was replicated 4 times in a randomized complete block design and each block had a potted maize companioned with test plant (maize+basil, maize+coriander and maize+mint) independently giving a total of 12 experimental units. A total number of 68 pairs of plants and 40 pairs of adults were used in each treatment.

3.5 Estimation of development duration and survival rate of FAW

Further screening of the treatments was done by estimating stage specific development duration and survival rate of FAW in two generations following methodology by Wang *et al*. (2025). Eggs laid by laboratory fourth generation colony were used to raise first experimental generation (F_1).

An estimated 200 eggs laid within 24 hours were collected from the laboratory fourth generation colony and incubated with the test plant and maize as a control in a dish of 8cm diameter by 2.5 cm height. After hatching the larvae were randomly selected and transferred to plastic flasks and feed with fresh leaves of each test plant. The leaves were changed after every 24 hours allowing sufficiency and freshness. The larvae instars identification were based on morphological observation as described by Kasige *et al.* (2022).

The incubation durations of the eggs, developmental periods and survival rates across all life stages (larvae, pupa and adult) were recorded daily. The weights of the pupas were also recorded individually after pupation. During the pupa stage the pupa sex was identified based on morphological features described by Navasero & Navasero (2020). Resulting pupa from the same treatment plants were paired randomly and kept in 1-liter plastic cup with parchment papers for oviposition after adult eclosion.

The adults were fed with 10% (w/v) solution of honey soaked in cotton balls. Adult reproductive variables determined included, adult longevity, fecundity measured by total number of eggs laid per female in life time, pre-oviposition period which is defined as duration (days) from adult enclosion to the laying of the first eggs. Egg laying period was also determined as duration in days from adult laying the first and last eggs.

The survival rates were determined based on the proportion of individual of FAW that developed successfully from one stage to the next stage until adults and calculated as follows.

$$\text{Survival rate} = \frac{\text{Number of FAW alive at specific stage}}{\text{total number of FAW hatched}} \times 100 \qquad \text{(Equation 1)}$$

To raise second experimental generation (F_2), in each of the treatment concurrent emerging one pair of adults were randomly selected and placed in oviposition cage containing the corresponding specific treatment and left to oviposit for 24 hours.

This was done to test the acceptance of the successfully FAW (that is first experimental generation) adults raised using the treatment plants for oviposition and also suitability of the resulting eggs to complete another generation (second experimental generation). The eggs were collected and incubated with the specific treatment plant and after hatching 50 larvae replicates were transferred to plastic flasks following standard procedure by Tao *et al.* (2024) and same protocol repeated as first experimental generation. Experimental setup for FAW developmental duration and survival assessment is presented in Appendix 6.

3.6 Determination of the olfactory selection rate of female FAW exposed to the basil, coriander and mint

The behavior of FAW moths was assessed in a Y shaped tube olfactometer with modification done by Zhang *et al.,* (2009) the olfactometer composed of 1 main stem of 20cm and two 10cm arms connected at 75 degrees from the main stem. The internal diameter was 2cm. Both arms were connected to 250 ml odor sources containers using silicon tubing. An air pump (for pumping, humidifying and purifying air) was also connected to the odor sources with an airflow of 400Ml min-1 (Tao *et al*. 2024) (Figure 11).

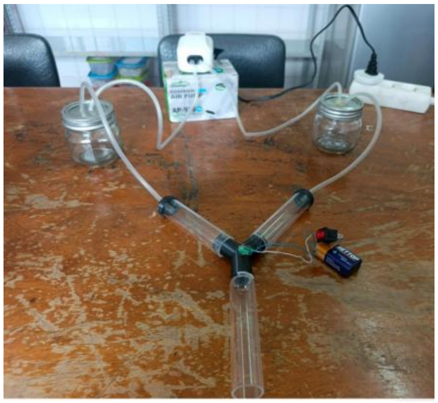

Figure 11. Assembled Y tube olfactometer with odors sources, air pump and tubes.

The sample test plants of equal mass were placed on the odor source bottles as leaves. In this bioassay, 4 days old female moths were used and had mated for 24 hours. Each moth was placed at the opening of the main stem. Choice was recorded positive if the insect moved along the stem and move in any of the arms within 5mins and settled for at least 30 seconds. If not, it was regarded invalid.

These bioassays were done in 3 scenarios. The first one involved basil, coriander and mint versus air independently, the second one involved test of maize versus basil, maize versus coriander and maize versus mint independently while the last scenario involved test plants combination with maize (maize+basil, maize+coriander and maize+mint) versus maize independently as summarized in Table 3.

Table 3. Experiment treatments in Y-olfactometer scenarios testing the olfactory behavior response of fall armyworm to maize, basil, coriander and mint.

Scenario	Treatment A versus Treatment B		Number of replicates
1	Maize	Air	10
1	Basil	Air	10
1	Coriander	Air	10
1	Mint	Air	10
2	Maize	Basil	10
2	Maize	Coriander	10
2	Maize	Mint	10
3	Maize + basil	Basil	10
3	Maize + coriander	Coriander	10
3	Maize + mint	Mint	10

Each trial was replicated 10 times and 100 female adults were used (Li *et al.*, 2025). The olfactometer was rotated after every 5 adults to avoid direction bias. Additionally, before testing the selected plants, clean air was first tested with empty odor sources first to avoid biasness. After every test the olfactometer was cleaned in alcohol and dried. The relative olfactory selection rate was calculated using the following equation 2.

$$\text{Olfactory selection rate} = \frac{\text{Number of FAW that selected the arm}}{\text{Total number of FAW tested}} * 100$$

(Equation 2)

3.7 Data analysis

To ascertain normality and homoscedasticity, prior tests were done using Shapiro-Wilk and Lavene’s tests. In no choice tests basil and maize number of egg were analyzed using unpaired t test, however basil and maize number of egg masses were analyzed using Mann-Whitney U test similar to coriander and mint number of egg masses as well as estimated number of eggs after violating normality and homoscedasticity assumptions despite successive transformations.

In the two choice laboratory assay basil and maize test and coriander and maize number of egg masses and mean number of eggs were analyzed using one-way ANOVA after square root transformation and Tukey's HSD test at 5% was used to separate the means. Mint and maize number of eggs were analyzed using one-way ANOVA and means separated using Tukey's HSD test at 5% however egg masses were analyzed using Kruskal and Willis test and means separated with Dunn Test multiple comparison with Bonferroni correction.

The semi field data on egg masses and estimated number of eggs on basil and maize and also maize and mint were analyzed using one-way ANOVA after square root transformation. While maize and coriander test were analyzed using one-way ANOVA and means separated using Tukey's HSD test at 5%.

Development duration estimates and reproductive parameter variables data was analyzed using Kruskal and Willis test and after assumptions failed even after transformation and means separated with Dunn Test multiple comparison with Bonferroni correction while survival rate was presented as percentages.

Chi square test analysis was used on the olfactory selection of FAW. All Statistical analysis were done using R software (version 4.5.2).

4.0 RESULTS

4.1 FAW oviposition in laboratory and semi- field conditions

4.1.1 Number of eggs and egg masses in no - choice bioassay

In maize experiment, the mean number of eggs varied significantly (*p*=0.0005) between the oviposition sites, with a higher mean number of eggs on maize in comparison to the walls. Similarly, the same was observed on the number of egg masses, with higher mean egg masses recorded on maize compared to the cage walls (Figure 12).

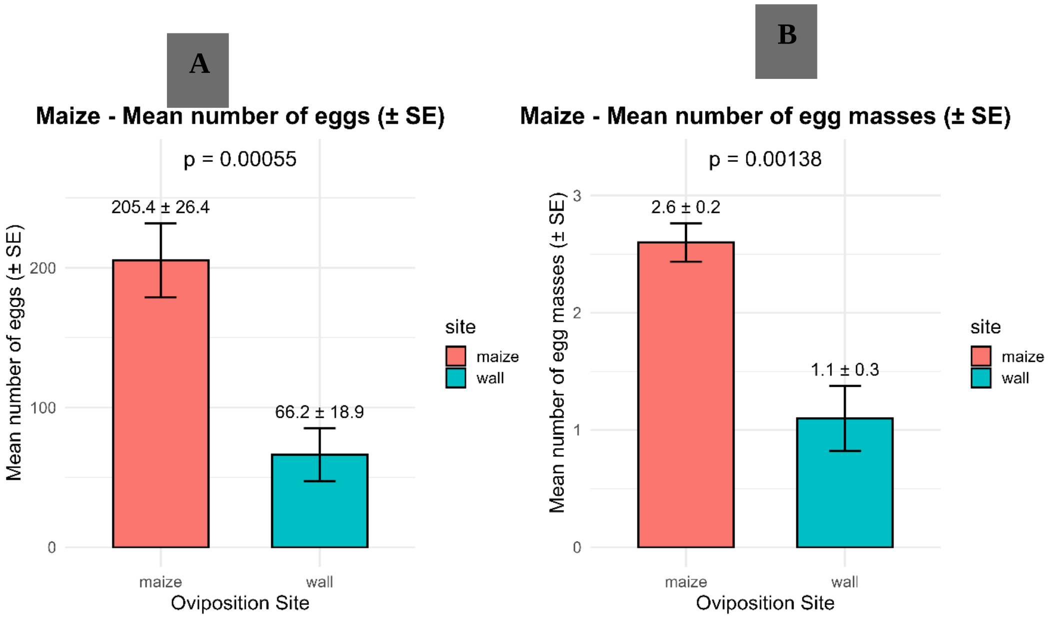

Figure 12. Graphs of mean number of eggs (A) and mean egg masses (B) ± SE laid by FAW in Maize in no choice experiment.

In basil bioassay, the fall armyworm oviposited on basil as well as on the inner walls of the cage, where basil tended to have more number of eggs as well as egg masses when compared to the walls, although no significant differences were observed between the two (basil and cage walls) (Figure 13A and 13B).

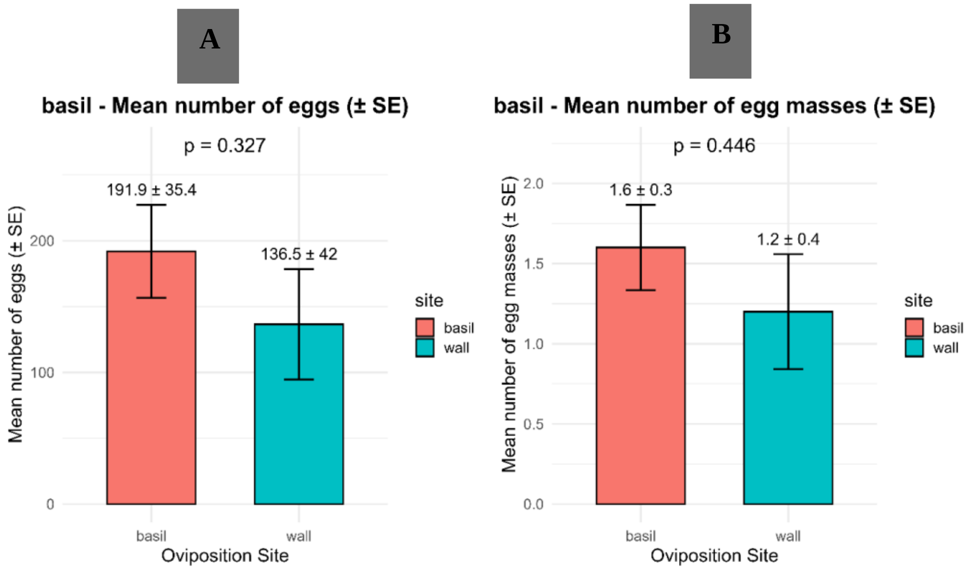

Figure 13**.** Graphs of mean number of eggs (A) and mean egg masses (B) ± SE laid by FAW in basil in no choice experiment.

In the coriander test, the opposite was observed, where the mean number of eggs as well as the egg masses on coriander tended to be lower when compared to the cage walls. However, the oviposition site had no significant effect on both variables (number of eggs $p = 0.137$; number of egg masses $p = 0.195$) (Figure 14A and 14B).

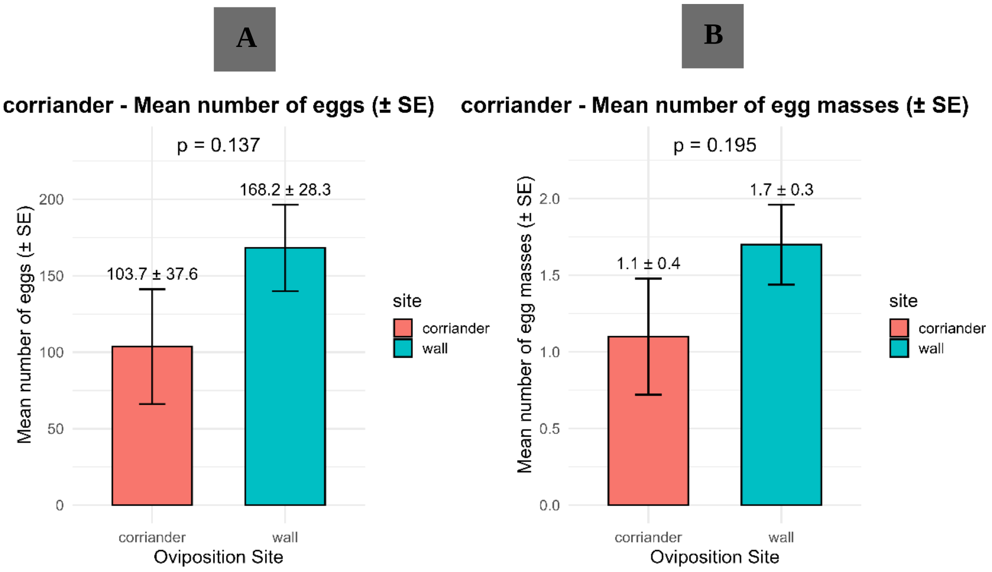

Figure 14. Graphs of mean number of eggs (A) and mean egg masses (B) ± SE laid by FAW in coriander in no choice.

In the mint bioassay, as observed in the coriander, the least mean number of eggs and egg masses was recorded on mint while the cage walls had highest. However, in contrast of coriander bioassay, in mint there was a significant effect of the treatment (plant or cage walls) in observed variables (*p* = 0.016 for mean number of eggs and *p* = 0.016 for the mean egg masses) (Figure 15A, 15B).

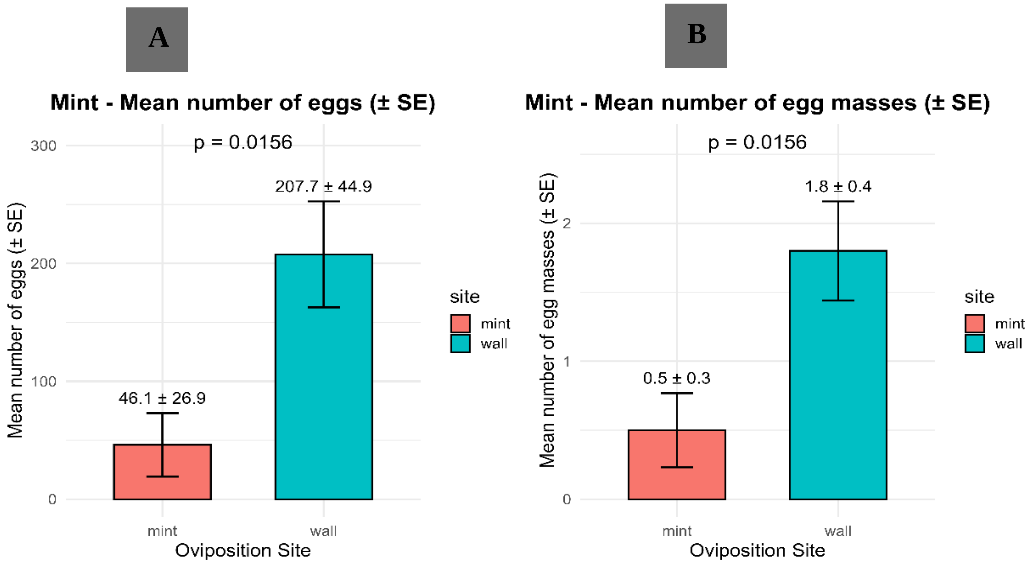

Figure 15. Graphs of mean number of eggs (A) and mean egg masses (B) SE laid by FAW in mint in no choice experiment.

4.1.2 Number of eggs and egg masses in the two- choice bioassays in laboratory

A) Basil and maize

The combination of basil and maize results revealed that the female FAW oviposited in all the three sites, showing a significant preference (*p* = 0.03) on maize with the highest mean number of eggs, which differed significantly from the means recorded on basil and cage walls. However, for the egg masses, no significant effect of the treatment was observed (*p* = 0.188) (Figure 16A and 16B).

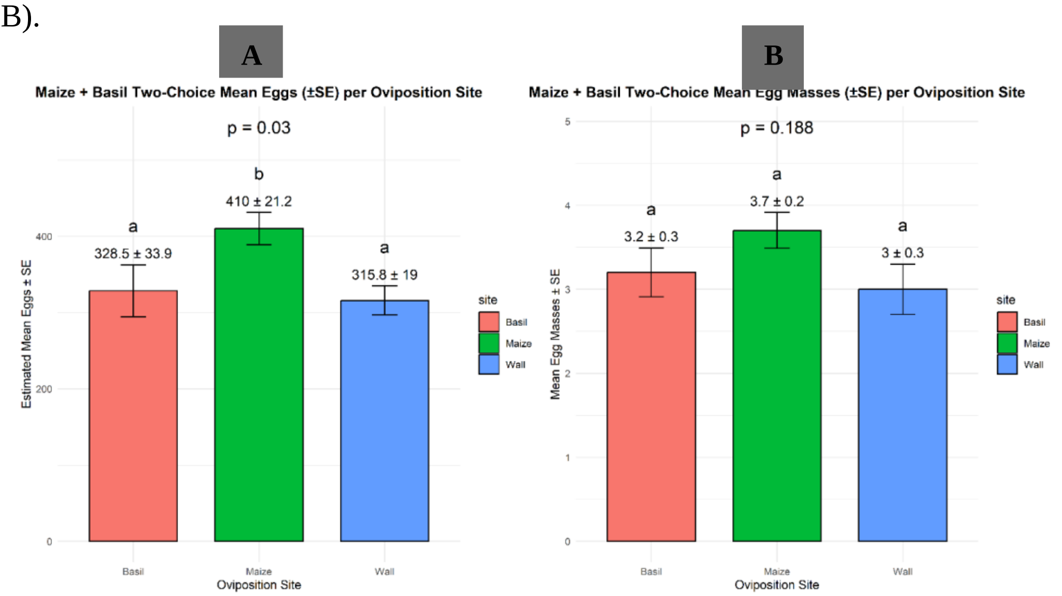

Figure 16. Graphs of mean eggs (A) and mean egg masses (B) ± SE laid by FAW. Bars bearing the same letters are not statistically different at $p<0.05$ (Tukey HSD).

B) Coriander and maize

In this trial, significant treatment effects were observed for both the mean number of eggs (*p* = 0.005) and egg masses (*p* = 0.001). Maize recorded the highest oviposition, with egg masses differing significantly from both cage walls and coriander, whereas cage walls and coriander did not differ significantly from each other (Figure 17A and 17B).

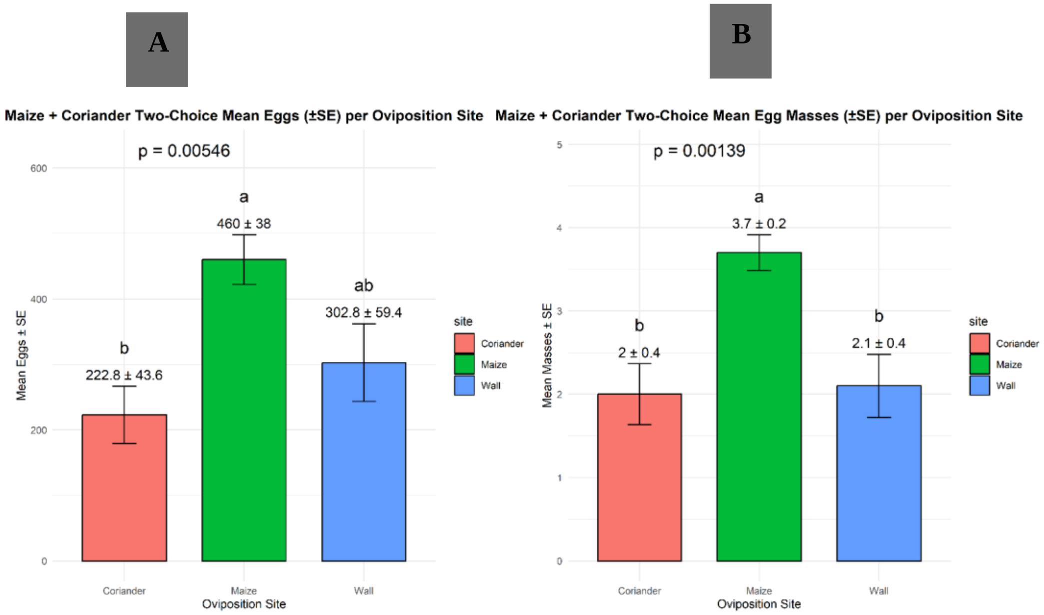

Figure 17. Graphs of mean eggs (A) and mean egg masses (B) ± SE laid by FAW in coriander and maize. Bars bearing the same letters are not statistically different at $p<0.05$ (Tukey HSD).

C) Mint and maize

On maize and mint test, contrasting the responses observed in other plants, FAW oviposited significantly more eggs (p = 0.0003) on cage walls (473 ± 64.8), followed by maize (277.8 ± 43.6), while mint recorded the lowest number of eggs (136.6 ± 38.5). Similarly, significant differences were observed in the mean number of egg masses (p = 0.003), with mint consistently recording lower egg masses compared to maize and cage walls, whereas maize and cage walls did not differ significantly (Figure 18A and 18B).

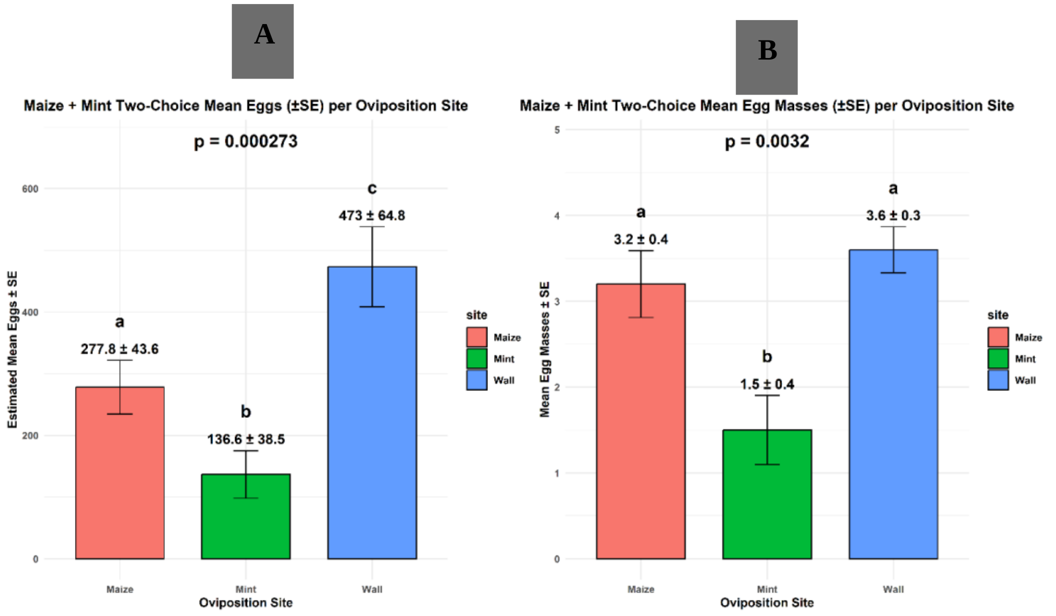

Figure 18. Graphs of mean eggs (A) and mean egg masses (B) and SE laid by FAW in mint and maize. Bars bearing the same letters are not statistically different at $p<0.05$**.**

4.1.3 Number of eggs and egg masses in two- choice bioassays in semi field conditions

In semi field experiment the eggs and egg masses were distributed across all oviposition sites and results showed significant effect of the treatment in the studied variables.

In basil and maize treatment, the highest mean number of FAW eggs and egg masses was oviposited on maize when compared to basil and net walls. There were significant differences in the mean number of eggs ($F_{2,6}$=17.90, p= 0.003) and egg masses ($F_{2,6}$=23.20, p= 0.002) on oviposited on basil and maize treatment. Tukey HSD multiple comparisons of means additionally revealed significantly more FAW egg masses were oviposited on maize and net walls (p adj=0.001) and also on basil and net walls (p adj=0.007) but, the FAW eggs oviposited on basil and maize did not differ from each other (p adj= 0.28). For the mean number of eggs oviposite on maize were significantly high (p adj=0.002) and also differed from the mean number of eggs oviposited on basil (p=0.03), however the number of eggs on net walls and basil did not statistically differ from each other (Table 4).

In regard to coriander and maize treatments, FAW moths oviposited more eggs on maize than on coriander and net walls. Significant differences were observed among oviposition sites for both the mean number of eggs ($F_{2,6}$ = 5.693, p = 0.04) and egg masses ($F_{2,6}$ = 6.29, p = 0.03). Pairwise comparisons revealed that numbers of eggs and egg masses oviposited on maize were significantly higher than on net walls (*p adj* = 0.03 and *p adj* = 0.033, respectively). However, no significant differences were observed between the numbers of eggs and egg masses oviposited on maize and coriander (*p* adj = 0.36 for eggs; *p* adj = 0.69 for egg masses) or on coriander and net walls (*p* adj = 0.23 for eggs; *p* adj = 0.10 for egg masses).

In the mint and maize experiment under semi-field conditions, FAW oviposited the highest number of eggs and egg masses on maize (1928 mean number of eggs and 8.25 mean number of egg masses). Significant differences were observed among treatments for both egg masses ($F_{2,6}$ = 5.29, *p* = 0.04) and number of eggs ($F_{2,6}$ = 7.853, *p* = 0.02). Pairwise comparisons revealed that oviposition on maize differed significantly from the oviposition on net walls for both number of eggs (*p* adj = 0.03) and egg masses (*p* adj = 0.004), while significant differences between oviposition on maize and mint were observed only for the number of eggs (*p* adj = 0.03) (Table 4).

Table 4. Mean number of eggs and mean egg masses ± SE on semi field conditions laid by FAW on basil, maize, coriander, net walls and mint.

Treatment	**Oviposition site**	**Mean number of eggs ± SE**	**Mean egg masses±SE**
Basil+ maize	Basil	1237 ± 135a	7.5 ± 0.5b
	Maize	1972 ± 145b	9.5 ±0.65b
	Net walls	655 ± 104a	3.75 ± 0.48a
Coriander + maize	Coriander	1231 ± 211ab	6.75 ± 0.95ab
	Maize	1762 ± 352a	8.0 ± 1.08a
	Net walls	569 ± 157b	3.0 ± 0.71b
Mint + maize	Mint	826 ± 25.0b	4.25 ± 0.25ab
	Maize	1928 ± 252a	8.25 ± 0.41a
	Net walls	842 ± 243b	3.75 ± 1.11b

*Means with same letters in the column are not statistically different at *p*<0.05 (Tukey HSD).

4.2 Development duration and survival rate of FAW on basil, coriander and mint

4.2.1 First experimental generation (F1) development duration.

Development duration of FAW had significant difference between the treatments, with clear stage specific variation as presented in Table 5.

Table 5: F_1 Mean ± SE of Fall Armyworm development duration at different stages and host plants

FAW development	**Maize (n=157)**	**Basil (n=106)**	**Coriander (n=89)**	**Mint (n=81)**	**X^2**	***p*-value**
Eggs hatching duration (days)	4±0.00a	4±0.00a	4±0.00a	4±0.00a	*	*
First instar duration (days)	2.56±0.05c (157)	3.10±0.09a(94)	3.99± 0.08b(72)	4.19±0.09b(47)	170.47	<0.001
Second instar duration (days)	3.24±0.06a(157)	3.51±0.10a(85)	4.06±0.09b(67)	4.18±0.11b(40)	68.05	<0.001
Third instar duration (days)	2.83±0.05c(150)	3.18±0.09a(85)	3.94±0.11b(64)	4.07±0.14b(29)	99.46	<0.001
Fourth instar duration (days)	2.87 ± 0.05c(147)	3.52±0.11a(80)	3.98±0.12b(57)	3.62±0.19ab(21)	65.84	<0.001
Fifth instar duration (days)	2.40± 0.05b(146)	3.61± 0.12a(79)	3.92± 0.15a(51)	*	103.73	<0.001
Sixth instar duration (days)	3.07±0.06b(146)	4.07±0.10a(76)	4.36±0.13a(44)	*	83.24	<0.001
Total larval duration (days)	17.0±0.13b	21.1±0.25a	23.2±0.70a	*	162.49	<0.001
Pre-pupa duration (days)	1.98±0.05a(145)	2.01± 0.06a(76)	2.18±0.14a(39)	*	2.129	0.345
Pupa duration	9.51± 0.08b(139)	11.2 ±0.20a(57)	11.1± 0.27a(31)	*	65.91	<0.001
Female pupa weight (gramms)	0.21 ± 0.004b	0.17 ± 0.005a	0.14 ± 0.007a	*	59.38	<0.001
Male pupa weight (gramms)	0.23 ± 0.004b	0.18 ± 0.004a	0.16 ± 0.007a	*	64.95	<0.001
Adults longevity	14.1 ±0.14b(139)	11.9 ±0.35a (57)	10.8±0.47a(36)	*	62.28	<0.001
Generation period (days)	41.6±1.13b	50.1±0.52a	48.4±1.87a	*	57.39	<0.001

The F_1 experimental generation had 157, 106, 89 and 81 larvae emerged from maize, basil, coriander and mint incubated eggs which were treated as biological replicates. Eggs had a mean duration of 4.00 days from oviposition to hatching across all the treatments and there was no variation among the treatments in F_1 generation.

The hatched eggs resulted into six larvae instars and as expected FAW reared on maize developed significantly faster across all larval instars compared to those reared on basil, coriander, and mint. Coriander and basil generally resulted in intermediate larval development durations, while mint caused the longest development periods during the early instars and prevented larval survival beyond the fourth instar. Overall, maize provided the most suitable host for larval development, whereas the test plants, particularly mint, negatively affected FAW growth and survival. (Specific instar mean development duration are summarized in Table 5

Generally, F_1 total FAW larval duration (TLD-cumulative duration from hatching of the eggs to final larvae instar) had clear difference in development duration. Maize reared FAW had pronounced shorter TLD (17.0 ± 0.13) days compared to basil (21.1 ± 0.26) and extended duration in coriander reared FAW (23.2 ± 0.70). The treatments exhibited significant variation among the treatments (p-value <0.001). However, basil and coriander reared larvae duration were statistically same (P=0.06) while maize caused significant shorter duration in comparison with basil and coriander.

F_1 pupa duration revealed significant difference among the treatments. Pupa from maize reared FAW pupated early (9.51 ± 0.08), compared to basil (11.1 ± 0.28) and coriander (11.2 ± 0.20) reared FAW. Additionally, maize reared larvae had statistically shorter pupation duration compared to basil and coriander while basil and coriander pupa had no statistical difference in pupation duration.

The pupa weight among the treatment varied significantly in F_1 generation in males and females. Maize reared FAW pupa weight in male (0.23 ± 0.004) and female (0.21 ± 0.004) were significantly heavier than basil pupated males (0.18 ± 0.004) and females (0.16 ± 0.007). Males pupa weight (0.17 ± 0.005) and female pupa weight (0.14 ± 0.007) emerged on coriander reared FAW had the least weight. However, it was noted that in all the treatments the male pupa weights were heavier than female weight.

The Adult longevity duration was statistically different between the treatments. Maize reared FAW had longer adult duration (14.1 ± 0.14) followed by basil (11.9 ± 0.35) and coriander (10.8 ± 0.47). Additionally, adult from maize reared FAW had statistically longer duration compared to basil and coriander. However, no significant difference between basil and coriander reared FAW on adult longevity (*p*=0.29).

The generation period differed significantly among host plant treatments (X^2=57.39, $p < 0.001$). Maize recorded the shortest generation period (41.6 ±1.13 days), while basil (50.1 ± 0.52 days) and coriander (48.4 ± 1.87 days) were significantly longer but not different from each other. No complete development was observed on mint, indicating unsuccessful development under this treatment. Significant differences were observed among treatments in generation period. Maize differed significantly from basil and coriander, which did not differ from each other. The reproductive parameters of F_1 generation are presented in the table 6 below.

Table 6. Means and SE of reproductive parameters of FAW F1 adults in different tested plants

Treatment	**Pre-oviposition period (days)**	**Total Oviposition period (days)**	**Fecudity (egg/female)**
Basil	2.29 ± 0.15a	4.29 ± 0.38a	915 ± 99.1a
Coriander	2.73 ± 0.15a	3.8 ± 0.39a	769 ± 135a
Maize	2.27 ± 0.10a	5 ± 0.20a	1051±75.8a
Mint	*	*	*
p-value	0.08	0.04	0.17
X^2	4.98	6.62	3.60

X^2 represent chi square while *p* value represents statistical significance in accordance to Kruskal-Wallis test at P<0.05. Same letters represent no significance difference in accordance to Kruskal-Wallis test at P<0.05. Same letters represent no statistical differences. * in mint represent no observations were made.

In the F_1 generation, maize reared FAW had shorter pre oviposition duration (2.27 ± 0.10) followed by basil reared (2.29 ± 0.15) while coriander (2.73 ± 0.15) had prolonged duration. The F_1 adult pre oviposition duration revealed to be statistically equal among the treatment (*p*-value = 0.08). Maize had the highest total oviposition period (5±0.20) while basil (4.29 ± 0.38) and coriander (3.8 ± 0.39) had shorter duration. There was no statistical difference between the treatments (p = 0.06).

The number of eggs were statistically equal among the treatments (p = 0.17). The mean fecundity was high in maize (1051 ± 75.8) reared FAW compared to basil (915 ± 99.1) and coriander (769 ± 135) reared FAW eggs. The mean adult oviposition period was statistically different among the treatments (*p* = 0.04). Maize reared FAW had highest mean duration (5 ± 0.20) followed by basil (4.29± 0.38) while coriander had the shortest duration (3.8 ± 0.39).

4.2.2 FAW second experimental generation (F_2) development duration

F_1 generation FAW larvae reared on mint did not complete full life cycle and therefore were exempted from the F_2 generation. The F_2 generation used 50 samples randomly selected which were treated as biological replicate from the incubated eggs. Similar to first generation, the second generation followed a similar stage specific pattern among the treatments with minor variations. F_2 egg duration revealed eggs had a mean duration of 4.00 days across all the treatments and there was no variation among the treatments in F_2 generation. maize consistently supported faster larval development across all instars, while coriander resulted in prolonged development and basil showed intermediate effects. Significant differences among treatments were observed during the early and fourth instars, although maize and basil did not differ significantly during the second instar. In the later instars (fifth and sixth), coriander maintained longer larval durations compared to maize and basil; however, these differences were not statistically significant (specific mean development duration are presented in Table 7).

Table 7. Mean ± SE of Fall Armyworm F_2 Generation development duration at different stages

FAW development	**Maize (n=50)**	**Basil (n=50)**	**Coriander (50)**	X^2	***p*-value**
Eggs hatching duration (days)	4.00 ± 0.00a	4.00 ± 0.00a	4.00 ± 0.00a	*	*
First instar duration (days)	1.22 ± 0.07c(50)	1.59 ±0.09a (44)	2.05 ± 0.11b(43)	34.95	<0.001
Second instar duration (days)	1.84 ± 0.09a (49)	1.86 ±0.11a (42)	2.73 ± 0.15b(37)	26.22	<0.001
Third instar duration (days)	2.02 ± 0.08c(48)	2.54 ±0.12a(39)	3.21 ± 0.13b(34)	41.99	<0.001
Fourth instar duration (days)	2.33 ± 0.09a(48)	2.54 ±0.11a(37)	3.44 ± 0.14b(32)	33.56	<0.001
Fifth instar duration (days)	3.52 ± 0.09b(48)	4.03 ± 0.15a(35)	4.13 ± 0.12a(30)	16.10	0.0003
Sixth instar duration (days)	3.54 ± 0.08a(48)	3.84 ±0.15a(32)	3.82 ± 0.14a(28)	4.25	0.12
Total larval duration (days)	14.5 ± 0.21c(48)	16.4 ±0.33a(32)	19.2 ±0.40b(28)	58.21	<0.001
Pre-pupa duration (days)	1.29 ± 0.07a(48)	1.32 ±0.09a(28)	1.65 ±0.15a(19)	5.58	0.06
Pupa duration (days)	9.34 ± 0.21b(44)	11.4 ±0.24a(26)	12.1 ± 0.39a(20)	44.51	<0.001
Female pupa weight (gramms)	0.20 ± 0.008b	0.16 ± 0.01a	0.14 ± 0.01a	19.04	<0.001
Male pupa weight (gramms)	0.24 ± 0.006b	0.19 ± 0.007a	0.17 ± 0.01a	28.46	<0.001
Adult longeivity duration (days)	12.9 ± 0.30b (44)	11.2 ±0.50a (26)	9.84 ± 0.64a (19)	21.65	<0.001
Generation duration (days)	42.1 ± 0.45b	44.5 ±0.66a	45.7 ± 1.19a	15.52	<0.001

X^2 represent the Chi Square and p values represent statistical significance according to Kruskal-Wallis analysis at $p<0.05$ Means with the same alphabets in the specific row are not statistically different in accordance to Dunn's test. The number enclosed in parenthesis represent the number of individuals at the specific stage.

The cumulative total larval duration (TLD-cumulative duration from hatching of the eggs to final larvae instar) in F_2 generation was resulted by the specific larvae instar duration. TLD revealed statistical difference among the treatments. Maize reared FAW had shortest duration (14.5 ± 0.21) followed by basil (16.4 ± 0.33) and longest in coriander (19.2 ± 0.40). Additionally, maize reared FAW had statistically shorter larval duration than basil and coriander. FAW reared larvae on basil also were statistically different from coriander.

The pupa duration on the F_2 FAW generation were statistically different. Maize reared FAW pupation were faster (9.34 ± 0.21) compared to basil (11.4 ± 0.24) and coriander (12.1 ± 0.39). There was significance difference between pupa duration reared on maize and coriander and basil however no significant difference between coriander and basil reared FAW pupa duration (p=1.00).

The adult longevity varied significantly among the treatments. Maize reared FAW adults had prolonged duration (12.9 ± 0.30) followed by basil (11.2 ± 0.50) and coriander (9.84 ± 0.64) had the least duration. Additionally, maize reared FAW were statistical shorter compared to basil ($p = 0.002$) and coriander however there was no significant difference in adult longevity duration between coriander and basil ($p = 0.22$).

The male and female pupa weight among the treatment varied significantly in F_2 generation, respectively. Maize reared FAW pupa weight in male (0.24 ± 0.006) and female (0.20 ± 0.008) were significantly heavier than males (0.19 ± 0.007; 0.17 ± 0.01) and females (0.16 ± 0.01; 0.14 ± 0.01) from basil and coriander, respectively.

Generation duration had significant differences among treatments ($X^2 = 15.52$, $p < 0.001$). Maize recorded a significantly shorter generation duration (42.1 ± 0.45) compared to the other basil (44.5±0.66) and coriander (45.7± 1.19), while no significant difference was observed between those basil and coriander, the analysis revealed significant variation among basil and coriander, with maize showing a significantly lower value compared to the other treatments.

Table 8. Means and SE of FAW F_2 adults reproductive parameters on basil, coriander and maize

Treatment	**Pre-oviposition period**	**Total Oviposition period**	**Fecundity**
Basil	1.91±0.21ab	8.18 ±0.97a	1193.±147a
Coriander	2.56±0.24a	6.56±1.42a	1012± 204a
Maize	1.7±0.19b	9.05±0.71a	1427±110a
p-value	0.04	0.001	0.14
X^2	6.37	13.76	3.94

X^2 represent chi square while *p* value represents statistical significance in accordance to Kruskal-Wallis test at $p<0.05$.

In regard to the reproductive parameters they are shown in the following table 8 above. The pre-oviposition duration in F_2 statistically varied among the treatment ($p = 0.04$). Maize reared FAW had shorter (1.7 ± 0.19) duration on preoviposition compared to basil (1.91 ± 0.21) and coriander (2.56 ±0.24). The pairwise comparison revealed maize pre-oviposition duration to be statistically different from coriander ($p = 0.04$), however there was no significant difference in pre-oviposition duration between maize and basil ($p =1.00$) and also basil and coriander ($p = 0.29$).

The total oviposition duration was long on maize (9.05 ± 0.71) while shorter on basil (8.18±0.97) and least on coriander (6.56 ± 1.42). However, there was no significant difference among the treatments ($p = 0.24$).

The pre-oviposition duration in F_2 statistically varied among the treatment ($p = 0.04$). Maize reared FAW had shorter (1.7 ± 0.19) duration on pre-oviposition compared to basil (1.91 ± 0.21) and coriander (2.56 ± 0.24). The pairwise comparison revealed maize pre-oviposition duration to be statistically different from coriander ($p = 0.04$), however there was no significant pre-oviposition duration between maize and basil ($p = 1.00$) and also basil and coriander ($p = 0.29$).

The adult fecundity was high on maize reared FAW (1427 ± 110) followed by basil (1193 ± 147) and coriander (1012 ± 204). However, there was no significant differences between the treatments ($p = 0.14$).

4.2 First and second experimental generation FAW survival rate on maize, basil and coriander

FAW survival in maize was the highest with 92.99% in larvae, 91.08% pupa and 88.54% adult emergence in F_1 generation. F_2 generation FAW reared on maize still had the highest survival with 96% larvae, 94% pupa and 88% adults. Basil reared FAW followed with 71.70% larvae, 71.70% pupa and 53.77% adult emergence in F_1 generation. The second generation basil reared FAW had 64%, 52% and 52% larval survival, pupation rate and adult emergence (table 9).

Table 9. FAW larval survival rate, pupation rate and adult survival of F_1 and F_2 generation reared on basil, maize, coriander and mint.

Stage of development	**Maize**		**Basil**		**Coriander**		**Mint**	
	F_1 (156)	F_2(50)	F_1(106)	F_2(50)	F_1(89)	F_2(50)	F_1(81)	F_2
First instar	100	100	88.68	88	80.90	86	58.02	*
Second instar	100	98	80.19	84	75.28	74	49.38	*
third instar	95.54	96	80.19	78	71.91	68	35.8	*
Fourth instar	93.63	96	75.47	74	64.04	64	25.93	*
Fifth instar	92.99	96	74.53	70	57.03	60	*	*
Sixth instar	92.99	96	71.70	64	49.44	56	*	*
larval survival	92.99	96	71.7	64	49.44	56	*	*
Pre pupa	92.36	96	71.70	56	43.82	52	*	*
Pupation rate	91.08	94	71.70	52	43.82	44	*	*
Adult emergence	88.54	88	53.77	52	40.45	38	*	*

The number in the brackets represent the sample sizes in each treatment. (*) in mint represent no data was collected.

Coriander reared FAW had low survival in F_1 generation with 49.44% larval survival, 43.82% pupation rate and 40.45% adult emergence. The F_2 generation similarly had 56% larval, 44% pupa and 38% survival mint reared fall armyworm had no complete larval survival and the development and survival was unknown in this study and according to this study the multigenerational effect of FAW feed on mint is unsuitable.

4.3 Olfactory selection rate of female FAW when exposed to basil, coriander and mint in laboratory conditions

In the first scenario between maize, basil, coriander and mint versus clean air revealed variation in FAW behavioral response when exposed to different stimuli as represented Figure 9. With exception of mint all the other potential repellent plants did attract FAW adult in relation to clean air. The selection rate on maize (88.9%), basil (75%) and coriander (57.1%) was high. Mint conversely, had high selection rate on clean air (85.7%) compared to mint arm (14.3%). Additionally, behavioral response showed statistical difference in maize versus air (p = 0.02). However, basil (p = 0.157), coriander (p= 0.705) and mint versus air (p = 0.317) trials did not show any significant difference on the moth's response.

The bioassay between potential repellent plants versus maize, the olfactory selection rate of 90% on maize and 10% on mint. Maize and coriander test also had high selection on maize (71.4%) compared to coriander (28.6%) and maize versus basil, the olfactory selection demonstrated high selection on maize (70%) than basil (30%) (Figure 19).

Additionally, there was statistical difference in choice of the FAW on maize versus mint (p = 0.011) but no statistical difference in selection of the stimuli maize versus basil test (p = 0.21) and maize versus coriander test (p = 0.26). In this trial besides maize having high attractiveness to the moths, basil and coriander showed some level of attractiveness while mint remained least preferred.

In the trial between maize versus maize combined with the potential repellent plants, the olfactory selection rate was high on maize (80%, 75%, 60%) in maize versus maize + mint, maize versus maize + coriander and maize versus maize + basil, respectively (Figure 20). Basil combination had highest preference (40%), while coriander (25%) and mint (20%) had the least preference. However, despite the noted difference Chi square revealed no statistical difference between in combination treatment with basil (p = 0.53), coriander (p = 0.16) and mint (p = 0.58).

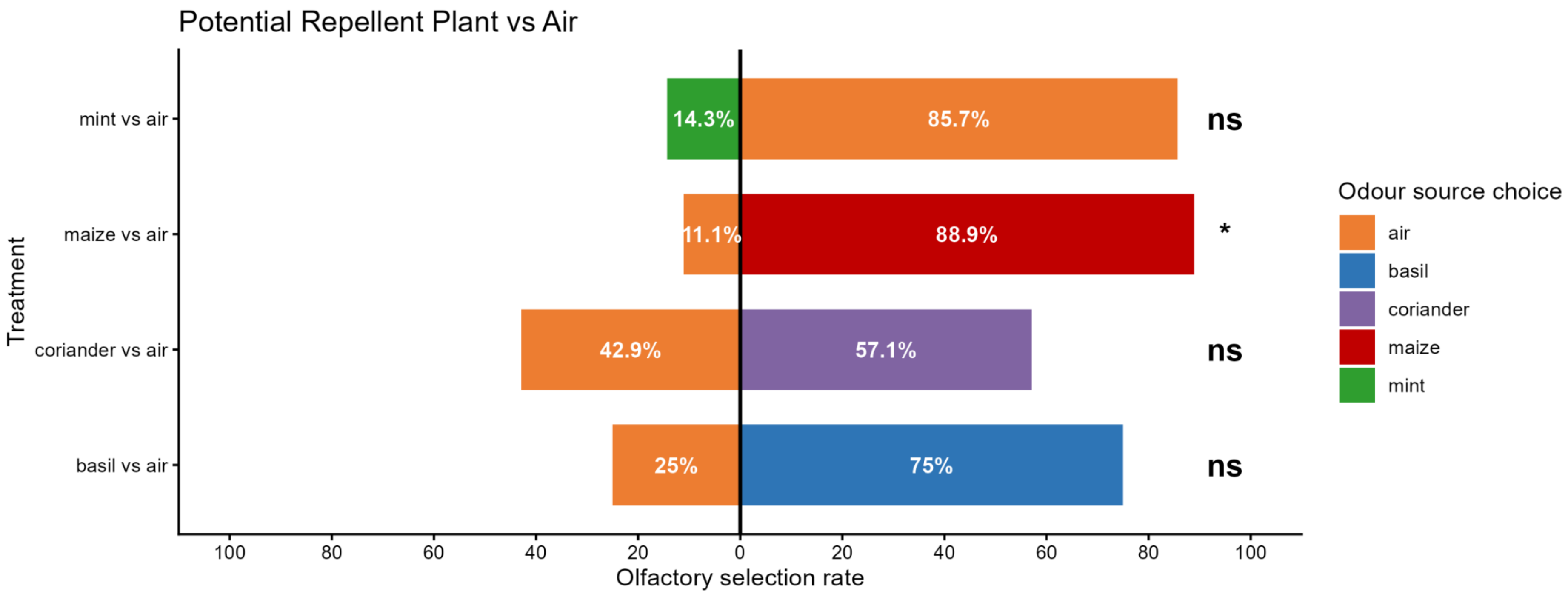

Figure 19. Olfactory choices of FAW gravid female when exposed to selected potential repellent plants and air. The numbers on the graph's horizontal axis show the percentage selection. Note * represent significant difference (chi square test *p* value <0.05) while “ns” represent insignificant (chi square test *p* value <0.05). Chi square was performed using actual count of the insects.

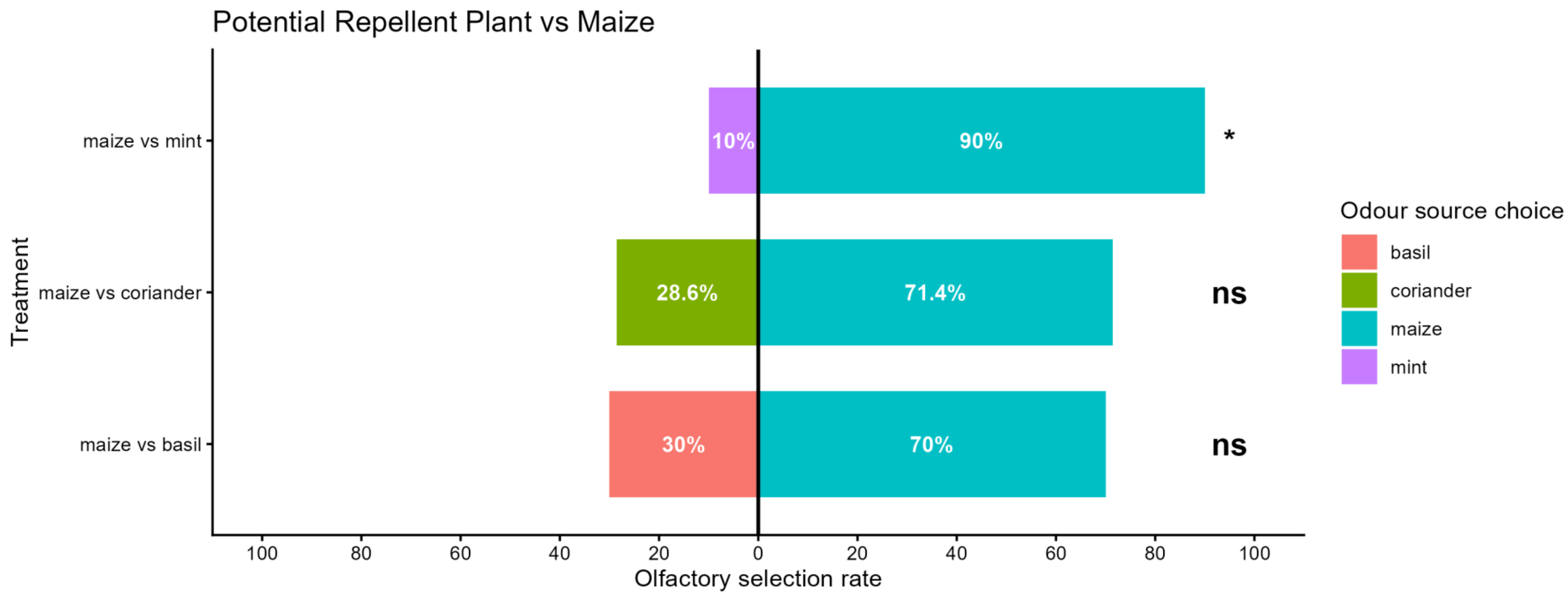

Figure 20. Olfactory choices of FAW gravid female when exposed to maize versus tested plants The numbers on the graph's horizontal axis show the percentage selection. Note * represent significant difference (chi square test *p* value <0.05) while ns represent insignificant (chi square test *p* value <0.05). Chi square was performed using actual count of the insect.

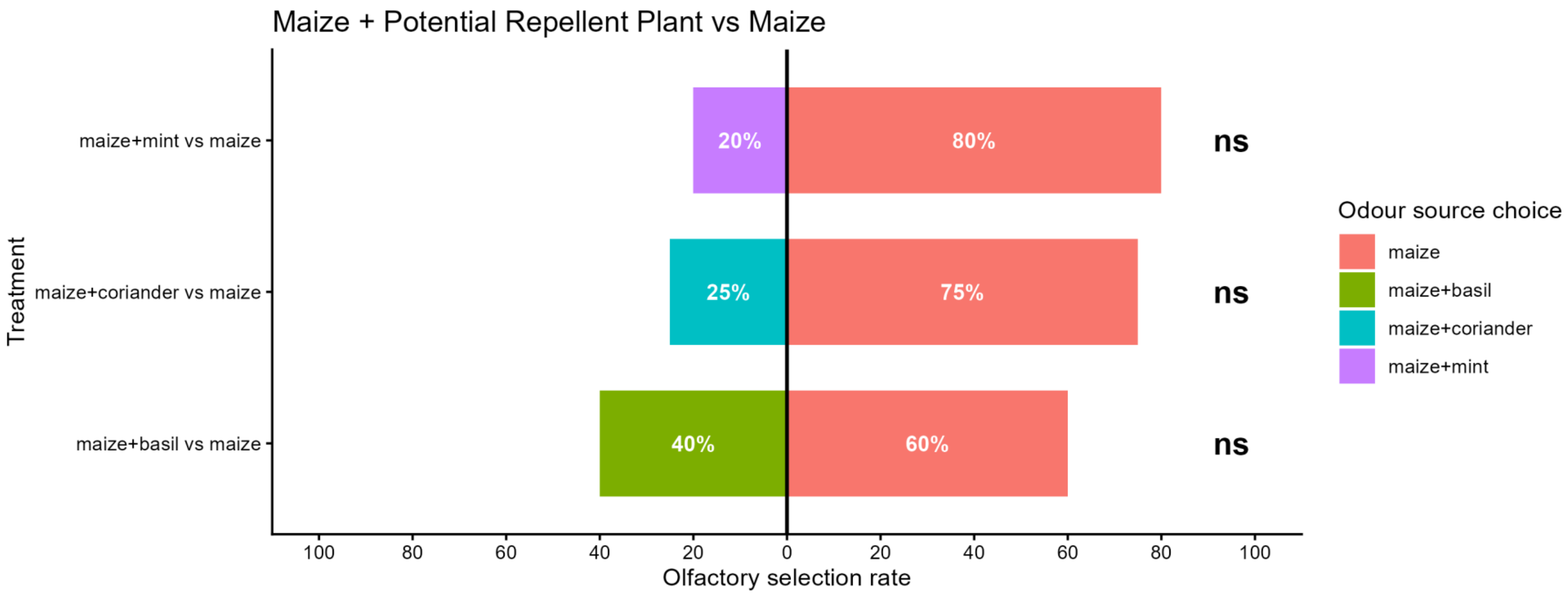

Figure 21. Olfactory choices of FAW gravid female when exposed to maize versus potential repellent plants combined with maize. The numbers on the graph's horizontal axis show the percentage selection. Note * represent significant difference (chi square test *p* value <0.05) while ns represent insignificant (chi square test *p* value <0.05). Chi square was performed using actual count of the insects.

5.0 DISCUSSION

5.1 FAW Oviposition preference on maize, basil, coriander, and mint under laboratory and semi-field conditions

The oviposition bioassays demonstrated that female fall armyworm exhibited different oviposition preferences among the potential repellent plants. In the no-choice experiment, maize received the highest number of eggs, followed by basil and coriander, while mint received the lowest number of eggs. A similar trend was observed for egg masses. In addition, females frequently oviposited eggs on the cage walls when exposed to coriander and mint, suggesting reduced acceptance of these plants as oviposition substrates. In contrast, oviposition on basil was higher than that on the cage walls, indicating that basil was more acceptable to the FAW than coriander and mint.

Similar behavior has been reported in studies demonstrating that FAW females preferentially lay eggs on more suitable hosts and may deposit eggs on cage surfaces when exposed to less preferred or repellent plants (Sisay *et al.,* 2023). Similar distribution and oviposition preference on object materials (cage net) has also been reported by other authors (Guo *et al.,* 2021; Rojas *et al.,* 2003). Can *et al*. (2024) found that several plants, including desmodium and molasses grass, significantly reduced oviposition compared with preferred hosts, highlighting the role of plant volatiles in influencing egg-laying behavior. Likewise, Sobhy *et al*. (2022) reported that volatile compounds released by desmodium species repel *S. frugiperda*, reducing host location and oviposition. The low number of eggs observed on mint may therefore be attributed to the repellent action of its volatile compounds, which are known to interfere with host-finding and oviposition. Furthermore, plant-derived volatile compounds and terpenoids have been shown to deter oviposition in *Spodoptera* species, suggesting that the strong aroma of mint may interfere with host recognition and egg-laying behavior (Can *et al*., 2024).

In the two-choice oviposition preference bioassay, the introduction of maize plants into the cages showed high FAW oviposition preference on maize when compared to basil, cage walls and coriander. Conversely, in the mint treatment bioassay, there was reduced oviposition preference of FAW on maize in comparison with coriander and basil bioassays. Generally, the number of eggs and egg masses of FAWon basil, coriander and mint, had similar results in both no choice and two-choice experiments, with FAW showing highest preference to oviposit on basil, followed by coriander and least on mint.

In the semi field experiment, maize plants was highly preferred compared to other oviposition sites, which was an expected behavior, since it is the FAW prefered host (Sotelo-Cardona *et al.* 2021; Sisay *et al.* 2023). In regard to other tested plants, basil and coriander was preferred while mint remained least preferred. However, the results from laboratory and semi-field experiments were slightly different. Under laboratory conditions, FAW females frequently oviposited on cage walls, particularly in the mint treatment, indicating avoidance of the tested plants. In contrast, under semi-field conditions, oviposition was concentrated mainly on the plants, with basil and coriander receiving substantially higher numbers of eggs and egg masses than observed in laboratory assays. Furthermore, coriander did not differ significantly from maize in the semi-field experiment, suggesting greater host acceptance under more natural conditions. The difference could have been attributed by the semi field experiment being in a more natural setting with adequate area allowing the insects to decisively identify and examine the host (Heard, 1999).

Despite its reported insect-repellent properties, basil emerged as the second most preferred plant after maize in the no-choice, two-choice, and semi-field experiments conducted in this study. This suggests that basil did not exert a strong deterrent effect on FAW under the conditions tested. The attractiveness of basil may be related to variation in basil chemotypes, plant growth stage, environmental conditions, or differences in the composition and concentration of volatile organic compounds (VOC's) released by the plants. While basil essential oils have demonstrated insecticidal, repellent, and antifeedant activity against several agricultural pests (Pavela, 2015; Isman, 2020), the response of insects to whole living plants can differ substantially from their response to concentrated essential oils. Furthermore, female FAW rely on a complex blend of visual and chemical cues when selecting oviposition sites (Renwick & Chew, 1994). Certain basil volatiles, such as linalool and methyl chavicol, may not be sufficiently repellent to prevent host acceptance and may even contribute to plant recognition under some circumstances. Similar inconsistencies in the attractiveness and repellency of companion plants have been reported for *S. frugiperda*, where plants expected to repel the pest did not always reduce oviposition or attraction under experimental conditions (Can *et al*., 2024). Therefore, the observed preference for basil indicates that its effectiveness as a repellent may be context-dependent and influenced by plant chemistry, insect behavior, and environmental factors.

Coriander showed and intermediate effect, exerting deterrent effect on oviposition by *S. frugiperda,* which is attributed to the high amount of volatile organic compounds (Al-Khayri *et al.,* 2023; Woldemelak, 2020; Chahal *et al.*, 2017) including linalool, α-pinene, and other terpenoids, which can influence insect behavior and reduce host acceptance by herbivorous insects. Coriander has been reported to possess repellent and insecticidal properties against several agricultural pests, such as *Thrips parvispinus*, *Helicoverpa armigera* and *Bactrocera dorsalis* (Pavela, 2017; Benelli *et. al*, 2018; Gunaeni *et al.,* 2024). The reduction in oviposition observed in the present study may therefore be attributed to the masking of host cues or the direct deterrent effect of coriander volatiles on female moths. However, the deterrent effect was weaker than that observed for mint, suggesting that coriander volatiles may be less effective in disrupting host-finding and oviposition behavior in FAW. Similar observations have been reported for companion plants whose volatile emissions reduce, but do not completely prevent, oviposition by fall armyworm and other lepidopteran pests (Sobhy *et al*., 2022; Can *et al*., 2024).

Mint exhibited the strongest deterrent effect on oviposition by FAW, receiving the lowest number of eggs among all treatments. This finding is likely associated with the high concentration of volatile compounds produced by mint, including menthol, menthone, pulegone, and limonene, which are known to affect insect orientation, host recognition, and oviposition behavior. Aromatic plants in the genus *Mentha* have been widely reported to possess repellent, antifeedant, and insecticidal properties against a range of lepidopteran and other agricultural pests (Isman, 2020; Pavela, 2015). The strong reduction in egg deposition observed in the present study suggests that mint volatiles may interfere with the ability of female *S. frugiperda* to identify suitable oviposition sites. Similar effects have been reported for companion plants that emit bioactive volatiles capable of repelling fall armyworm and reducing oviposition, such as desmodium species in push–pull systems (Sobhy *et al*., 2022). Therefore, mint shows potential as a companion or intercrop plant for the behavioral management of *S. frugiperda* through the disruption of host-finding and oviposition processes.

The present study found limited evidence of a push effect for coriander and basil. Although maize remained the preferred host in the two-choice assays, substantial oviposition occurred on coriander and basil, particularly under semi-field conditions. This suggests that the volatile cues emitted by these plants were insufficient to mask or override the attractive cues from maize. Consequently, coriander and basil may not be suitable push plants for the management of FAW, unlike more effective repellent species such as desmodium, which have been shown to reduce host location and oviposition through volatile-mediated repellency (Sobhy *et al*., 2022).

5.2 Olfactory selection behavior of female FAW in laboratory conditions

The above oviposition results are supported by the olfactometer experiment. To distinguish between host and non-host plants, olfaction plays a critical role in phytophagous insects. The integration of many sensory inputs, such as gustatory or olfactory semiochemical cues and physical information like plant color, shape, and texture, within the insect central nervous system (CNS) mediates this process (Bernays, 2001; Bruce *et al.*, 2005). In the current study the olfactometer bioassay showed much preference on maize aligning with other studies (Sisay *et al.*, 2023) with reports by Pinto-Zevallos *et al.*, (2016) associating volatiles to cause maize attractiveness.

The Y tube olfactometer study revealed variation in FAW behavior when tested alone or in combination. Maize remained best host choice in all the experiments aligning with Montezano *et al.* (2018) reports on high preference on maize. The Y olfactometer experiment revealed preference of clean air than mint aligning with Zhang *et al.* (2024) reports on repellency of mint on winged cotton aphid, however in the coriander, basil and maize most moths choose the plants over air. This signifies the volatile organic compounds produced by mint being unsuitable for the gravid moths while that of basil, coriander and maize being appealing for oviposition. In the combined experiment and the maize versus plant test maize was preferred compared to other plants. Interestingly the basil trial of combined experiment had higher choice compared to other mint-maize combination and coriander -maize combination. This support earlier results found on oviposition experiment.

5.3 Developmental duration and survival of FAW to basil, coriander, and mint

The current study also sought to assess effect of mint, coriander, basil on growth and development, survival and reproductive rates of FAW. The finding from the current study demonstrated that the tested hosts species significantly vary depending on the host type. The study found FAW can complete multigenerational life cycle on basil, coriander and maize.

In the two generations, FAW reared on maize demonstrated to have shortest larval development period, heavier pupa weight, longest adult longevity, highest fecundity and highest survival rates in comparison with mint, basil and coriander suggesting maize as the most suitable host. This differences may be as a result of nutritional composition (Kazemi *et al.,* 2001).

The life history of insects is significantly implicated by the host type (Chen *et al.,* 2022; Xie *et al.,* 2021). Specifically, polyphagous insect's feeding and oviposition are highly determined by host quality (Orsucci *et al.,* 2018). The host plant suitability is demonstrated in insect's fitness through exhibiting shorter growth and development duration, higher survival rates and also high reproductive rates (Chen *et al.,* 2018).

Nutritional quality is the primary factor that influence survival, growth and reproduction of FAW (Schoonhoven *et al.,* 2005; Awmack & Leather, 2002; McCormick *et al.,* 2019). FAW have shown similar preference on maize demonstrated by numerous studies (Su *et al.,* 2022; Guo *et al.,* 2021; Wang *et al.,* 2020; Ba *et al.,* 2020; Barros *et al.,* 2010).

The study revealed FAW can also host on basil and coriander supporting earlier findings by Montezano *et al.* (2018), however sub optimal fitness is evident in basil and coriander compared to maize due to the low survival and longer development duration while mint had poor fitness and 100% mortality of the FAW larvae.

Low survival rates and longer larval duration, are markers of a poor nutritional status of a host species. Silva *et al.* (2017) presumes this can be linked by low protein uptake and physiological stress of the larvae slowing growth rate and therefore poor quality host is compensated by prolonged larval stage duration and Barfield *et al.* (1980) study support this. Additionally, Liu *et al.* (2023) demonstrates disparities in larval food usage efficiency may be the cause of FAW varied progeny performance among the hosts. This could be speculated of low fitness demonstrated in FAW reared on basil, coriander and mint. However, the exact mechanism needs to be further investigated.

In the current study mint demonstrated lethal effect on the FAW larvae and could not support a single generation life cycle. Secondary plant metabolites, are defensive mechanisms adopted by plants against phytophagous insects which may exists as terpenes or phenolic compounds (Wink, 2003). Existence of phenolic and terpenes compounds in mint have been previously documented to cause antibiosis and anti-feedants properties with a record of up to 97% feeding deterrence on FAW (Peprah-Yamoah *et al.*, 2022). Similar mortality reports have been reported by Kalinda & Rioba (2020). Can *et al.* (2024) also associates presence of phenolic substances to cause deterrent effect against FAW. The secondary metabolites of mint could be speculated to have caused the mortality of FAW.

The pupa weight has been used to mirror the host suitability of pre adult and also can be used to influence the adult fitness (Soto *et al.*, 2018). In the current study the pupa weight on maize reared FAW were significantly higher than those reared on basil and coriander in both generations. This demonstrates the suitability of maize than coriander and basil. This study correlates with other studies which argue pupa weight as a product of nutrient accumulation (Liu *et al.*, 2023; Wang *et al.*, 2020; Zhang *et al.*, 2021).

Besides the reproductive parameters of FAW been influenced by adult nutrition intake, it has also been reported to be influenced by the type of larvae host (Liu *et al.*, 2023; Awmack & Leather, 2002). Suitable hosts result to high fecundity, prolonged total oviposition duration and short pre oviposition period. In consistency with previous studies by Cao *et al.*, (2021), the present study, FAW exhibited high reproductive fitness in maize compared to other test plants, followed by basil and coriander. Additionally, Barcelos *et al.* (2024) demonstrates small adults are yielded by lighter pupa which also results to low reproductive fitness. Therefore, the FAW larvae nutritional intake by maize, coriander and basil larvae resulted to difference reproductive characteristics with maize being more fit compared to the other hosts.

The study therefore aligns with Sisay *et al.* (2023) findings that companion planting with suboptimal plants could build synergies by lessening oviposition in the primary plant. Basil and coriander could not fit in push pull cropping system as either repellent or pull crop because they had considerable preference on oviposition, olfactometer choice and supported growth and development and survival of FAW for two generations. Fundamentally Guera *et al.*, (2020) reports the pull or trap crop should encourage FAW colonization but fail to support development of the FAW therefore utilizing these plants could risk increase in pest population within the pest populations. Therefore, based on the evidence generated in this study, basil and coriander cannot be recommended as push crops for FAW management.

The detailed planting patterns (row arrangement, spacing and planting density) remain to be explored in further field investigations, however mint could be planted along with maize similar to the established convectional push pull system (Khan *et al.*,2018), however analyzing the planting ratio of main crops and intercropped plants and the impact of this introduction on the dynamics of arthropod communities, especially of natural enemies remain to be researched. Similarly, the economic feasibility was beyond the scope of the study but focused on the viability of the proposed repellent plants, however mint has economical value which generates extra income. Additionally study by Sileshi *et al.*, (2025) reports a comprehensive systematic review on economic feasibility in various push pull cropping system and based on seven publications that analyzed the financial returns of PPT their results provide strong evidence that the benefits of PPT outweigh the costs.

Overall, the effectiveness of a push crop depends not only on its ability to deter oviposition by gravid females but also on its capacity to reduce pest survival, development, and reproduction when insects encounter or utilize the plant. In the present study, mint emerged as the most promising candidate for the push component of a push–pull system against *S. frugiperda*. Mint received the lowest number of eggs in no-choice, two-choice, and olfactometer experiments, and females showed a strong preference for clean air or maize over mint. Furthermore, larvae emerging from eggs associated with mint failed to complete development beyond the fourth instar, preventing pupation, adult emergence, and reproduction. These findings indicate that mint possesses both behavioral and biological suppressive effects on FAW populations, making it a potentially effective repellent intercrop.

In contrast, basil and coriander showed limited suitability as push crops. Although coriander received fewer eggs than maize and demonstrated some level of oviposition deterrence, it did not effectively prevent host acceptance under semi-field conditions. Likewise, basil was consistently the second most preferred plant after maize in oviposition and olfactory bioassays. Females were attracted to basil and coriander odors, and neither plant significantly reduced moth orientation toward maize when presented in combination with the crop. These results suggest that the volatile emissions from basil and coriander were insufficient to disrupt host-finding by gravid FAW females.

Nevertheless, both basil and coriander negatively affected FAW performance after feeding. Larvae reared on these plants exhibited prolonged development periods, lower pupal weights, reduced adult longevity, lower survival rates, and longer generation times compared with maize-fed insects. Coriander produced particularly strong sublethal effects, reducing larval survival to approximately 49% and adult emergence to 40% in the first generation, while basil reduced adult emergence to about 54%. In the second generation, these effects persisted, with coriander and basil continuing to delay development and reduce survival relative to maize. Such reductions in fitness indicate that although basil and coriander may not function effectively as push crops, they may contribute to population suppression by decreasing the quality of the host environment and reducing the rate of population increase.

From a practical perspective, the results suggest different roles for the tested plants within an integrated pest management strategy. Mint has the greatest potential as a push crop and could be planted as border rows or intercrops within maize fields to create a volatile barrier that deters FAW females and suppresses larval survival. Basil and coriander are less suitable as push plants because they did not adequately repel moths from maize; however, their negative effects on development, survival, and reproduction suggest that they may still contribute to pest suppression when used as companion plants. Future studies should evaluate whether combining mint with established pull crops such as Brachiaria or Napier grass can improve the effectiveness of push–pull systems for FAW management under field conditions.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

- Oviposition bioassays showed FAW moths had consistent behavior both in cage and semi field conditions, with least eggs oviposited on mint, showing its deterrent effects.

- FAW successfully survived two experimental generations in coriander and basil however the host significantly affected growth and development, survival and reproductive rates and could not complete life cycle when reared on mint indicating unsuitability and possible antibiosis.

- The olfactory selection rate showed less preference on mint while basil and coriander had considerable choice by FAW.

6.2 RECOMMENDATIONS.

- Maize and mint companion planting should be further tested as a viable candidate "push" unit in to manage FAW in maize.

- Field experiments should be conducted to validate the current study findings under ideal and natural conditions.

- Further in-depth research gas chromatography analysis and electrophysiological bioassays will be required to gain a deeper understanding of the interaction between *S. frugiperda* and the plants examined here and the responsible compounds with deterrent and mortality effect.

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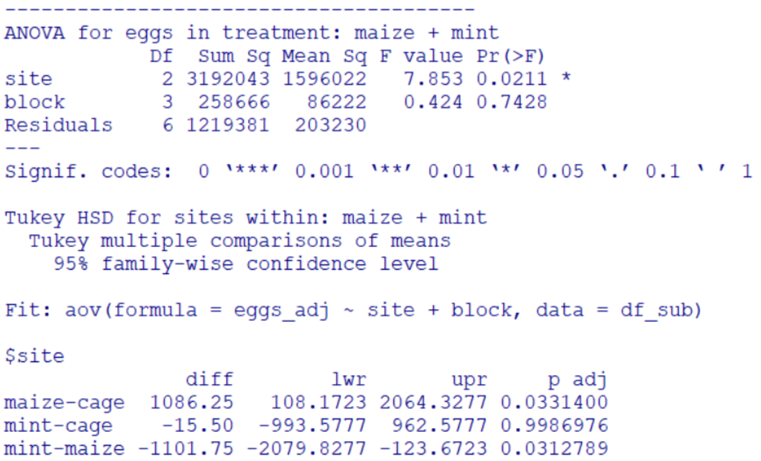
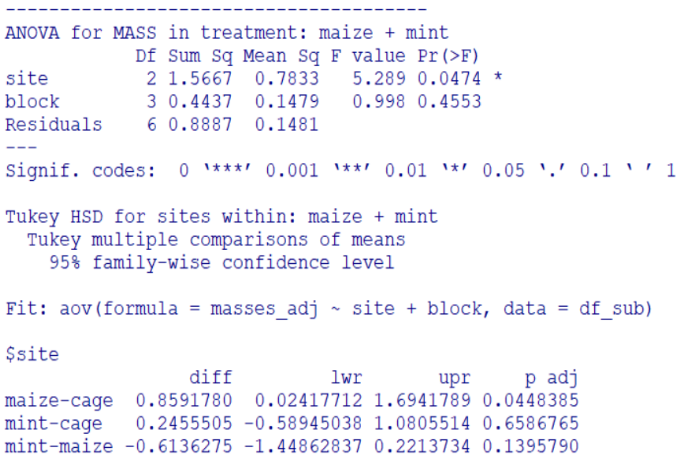
APPENDICES

Appendix 1. Semi Field Oviposition Experiment Eggs and Egg Masses Anova Tables On Various Treatments

a) Maize + mint eggs and egg masses

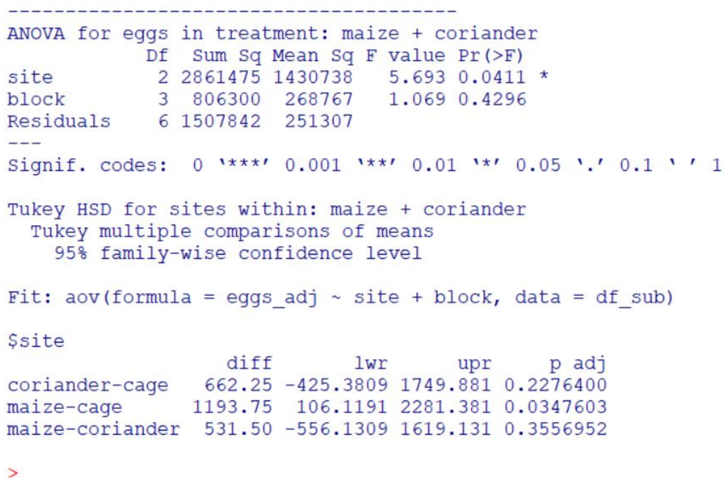


```
---------------------------------------
ANOVA for eggs in treatment: maize + mint
            Df  Sum Sq Mean Sq F value Pr(>F)  
site         2 3192043 1596022   7.853 0.0211 *
block        3  258666   86222   0.424 0.7428  
Residuals    6 1219381  203230                 
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Tukey HSD for sites within: maize + mint
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = eggs_adj ~ site + block, data = df_sub)

$site
               diff        lwr       upr     p adj
maize-cage  1086.25   108.1723 2064.3277 0.0331400
mint-cage    -15.50  -993.5777  962.5777 0.9986976
mint-maize -1101.75 -2079.8277 -123.6723 0.0312789
```

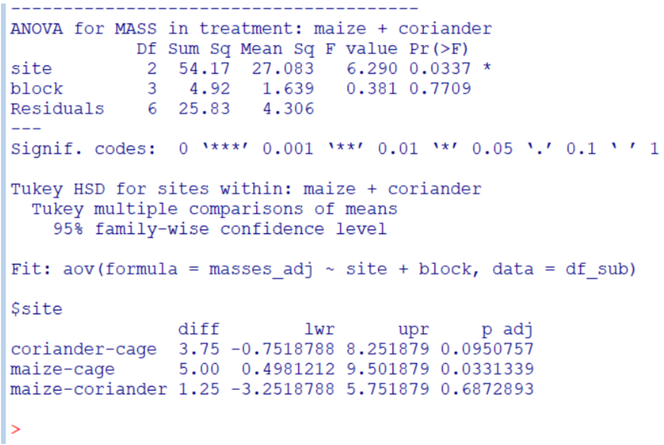


```
-----------------------------------
ANOVA for MASS in treatment: maize + mint
            Df Sum Sq Mean Sq F value Pr(>F)  
site         2 1.5667  0.7833   5.289 0.0474 *
block        3 0.4437  0.1479   0.998 0.4553  
Residuals    6 0.8887  0.1481                 
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Tukey HSD for sites within: maize + mint
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = masses_adj ~ site + block, data = df_sub)

$site
                 diff         lwr       upr     p adj
maize-cage  0.8591780  0.02417712 1.6941789 0.0448385
mint-cage   0.2455505 -0.58945038 1.0805514 0.6586765
mint-maize -0.6136275 -1.44862837 0.2213734 0.1395790
```

b) Maize + coriander eggs and egg masses

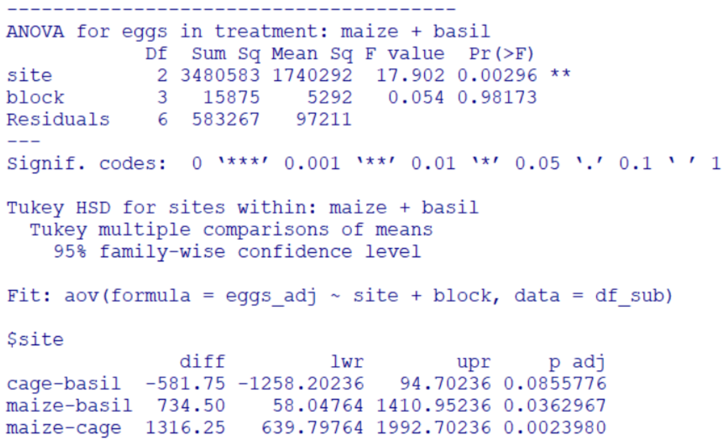


```
---------------------------------------
ANOVA for eggs in treatment: maize + coriander
            Df  Sum Sq Mean Sq F value Pr(>F)
site         2 2861475 1430738   5.693 0.0411 *
block        3  806300  268767   1.069 0.4296
Residuals    6 1507842  251307
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Tukey HSD for sites within: maize + coriander
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = eggs_adj ~ site + block, data = df_sub)

$site
                   diff       lwr      upr     p adj
coriander-cage   662.25 -425.3809 1749.881 0.2276400
maize-cage      1193.75  106.1191 2281.381 0.0347603
maize-coriander  531.50 -556.1309 1619.131 0.3556952

>
```

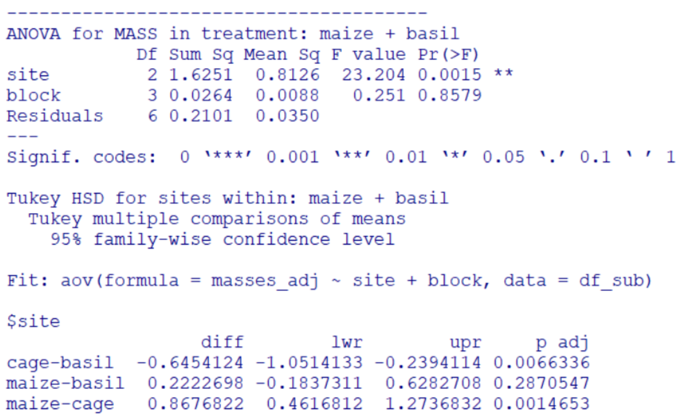


```
---------------------------------------
ANOVA for MASS in treatment: maize + coriander
            Df Sum Sq Mean Sq F value Pr(>F)
site         2  54.17  27.083   6.290 0.0337 *
block        3   4.92   1.639   0.381 0.7709
Residuals    6  25.83   4.306
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Tukey HSD for sites within: maize + coriander
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = masses_adj ~ site + block, data = df_sub)

$site
                diff        lwr      upr     p adj
coriander-cage  3.75 -0.7518788 8.251879 0.0950757
maize-cage      5.00  0.4981212 9.501879 0.0331339
maize-coriander 1.25 -3.2518788 5.751879 0.6872893

>
```

c) Maize + mint eggs and egg masses



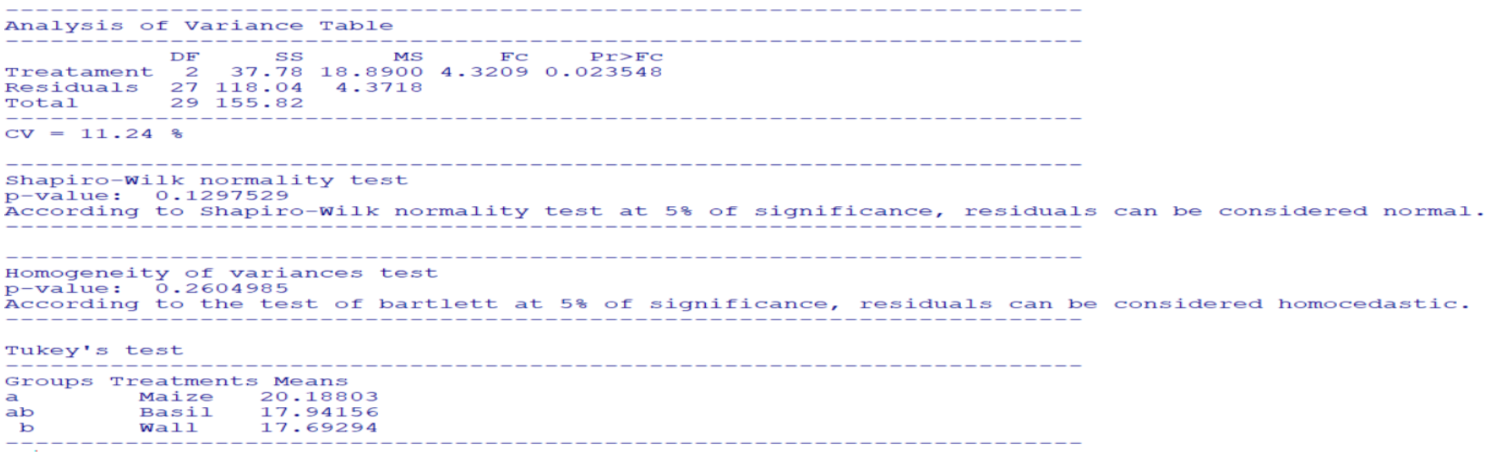
```
---------------------------------------
ANOVA for eggs in treatment: maize + basil
            Df  Sum Sq Mean Sq F value  Pr(>F)
site         2 3480583 1740292  17.902 0.00296 **
block        3   15875    5292   0.054 0.98173
Residuals    6  583267   97211
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Tukey HSD for sites within: maize + basil
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = eggs_adj ~ site + block, data = df_sub)

$site
               diff         lwr        upr     p adj
cage-basil  -581.75 -1258.20236   94.70236 0.0855776
maize-basil  734.50    58.04764 1410.95236 0.0362967
maize-cage  1316.25   639.79764 1992.70236 0.0023980
```



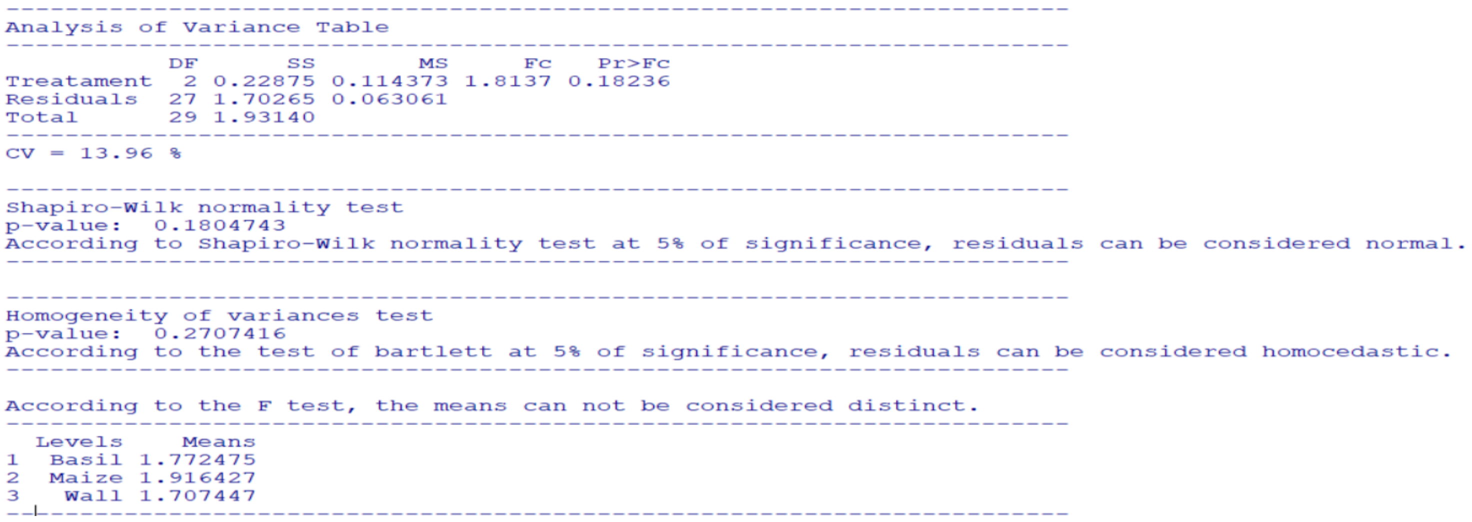
```
---------------------------------------
ANOVA for MASS in treatment: maize + basil
            Df Sum Sq Mean Sq F value Pr(>F)
site         2 1.6251  0.8126  23.204 0.0015 **
block        3 0.0264  0.0088   0.251 0.8579
Residuals    6 0.2101  0.0350
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Tukey HSD for sites within: maize + basil
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = masses_adj ~ site + block, data = df_sub)

$site
                  diff        lwr        upr     p adj
cage-basil  -0.6454124 -1.0514133 -0.2394114 0.0066336
maize-basil  0.2222698 -0.1837311  0.6282708 0.2870547
maize-cage   0.8676822  0.4616812  1.2736832 0.0014653
```

Appendix 2. Laboratory Two Choice Test Eggs and Egg Masses Anova Tables On Various Treatments

2.1 Number of eggs and egg masses on basil two choice ANOVA output after square root transformation

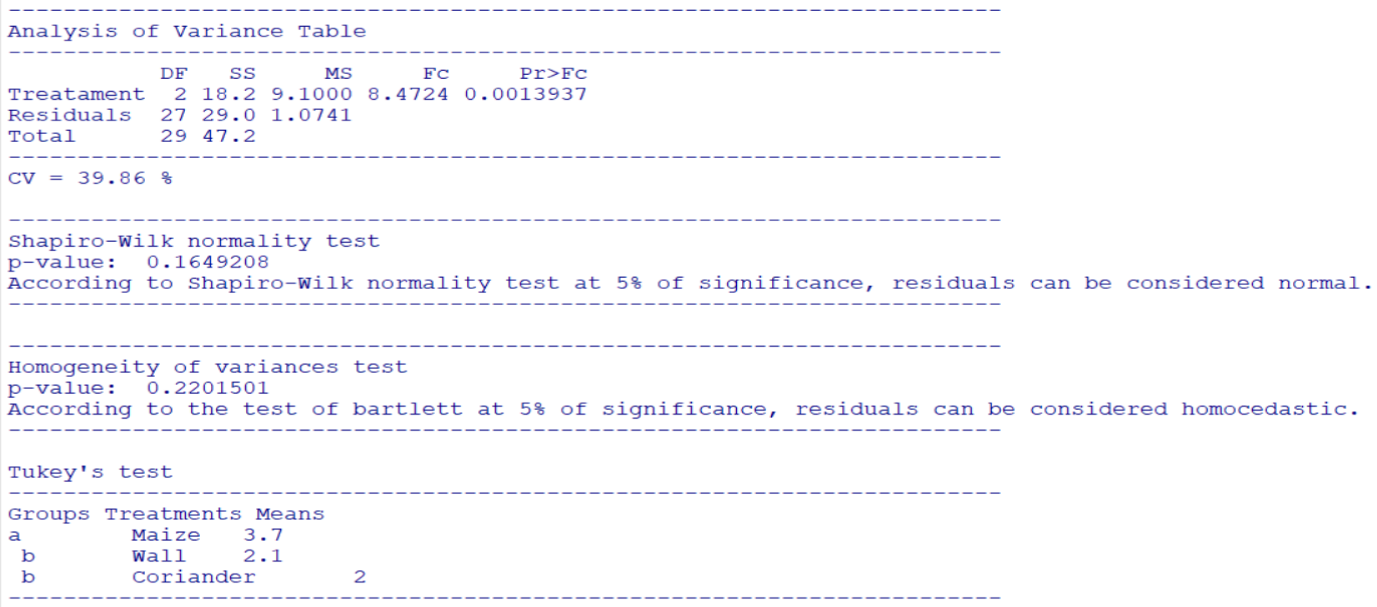


```
------------------------------------------------------------------------
Analysis of Variance Table
------------------------------------------------------------------------
           DF     SS      MS     Fc    Pr>Fc
Treatament  2  37.78 18.8900 4.3209 0.023548
Residuals  27 118.04  4.3718
Total      29 155.82
------------------------------------------------------------------------
CV = 11.24 %

------------------------------------------------------------------------
Shapiro-Wilk normality test
p-value:  0.1297529
According to Shapiro-Wilk normality test at 5% of significance, residuals can be considered normal.
------------------------------------------------------------------------

------------------------------------------------------------------------
Homogeneity of variances test
p-value:  0.2604985
According to the test of bartlett at 5% of significance, residuals can be considered homocedastic.
------------------------------------------------------------------------

Tukey's test
------------------------------------------------------------------------
Groups Treatments Means
a        Maize    20.18803
ab       Basil    17.94156
 b       Wall     17.69294
------------------------------------------------------------------------
```

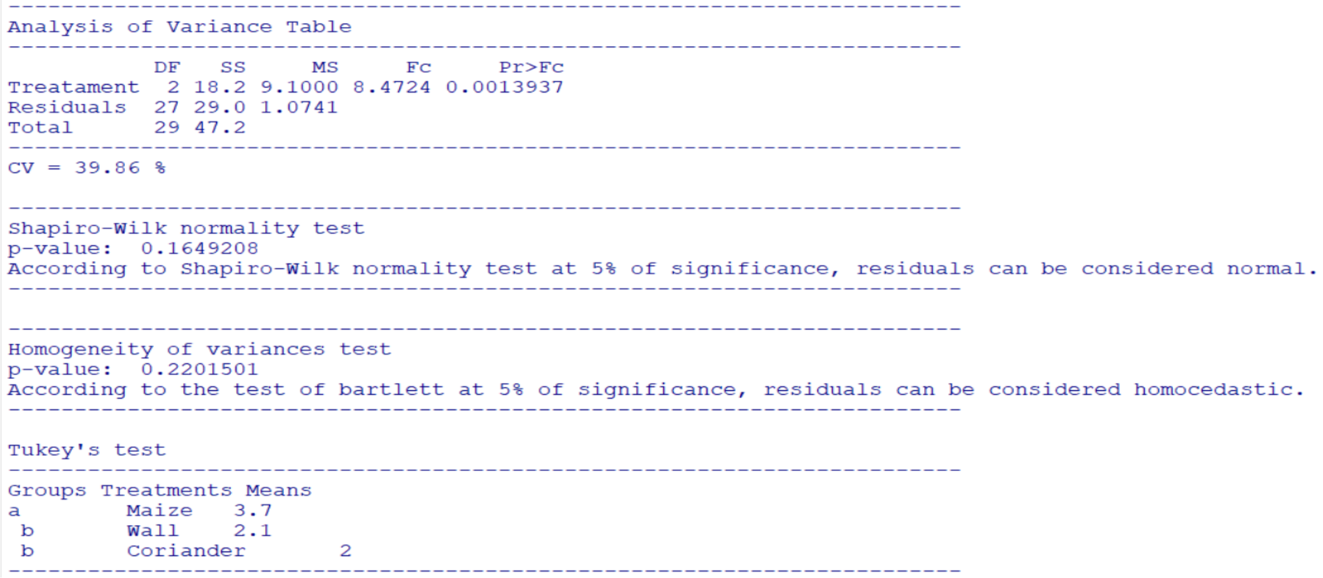


```
------------------------------------------------------------------------
Analysis of Variance Table
------------------------------------------------------------------------
           DF      SS       MS     Fc   Pr>Fc
Treatament  2 0.22875 0.114373 1.8137 0.18236
Residuals  27 1.70265 0.063061
Total      29 1.93140
------------------------------------------------------------------------
CV = 13.96 %

------------------------------------------------------------------------
Shapiro-Wilk normality test
p-value:  0.1804743
According to Shapiro-Wilk normality test at 5% of significance, residuals can be considered normal.
------------------------------------------------------------------------

------------------------------------------------------------------------
Homogeneity of variances test
p-value:  0.2707416
According to the test of bartlett at 5% of significance, residuals can be considered homocedastic.
------------------------------------------------------------------------

According to the F test, the means can not be considered distinct.
------------------------------------------------------------------------
  Levels    Means
1  Basil 1.772475
2  Maize 1.916427
3   Wall 1.707447
------------------------------------------------------------------------
```

2.2. Analysis of variance of coriander two choice mean egg masses and mean number of egg oviposition test

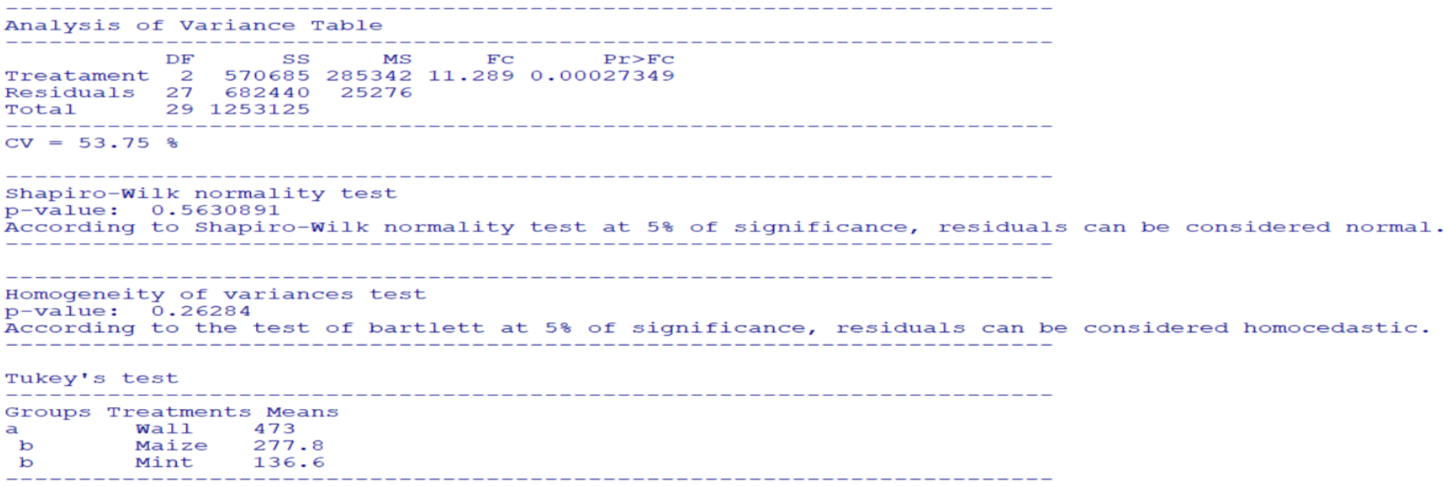


```
------------------------------------------------------------------------
Analysis of Variance Table
------------------------------------------------------------------------
           DF   SS     MS     Fc     Pr>Fc
Treatament  2 18.2 9.1000 8.4724 0.0013937
Residuals  27 29.0 1.0741
Total      29 47.2
------------------------------------------------------------------------
CV = 39.86 %

------------------------------------------------------------------------
Shapiro-Wilk normality test
p-value:  0.1649208
According to Shapiro-Wilk normality test at 5% of significance, residuals can be considered normal.
------------------------------------------------------------------------

------------------------------------------------------------------------
Homogeneity of variances test
p-value:  0.2201501
According to the test of bartlett at 5% of significance, residuals can be considered homocedastic.
------------------------------------------------------------------------

Tukey's test
------------------------------------------------------------------------
Groups Treatments Means
a        Maize    3.7
 b       Wall     2.1
 b       Coriander       2
------------------------------------------------------------------------
```

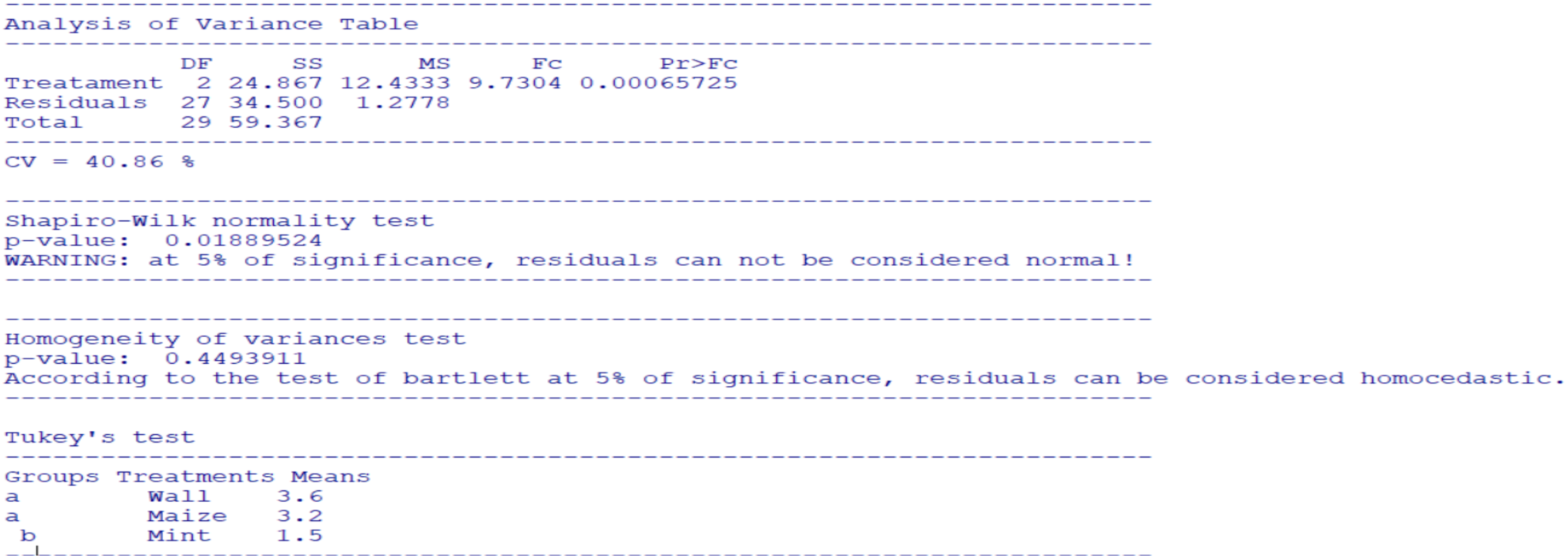


```
------------------------------------------------------------------------
Analysis of Variance Table
------------------------------------------------------------------------
           DF   SS     MS     Fc     Pr>Fc
Treatament  2 18.2 9.1000 8.4724 0.0013937
Residuals  27 29.0 1.0741
Total      29 47.2
------------------------------------------------------------------------
CV = 39.86 %

------------------------------------------------------------------------
Shapiro-Wilk normality test
p-value:  0.1649208
According to Shapiro-Wilk normality test at 5% of significance, residuals can be considered normal.
------------------------------------------------------------------------

------------------------------------------------------------------------
Homogeneity of variances test
p-value:  0.2201501
According to the test of bartlett at 5% of significance, residuals can be considered homocedastic.
------------------------------------------------------------------------

Tukey's test
------------------------------------------------------------------------
Groups Treatments Means
a        Maize    3.7
 b       Wall     2.1
 b       Coriander       2
------------------------------------------------------------------------
```

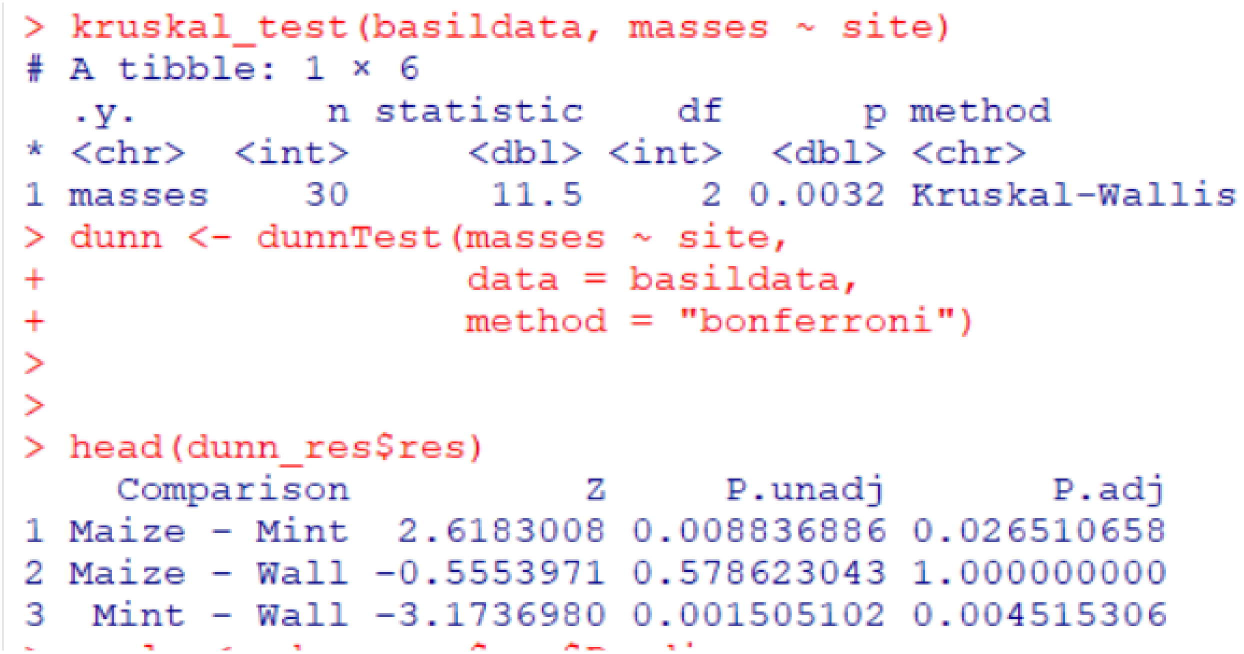
2.3 Analysis of variance of mint two choice mean egg masses and Kruskal Wallis mint two choice mean egg masses oviposition test and mean number of egg oviposition test



```
------------------------------------------------------------------------
Analysis of Variance Table
------------------------------------------------------------------------
           DF      SS     MS     Fc      Pr>Fc
Treatament  2  570685 285342 11.289 0.00027349
Residuals  27  682440  25276
Total      29 1253125
------------------------------------------------------------------------
CV = 53.75 %

------------------------------------------------------------------------
Shapiro-Wilk normality test
p-value:  0.5630891
According to Shapiro-Wilk normality test at 5% of significance, residuals can be considered normal.
------------------------------------------------------------------------

------------------------------------------------------------------------
Homogeneity of variances test
p-value:  0.26284
According to the test of bartlett at 5% of significance, residuals can be considered homocedastic.
------------------------------------------------------------------------

Tukey's test
------------------------------------------------------------------------
Groups Treatments Means
a        Wall     473
 b       Maize    277.8
 b       Mint     136.6
------------------------------------------------------------------------
```



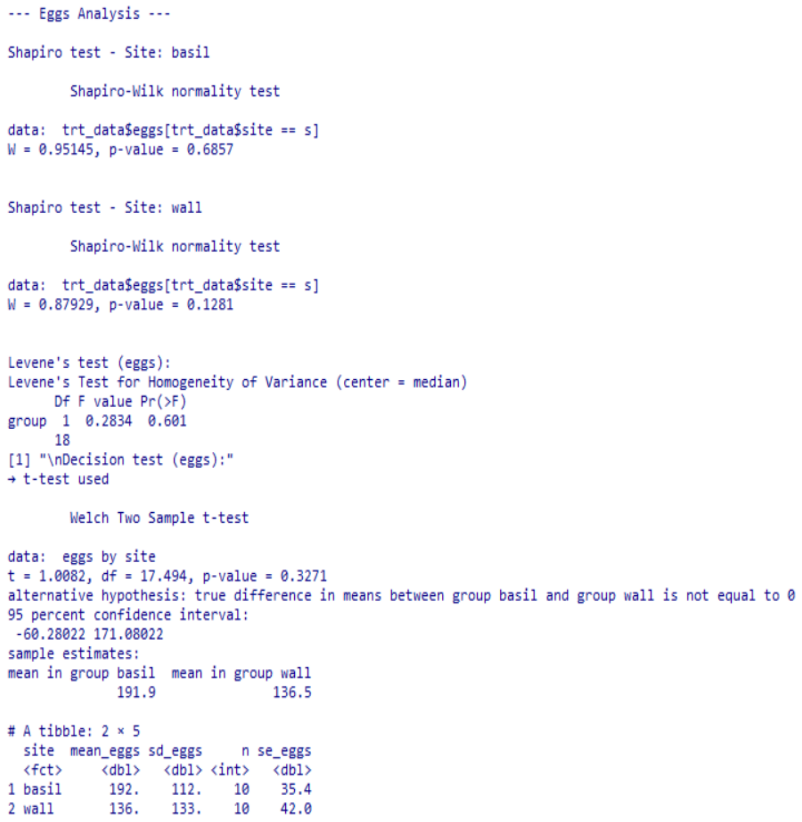
```
------------------------------------------------------------------------
Analysis of Variance Table
------------------------------------------------------------------------
           DF     SS      MS     Fc      Pr>Fc
Treatament  2 24.867 12.4333 9.7304 0.00065725
Residuals  27 34.500  1.2778
Total      29 59.367
------------------------------------------------------------------------
CV = 40.86 %

------------------------------------------------------------------------
Shapiro-Wilk normality test
p-value:  0.01889524
WARNING: at 5% of significance, residuals can not be considered normal!
------------------------------------------------------------------------

------------------------------------------------------------------------
Homogeneity of variances test
p-value:  0.4493911
According to the test of bartlett at 5% of significance, residuals can be considered homocedastic.
------------------------------------------------------------------------

Tukey's test
------------------------------------------------------------------------
Groups Treatments Means
a        Wall     3.6
a        Maize    3.2
 b       Mint     1.5
------------------------------------------------------------------------
```



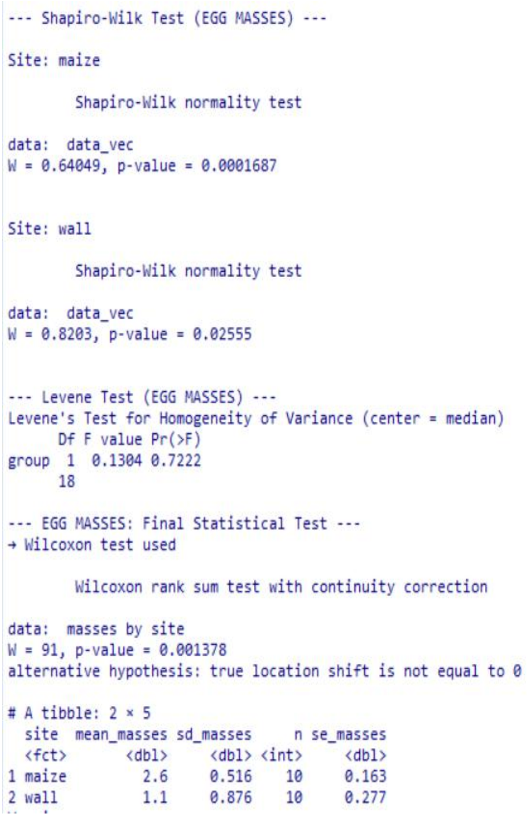
```
> kruskal_test(basildata, masses ~ site)
# A tibble: 1 × 6
  .y.        n statistic    df       p method
* <chr>  <int>     <dbl> <int>   <dbl> <chr>
1 masses    30      11.5     2 0.0032 Kruskal-Wallis
> dunn <- dunnTest(masses ~ site,
+                  data = basildata,
+                  method = "bonferroni")
>
>
> head(dunn_res$res)
    Comparison          Z      P.unadj        P.adj
1 Maize - Mint  2.6183008 0.008836886 0.026510658
2 Maize - Wall -0.5553971 0.578623043 1.000000000
3  Mint - Wall -3.1736980 0.001505102 0.004515306
```

Appendix 3.No Choice Test Eggs And Egg Masses T Test/Wilcoxon Tables On Various Treatments

3.1 Basil Number of Egg and egg masses normality and equal variance tests and T test (eggs) and Wilcoxon rank test (egg masses)

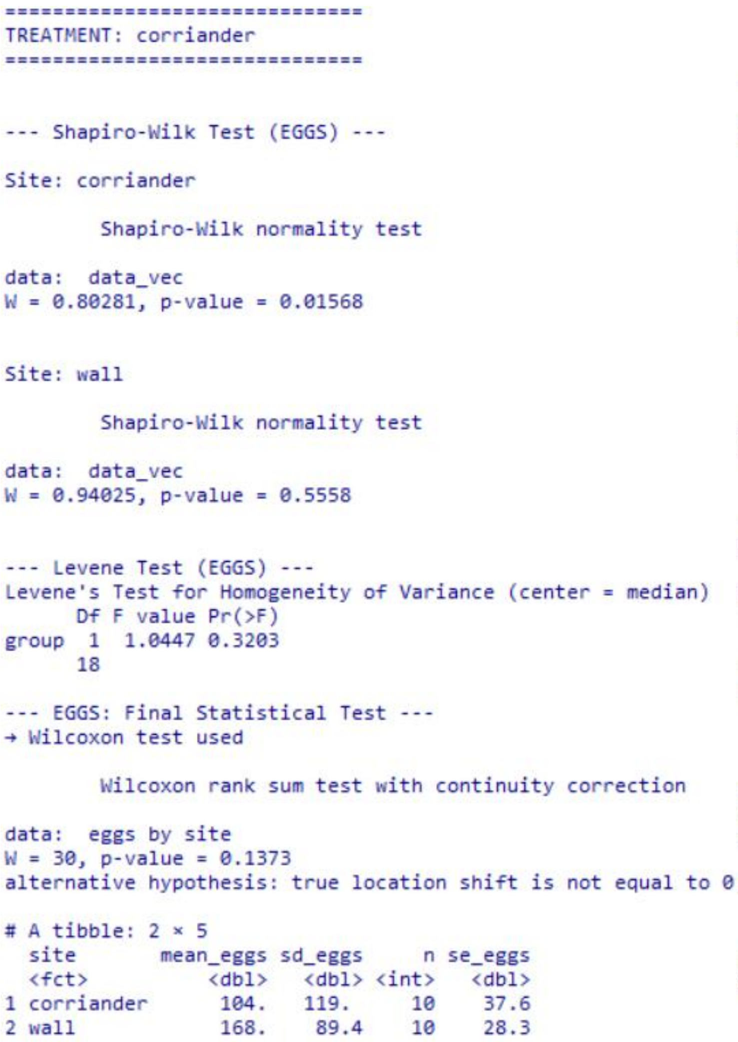


```
--- Eggs Analysis ---

Shapiro test - Site: basil

        Shapiro-Wilk normality test

data:  trt_data$eggs[trt_data$site == s]
W = 0.95145, p-value = 0.6857


Shapiro test - Site: wall

        Shapiro-Wilk normality test

data:  trt_data$eggs[trt_data$site == s]
W = 0.87929, p-value = 0.1281


Levene's test (eggs):
Levene's Test for Homogeneity of Variance (center = median)
      Df F value Pr(>F)
group  1  0.2834  0.601
      18
[1] "\nDecision test (eggs):"
→ t-test used

        Welch Two Sample t-test

data:  eggs by site
t = 1.0082, df = 17.494, p-value = 0.3271
alternative hypothesis: true difference in means between group basil and group wall is not equal to 0
95 percent confidence interval:
 -60.28022 171.08022
sample estimates:
mean in group basil  mean in group wall 
              191.9               136.5 

# A tibble: 2 × 5
  site  mean_eggs sd_eggs     n se_eggs
  <fct>     <dbl>   <dbl> <int>   <dbl>
1 basil      192.    112.    10    35.4
2 wall       136.    133.    10    42.0
```

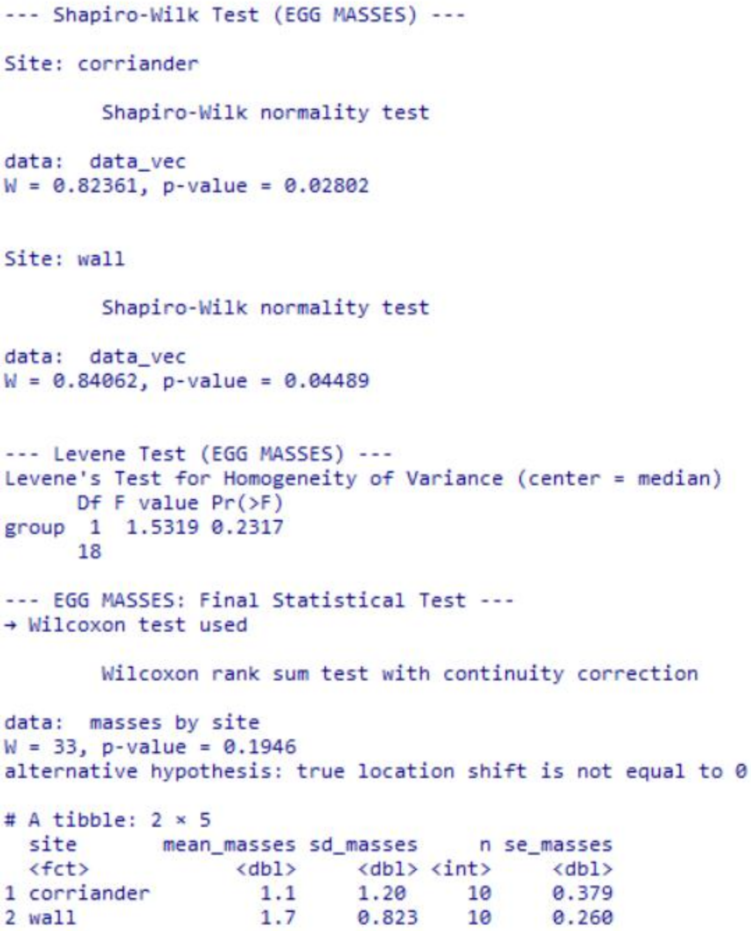


```
--- Shapiro-Wilk Test (EGG MASSES) ---

Site: maize

        Shapiro-Wilk normality test

data:  data_vec
W = 0.64049, p-value = 0.0001687


Site: wall

        Shapiro-Wilk normality test

data:  data_vec
W = 0.8203, p-value = 0.02555


--- Levene Test (EGG MASSES) ---
Levene's Test for Homogeneity of Variance (center = median)
      Df F value Pr(>F)
group  1  0.1304 0.7222
      18

--- EGG MASSES: Final Statistical Test ---
→ Wilcoxon test used

        Wilcoxon rank sum test with continuity correction

data:  masses by site
W = 91, p-value = 0.001378
alternative hypothesis: true location shift is not equal to 0

# A tibble: 2 × 5
  site  mean_masses sd_masses     n se_masses
  <fct>       <dbl>     <dbl> <int>     <dbl>
1 maize         2.6     0.516    10     0.163
2 wall          1.1     0.876    10     0.277
```

3.2 Coriander no choice number of eggs and egg masses normality and homoscedasticity tests and Wilcoxon rank tests.

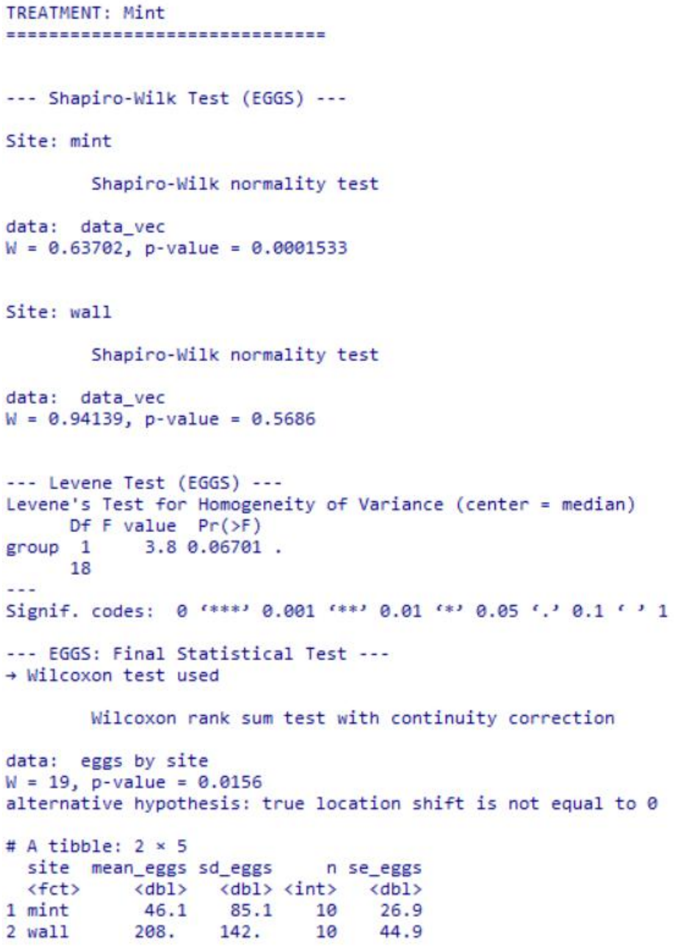


```
==============================
TREATMENT: corriander
==============================


--- Shapiro-Wilk Test (EGGS) ---

Site: corriander

        Shapiro-Wilk normality test

data:  data_vec
W = 0.80281, p-value = 0.01568


Site: wall

        Shapiro-Wilk normality test

data:  data_vec
W = 0.94025, p-value = 0.5558


--- Levene Test (EGGS) ---
Levene's Test for Homogeneity of Variance (center = median)
      Df F value Pr(>F)
group  1  1.0447 0.3203
      18

--- EGGS: Final Statistical Test ---
→ Wilcoxon test used

        Wilcoxon rank sum test with continuity correction

data:  eggs by site
W = 30, p-value = 0.1373
alternative hypothesis: true location shift is not equal to 0

# A tibble: 2 × 5
  site       mean_eggs sd_eggs     n se_eggs
  <fct>          <dbl>   <dbl> <int>   <dbl>
1 corriander      104.    119.    10    37.6
2 wall            168.     89.4   10    28.3
```

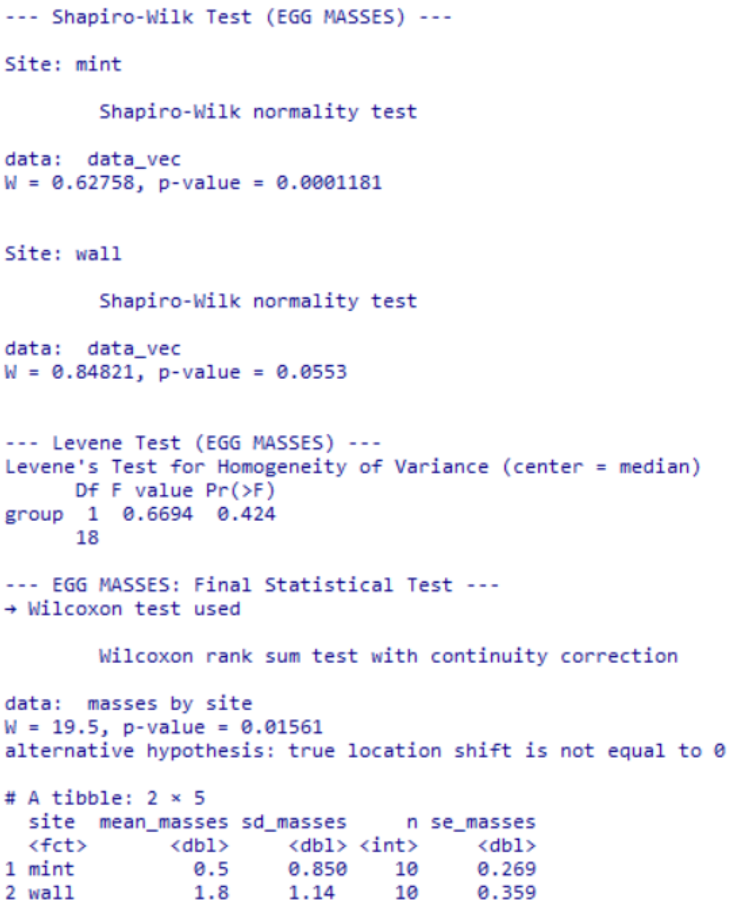


```
--- Shapiro-Wilk Test (EGG MASSES) ---

Site: corriander

        Shapiro-Wilk normality test

data:  data_vec
W = 0.82361, p-value = 0.02802


Site: wall

        Shapiro-Wilk normality test

data:  data_vec
W = 0.84062, p-value = 0.04489


--- Levene Test (EGG MASSES) ---
Levene's Test for Homogeneity of Variance (center = median)
      Df F value Pr(>F)
group  1  1.5319 0.2317
      18

--- EGG MASSES: Final Statistical Test ---
→ Wilcoxon test used

        Wilcoxon rank sum test with continuity correction

data:  masses by site
W = 33, p-value = 0.1946
alternative hypothesis: true location shift is not equal to 0
# A tibble: 2 × 5
  site       mean_masses sd_masses     n se_masses
  <fct>            <dbl>     <dbl> <int>     <dbl>
1 corriander         1.1     1.20     10     0.379
2 wall               1.7     0.823    10     0.260
```

3.3 Mint no choice normality and homoscedasticity test on eggs and egg masses and Wilcoxon test.

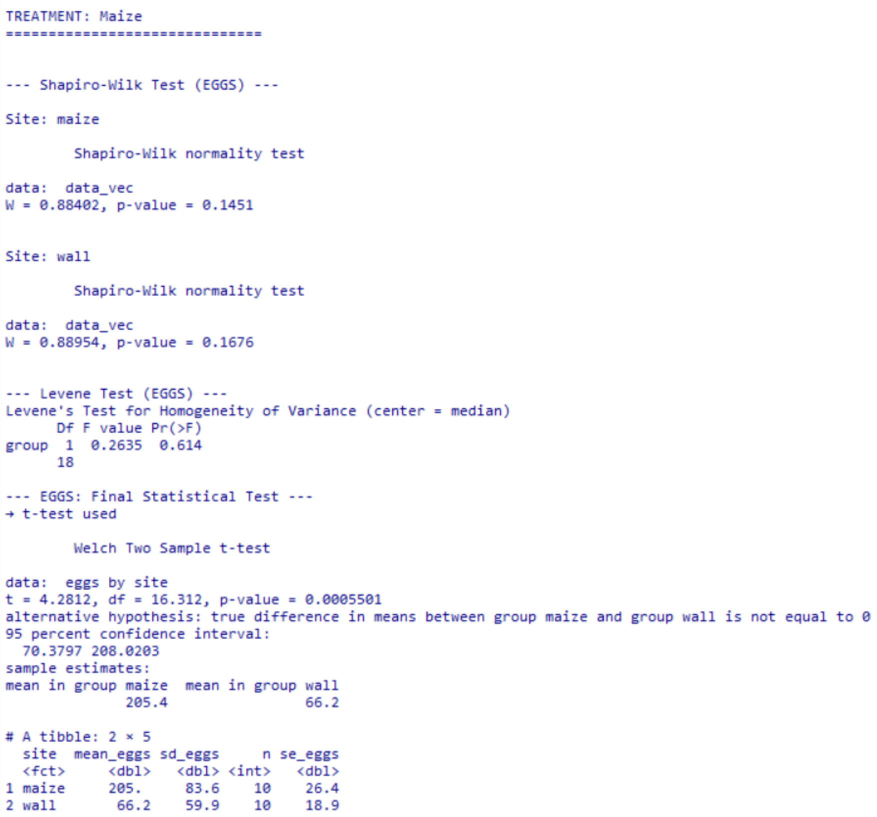


```
TREATMENT: Mint
==============================


--- Shapiro-Wilk Test (EGGS) ---

Site: mint

        Shapiro-Wilk normality test

data:  data_vec
W = 0.63702, p-value = 0.0001533


Site: wall

        Shapiro-Wilk normality test

data:  data_vec
W = 0.94139, p-value = 0.5686


--- Levene Test (EGGS) ---
Levene's Test for Homogeneity of Variance (center = median)
      Df F value  Pr(>F)  
group  1     3.8 0.06701 .
      18                  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

--- EGGS: Final Statistical Test ---
→ Wilcoxon test used

        Wilcoxon rank sum test with continuity correction

data:  eggs by site
W = 19, p-value = 0.0156
alternative hypothesis: true location shift is not equal to 0

# A tibble: 2 × 5
  site  mean_eggs sd_eggs     n se_eggs
  <fct>     <dbl>   <dbl> <int>   <dbl>
1 mint       46.1    85.1    10    26.9
2 wall      208.    142.     10    44.9
```

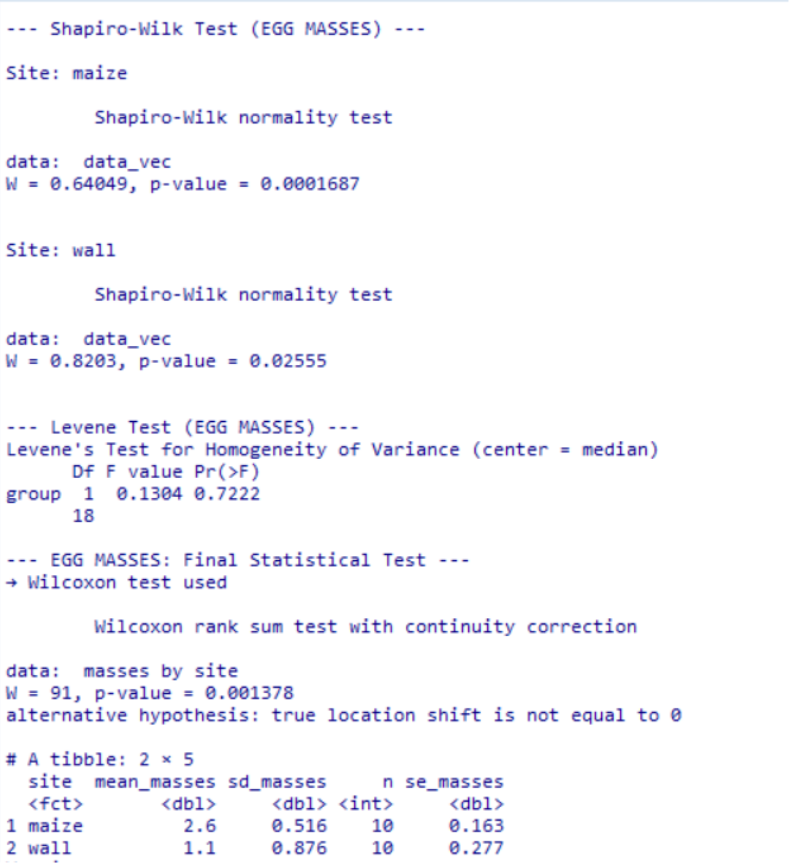


```
--- Shapiro-Wilk Test (EGG MASSES) ---

Site: mint

        Shapiro-Wilk normality test

data:  data_vec
W = 0.62758, p-value = 0.0001181


Site: wall

        Shapiro-Wilk normality test

data:  data_vec
W = 0.84821, p-value = 0.0553


--- Levene Test (EGG MASSES) ---
Levene's Test for Homogeneity of Variance (center = median)
      Df F value Pr(>F)
group  1  0.6694  0.424
      18               

--- EGG MASSES: Final Statistical Test ---
→ Wilcoxon test used

        Wilcoxon rank sum test with continuity correction

data:  masses by site
W = 19.5, p-value = 0.01561
alternative hypothesis: true location shift is not equal to 0

# A tibble: 2 × 5
  site  mean_masses sd_masses     n se_masses
  <fct>       <dbl>     <dbl> <int>     <dbl>
1 mint          0.5     0.850    10     0.269
2 wall          1.8     1.14     10     0.359
```

3.4 Maize no choice normality and homoscedasticity test on eggs and egg masses T test (eggs)and Wilcoxon test (egg masses).

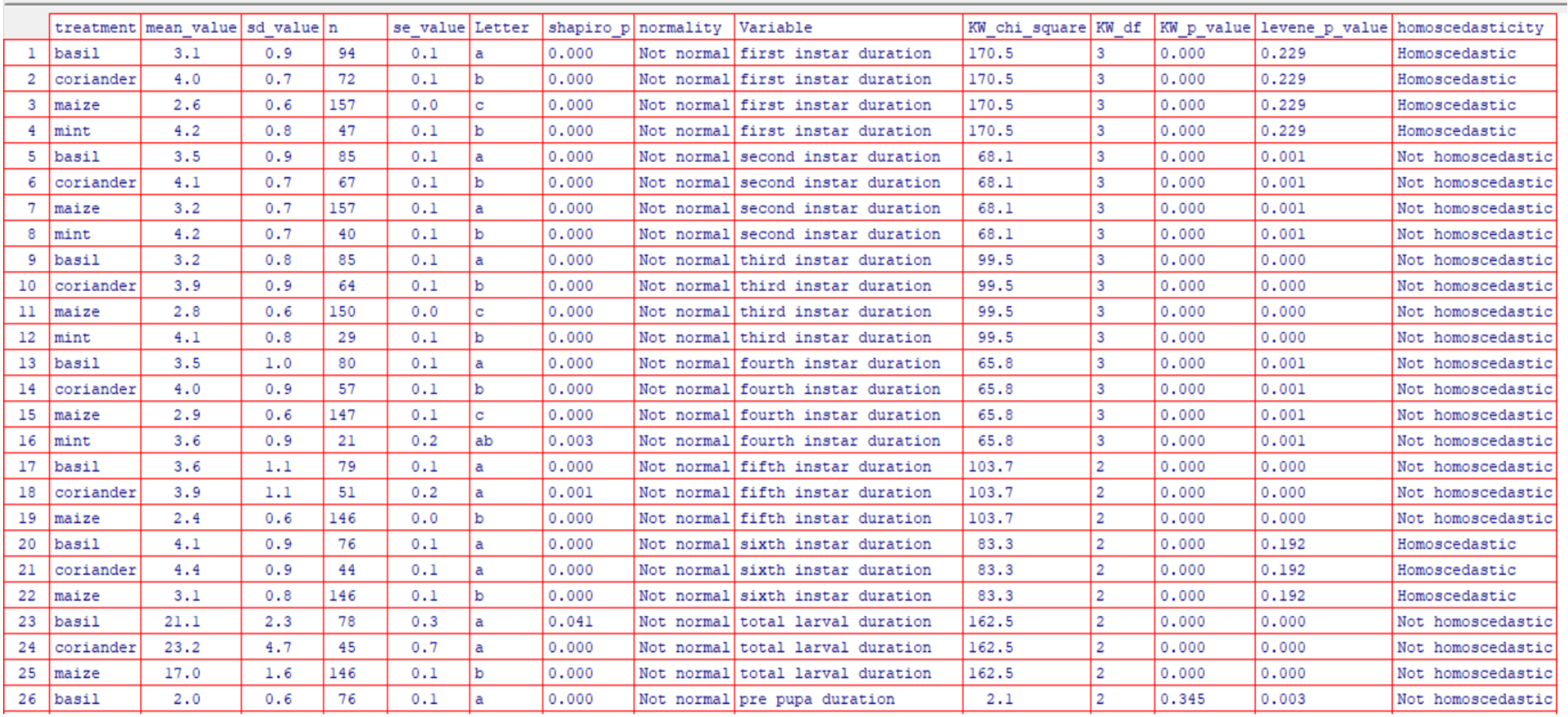


```
TREATMENT: Maize
==============================


--- Shapiro-Wilk Test (EGGS) ---

Site: maize

        Shapiro-Wilk normality test

data:  data_vec
W = 0.88402, p-value = 0.1451


Site: wall

        Shapiro-Wilk normality test

data:  data_vec
W = 0.88954, p-value = 0.1676


--- Levene Test (EGGS) ---
Levene's Test for Homogeneity of Variance (center = median)
      Df F value Pr(>F)
group  1  0.2635  0.614
      18

--- EGGS: Final Statistical Test ---
→ t-test used

        Welch Two Sample t-test

data:  eggs by site
t = 4.2812, df = 16.312, p-value = 0.0005501
alternative hypothesis: true difference in means between group maize and group wall is not equal to 0
95 percent confidence interval:
  70.3797 208.0203
sample estimates:
mean in group maize  mean in group wall
              205.4                66.2

# A tibble: 2 × 5
  site  mean_eggs sd_eggs     n se_eggs
  <fct>     <dbl>   <dbl> <int>   <dbl>
1 maize     205.     83.6    10    26.4
2 wall       66.2    59.9    10    18.9
```

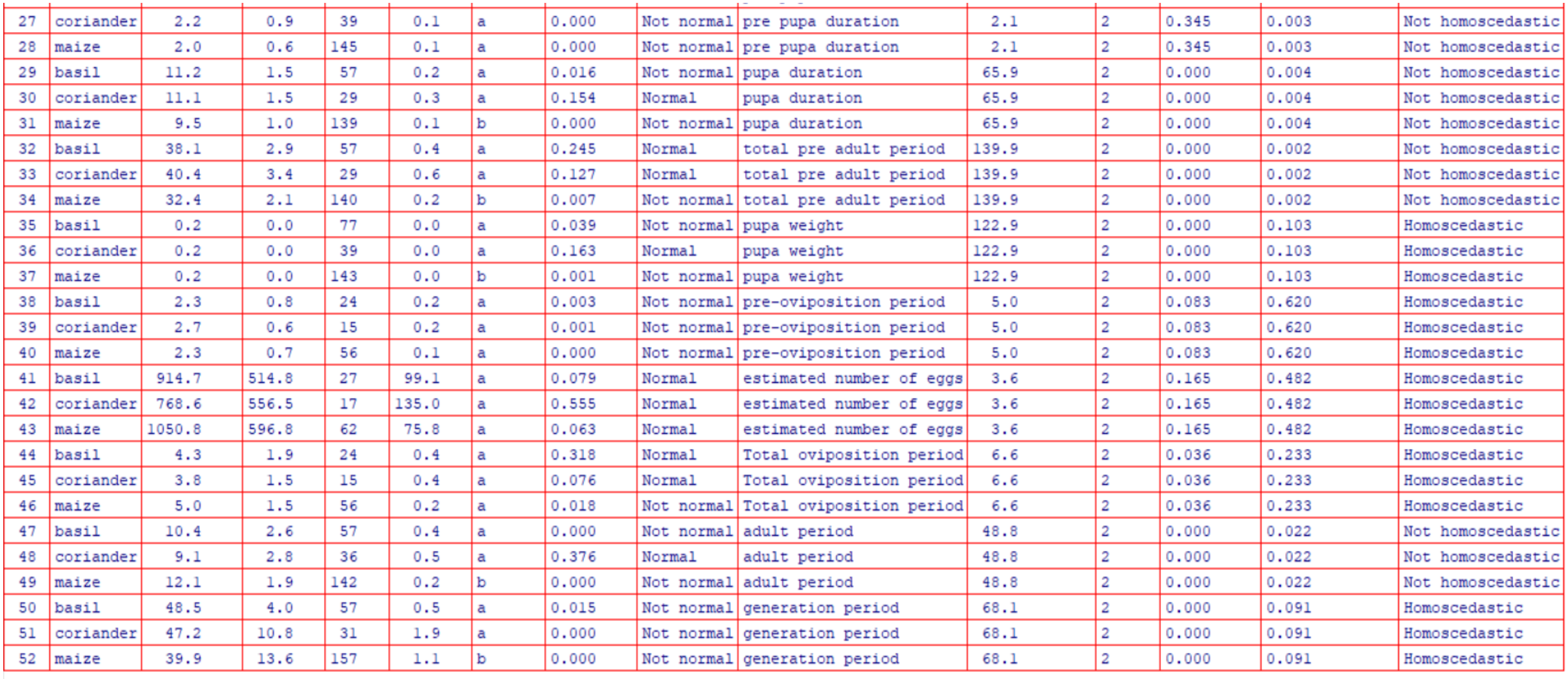


```
--- Shapiro-Wilk Test (EGG MASSES) ---

Site: maize

        Shapiro-Wilk normality test

data:  data_vec
W = 0.64049, p-value = 0.0001687


Site: wall

        Shapiro-Wilk normality test

data:  data_vec
W = 0.8203, p-value = 0.02555


--- Levene Test (EGG MASSES) ---
Levene's Test for Homogeneity of Variance (center = median)
      Df F value Pr(>F)
group  1  0.1304 0.7222
      18

--- EGG MASSES: Final Statistical Test ---
→ Wilcoxon test used

        Wilcoxon rank sum test with continuity correction

data:  masses by site
W = 91, p-value = 0.001378
alternative hypothesis: true location shift is not equal to 0

# A tibble: 2 × 5
  site  mean_masses sd_masses     n se_masses
  <fct>       <dbl>     <dbl> <int>     <dbl>
1 maize         2.6     0.516    10     0.163
2 wall          1.1     0.876    10     0.277
```

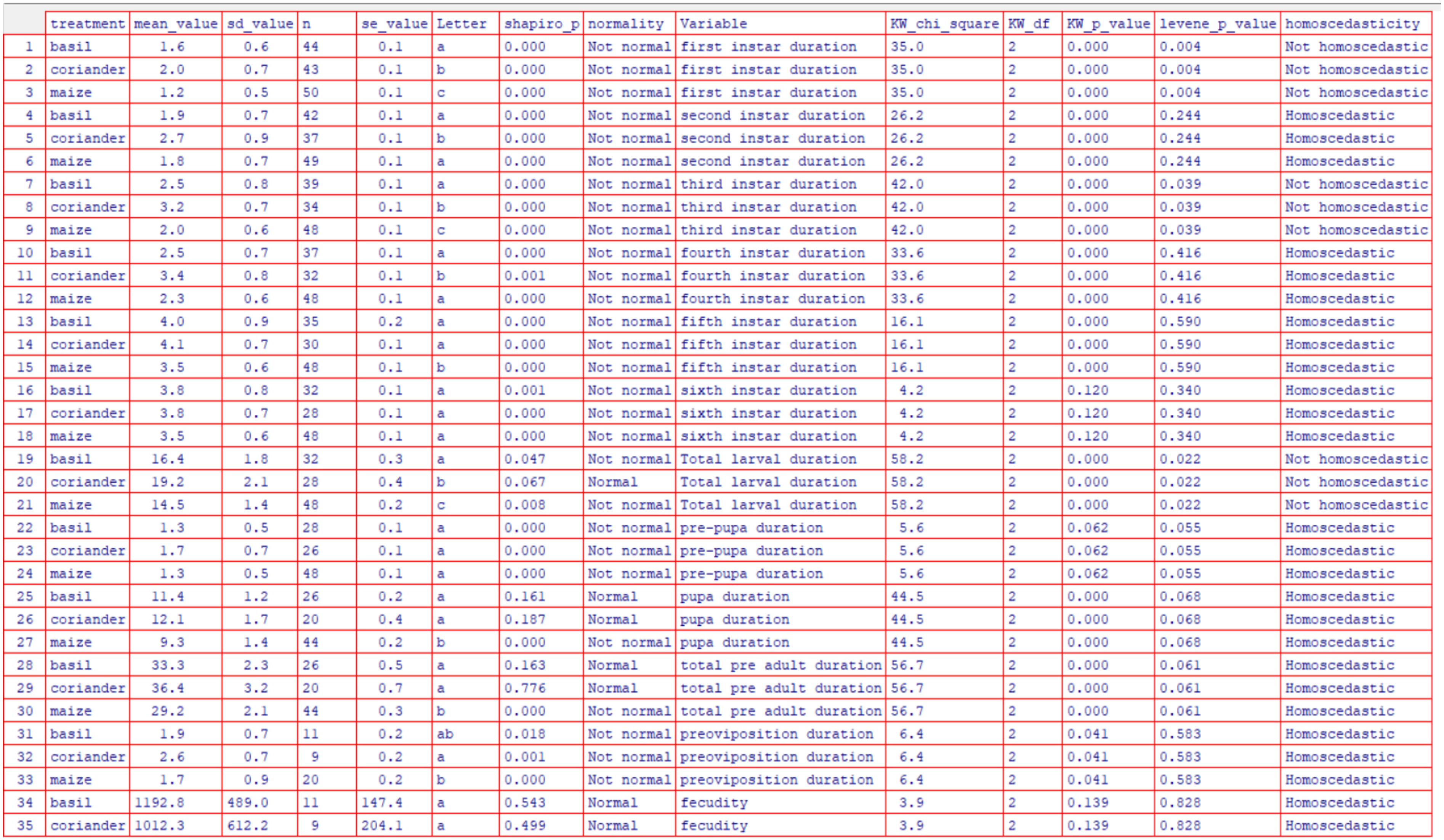
Appendix 4. Survival and development analysis outputs for F_1 and F_2 generation.



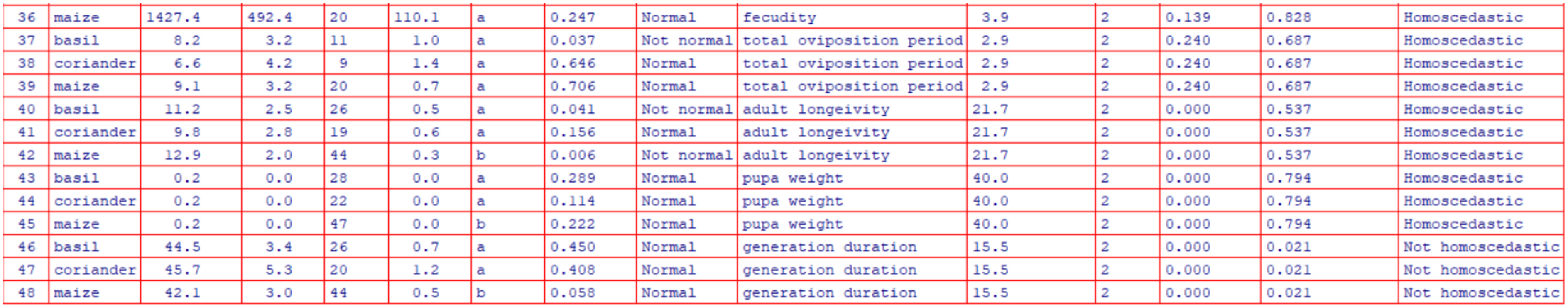
	treatment	mean_value	sd_value	n	se_value	Letter	shapiro_p	normality	Variable	KW_chi_square	KW_df	KW_p_value	levene_p_value	homoscedasticity
1	basil	3.1	0.9	94	0.1	a	0.000	Not normal	first instar duration	170.5	3	0.000	0.229	Homoscedastic
2	coriander	4.0	0.7	72	0.1	b	0.000	Not normal	first instar duration	170.5	3	0.000	0.229	Homoscedastic
3	maize	2.6	0.6	157	0.0	c	0.000	Not normal	first instar duration	170.5	3	0.000	0.229	Homoscedastic
4	mint	4.2	0.8	47	0.1	b	0.000	Not normal	first instar duration	170.5	3	0.000	0.229	Homoscedastic
5	basil	3.5	0.9	85	0.1	a	0.000	Not normal	second instar duration	68.1	3	0.000	0.001	Not homoscedastic
6	coriander	4.1	0.7	67	0.1	b	0.000	Not normal	second instar duration	68.1	3	0.000	0.001	Not homoscedastic
7	maize	3.2	0.7	157	0.1	a	0.000	Not normal	second instar duration	68.1	3	0.000	0.001	Not homoscedastic
8	mint	4.2	0.7	40	0.1	b	0.000	Not normal	second instar duration	68.1	3	0.000	0.001	Not homoscedastic
9	basil	3.2	0.8	85	0.1	a	0.000	Not normal	third instar duration	99.5	3	0.000	0.000	Not homoscedastic
10	coriander	3.9	0.9	64	0.1	b	0.000	Not normal	third instar duration	99.5	3	0.000	0.000	Not homoscedastic
11	maize	2.8	0.6	150	0.0	c	0.000	Not normal	third instar duration	99.5	3	0.000	0.000	Not homoscedastic
12	mint	4.1	0.8	29	0.1	b	0.000	Not normal	third instar duration	99.5	3	0.000	0.000	Not homoscedastic
13	basil	3.5	1.0	80	0.1	a	0.000	Not normal	fourth instar duration	65.8	3	0.000	0.001	Not homoscedastic
14	coriander	4.0	0.9	57	0.1	b	0.000	Not normal	fourth instar duration	65.8	3	0.000	0.001	Not homoscedastic
15	maize	2.9	0.6	147	0.1	c	0.000	Not normal	fourth instar duration	65.8	3	0.000	0.001	Not homoscedastic
16	mint	3.6	0.9	21	0.2	ab	0.003	Not normal	fourth instar duration	65.8	3	0.000	0.001	Not homoscedastic
17	basil	3.6	1.1	79	0.1	a	0.000	Not normal	fifth instar duration	103.7	2	0.000	0.000	Not homoscedastic
18	coriander	3.9	1.1	51	0.2	a	0.001	Not normal	fifth instar duration	103.7	2	0.000	0.000	Not homoscedastic
19	maize	2.4	0.6	146	0.0	b	0.000	Not normal	fifth instar duration	103.7	2	0.000	0.000	Not homoscedastic
20	basil	4.1	0.9	76	0.1	a	0.000	Not normal	sixth instar duration	83.3	2	0.000	0.192	Homoscedastic
21	coriander	4.4	0.9	44	0.1	a	0.000	Not normal	sixth instar duration	83.3	2	0.000	0.192	Homoscedastic
22	maize	3.1	0.8	146	0.1	b	0.000	Not normal	sixth instar duration	83.3	2	0.000	0.192	Homoscedastic
23	basil	21.1	2.3	78	0.3	a	0.041	Not normal	total larval duration	162.5	2	0.000	0.000	Not homoscedastic
24	coriander	23.2	4.7	45	0.7	a	0.000	Not normal	total larval duration	162.5	2	0.000	0.000	Not homoscedastic
25	maize	17.0	1.6	146	0.1	b	0.000	Not normal	total larval duration	162.5	2	0.000	0.000	Not homoscedastic
26	basil	2.0	0.6	76	0.1	a	0.000	Not normal	pre pupa duration	2.1	2	0.345	0.003	Not homoscedastic



27	coriander	2.2	0.9	39	0.1	a	0.000	Not normal	pre pupa duration	2.1	2	0.345	0.003	Not homoscedastic
28	maize	2.0	0.6	145	0.1	a	0.000	Not normal	pre pupa duration	2.1	2	0.345	0.003	Not homoscedastic
29	basil	11.2	1.5	57	0.2	a	0.016	Not normal	pupa duration	65.9	2	0.000	0.004	Not homoscedastic
30	coriander	11.1	1.5	29	0.3	a	0.154	Normal	pupa duration	65.9	2	0.000	0.004	Not homoscedastic
31	maize	9.5	1.0	139	0.1	b	0.000	Not normal	pupa duration	65.9	2	0.000	0.004	Not homoscedastic
32	basil	38.1	2.9	57	0.4	a	0.245	Normal	total pre adult period	139.9	2	0.000	0.002	Not homoscedastic
33	coriander	40.4	3.4	29	0.6	a	0.127	Normal	total pre adult period	139.9	2	0.000	0.002	Not homoscedastic
34	maize	32.4	2.1	140	0.2	b	0.007	Not normal	total pre adult period	139.9	2	0.000	0.002	Not homoscedastic
35	basil	0.2	0.0	77	0.0	a	0.039	Not normal	pupa weight	122.9	2	0.000	0.103	Homoscedastic
36	coriander	0.2	0.0	39	0.0	a	0.163	Normal	pupa weight	122.9	2	0.000	0.103	Homoscedastic
37	maize	0.2	0.0	143	0.0	b	0.001	Not normal	pupa weight	122.9	2	0.000	0.103	Homoscedastic
38	basil	2.3	0.8	24	0.2	a	0.003	Not normal	pre-oviposition period	5.0	2	0.083	0.620	Homoscedastic
39	coriander	2.7	0.6	15	0.2	a	0.001	Not normal	pre-oviposition period	5.0	2	0.083	0.620	Homoscedastic
40	maize	2.3	0.7	56	0.1	a	0.000	Not normal	pre-oviposition period	5.0	2	0.083	0.620	Homoscedastic
41	basil	914.7	514.8	27	99.1	a	0.079	Normal	estimated number of eggs	3.6	2	0.165	0.482	Homoscedastic
42	coriander	768.6	556.5	17	135.0	a	0.555	Normal	estimated number of eggs	3.6	2	0.165	0.482	Homoscedastic
43	maize	1050.8	596.8	62	75.8	a	0.063	Normal	estimated number of eggs	3.6	2	0.165	0.482	Homoscedastic
44	basil	4.3	1.9	24	0.4	a	0.318	Normal	Total oviposition period	6.6	2	0.036	0.233	Homoscedastic
45	coriander	3.8	1.5	15	0.4	a	0.076	Normal	Total oviposition period	6.6	2	0.036	0.233	Homoscedastic
46	maize	5.0	1.5	56	0.2	a	0.018	Not normal	Total oviposition period	6.6	2	0.036	0.233	Homoscedastic
47	basil	10.4	2.6	57	0.4	a	0.000	Not normal	adult period	48.8	2	0.000	0.022	Not homoscedastic
48	coriander	9.1	2.8	36	0.5	a	0.376	Normal	adult period	48.8	2	0.000	0.022	Not homoscedastic
49	maize	12.1	1.9	142	0.2	b	0.000	Not normal	adult period	48.8	2	0.000	0.022	Not homoscedastic
50	basil	48.5	4.0	57	0.5	a	0.015	Not normal	generation period	68.1	2	0.000	0.091	Homoscedastic
51	coriander	47.2	10.8	31	1.9	a	0.000	Not normal	generation period	68.1	2	0.000	0.091	Homoscedastic
52	maize	39.9	13.6	157	1.1	b	0.000	Not normal	generation period	68.1	2	0.000	0.091	Homoscedastic



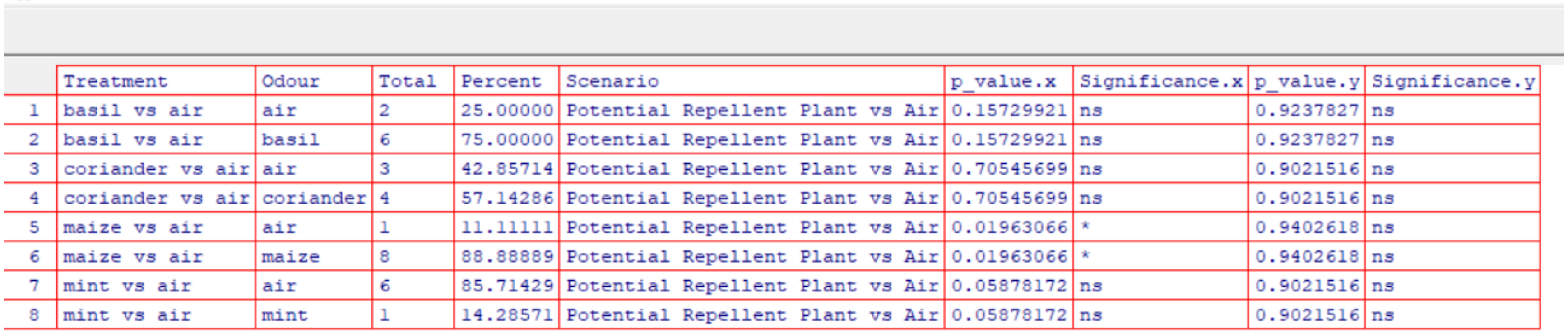
	treatment	mean_value	sd_value	n	se_value	Letter	shapiro_p	normality	Variable	KW_chi_square	KW_df	KW_p_value	levene_p_value	homoscedasticity
1	basil	1.6	0.6	44	0.1	a	0.000	Not normal	first instar duration	35.0	2	0.000	0.004	Not homoscedastic
2	coriander	2.0	0.7	43	0.1	b	0.000	Not normal	first instar duration	35.0	2	0.000	0.004	Not homoscedastic
3	maize	1.2	0.5	50	0.1	c	0.000	Not normal	first instar duration	35.0	2	0.000	0.004	Not homoscedastic
4	basil	1.9	0.7	42	0.1	a	0.000	Not normal	second instar duration	26.2	2	0.000	0.244	Homoscedastic
5	coriander	2.7	0.9	37	0.1	b	0.000	Not normal	second instar duration	26.2	2	0.000	0.244	Homoscedastic
6	maize	1.8	0.7	49	0.1	a	0.000	Not normal	second instar duration	26.2	2	0.000	0.244	Homoscedastic
7	basil	2.5	0.8	39	0.1	a	0.000	Not normal	third instar duration	42.0	2	0.000	0.039	Not homoscedastic
8	coriander	3.2	0.7	34	0.1	b	0.000	Not normal	third instar duration	42.0	2	0.000	0.039	Not homoscedastic
9	maize	2.0	0.6	48	0.1	c	0.000	Not normal	third instar duration	42.0	2	0.000	0.039	Not homoscedastic
10	basil	2.5	0.7	37	0.1	a	0.000	Not normal	fourth instar duration	33.6	2	0.000	0.416	Homoscedastic
11	coriander	3.4	0.8	32	0.1	b	0.001	Not normal	fourth instar duration	33.6	2	0.000	0.416	Homoscedastic
12	maize	2.3	0.6	48	0.1	a	0.000	Not normal	fourth instar duration	33.6	2	0.000	0.416	Homoscedastic
13	basil	4.0	0.9	35	0.2	a	0.000	Not normal	fifth instar duration	16.1	2	0.000	0.590	Homoscedastic
14	coriander	4.1	0.7	30	0.1	a	0.000	Not normal	fifth instar duration	16.1	2	0.000	0.590	Homoscedastic
15	maize	3.5	0.6	48	0.1	b	0.000	Not normal	fifth instar duration	16.1	2	0.000	0.590	Homoscedastic
16	basil	3.8	0.8	32	0.1	a	0.001	Not normal	sixth instar duration	4.2	2	0.120	0.340	Homoscedastic
17	coriander	3.8	0.7	28	0.1	a	0.000	Not normal	sixth instar duration	4.2	2	0.120	0.340	Homoscedastic
18	maize	3.5	0.6	48	0.1	a	0.000	Not normal	sixth instar duration	4.2	2	0.120	0.340	Homoscedastic
19	basil	16.4	1.8	32	0.3	a	0.047	Not normal	Total larval duration	58.2	2	0.000	0.022	Not homoscedastic
20	coriander	19.2	2.1	28	0.4	b	0.067	Normal	Total larval duration	58.2	2	0.000	0.022	Not homoscedastic
21	maize	14.5	1.4	48	0.2	c	0.008	Not normal	Total larval duration	58.2	2	0.000	0.022	Not homoscedastic
22	basil	1.3	0.5	28	0.1	a	0.000	Not normal	pre-pupa duration	5.6	2	0.062	0.055	Homoscedastic
23	coriander	1.7	0.7	26	0.1	a	0.000	Not normal	pre-pupa duration	5.6	2	0.062	0.055	Homoscedastic
24	maize	1.3	0.5	48	0.1	a	0.000	Not normal	pre-pupa duration	5.6	2	0.062	0.055	Homoscedastic
25	basil	11.4	1.2	26	0.2	a	0.161	Normal	pupa duration	44.5	2	0.000	0.068	Homoscedastic
26	coriander	12.1	1.7	20	0.4	a	0.187	Normal	pupa duration	44.5	2	0.000	0.068	Homoscedastic
27	maize	9.3	1.4	44	0.2	b	0.000	Not normal	pupa duration	44.5	2	0.000	0.068	Homoscedastic
28	basil	33.3	2.3	26	0.5	a	0.163	Normal	total pre adult duration	56.7	2	0.000	0.061	Homoscedastic
29	coriander	36.4	3.2	20	0.7	a	0.776	Normal	total pre adult duration	56.7	2	0.000	0.061	Homoscedastic
30	maize	29.2	2.1	44	0.3	b	0.000	Not normal	total pre adult duration	56.7	2	0.000	0.061	Homoscedastic
31	basil	1.9	0.7	11	0.2	ab	0.018	Not normal	preoviposition duration	6.4	2	0.041	0.583	Homoscedastic
32	coriander	2.6	0.7	9	0.2	a	0.001	Not normal	preoviposition duration	6.4	2	0.041	0.583	Homoscedastic
33	maize	1.7	0.9	20	0.2	b	0.000	Not normal	preoviposition duration	6.4	2	0.041	0.583	Homoscedastic
34	basil	1192.8	489.0	11	147.4	a	0.543	Normal	fecudity	3.9	2	0.139	0.828	Homoscedastic
35	coriander	1012.3	612.2	9	204.1	a	0.499	Normal	fecudity	3.9	2	0.139	0.828	Homoscedastic



36	maize	1427.4	492.4	20	110.1	a	0.247	Normal	fecudity	3.9	2	0.139	0.828	Homoscedastic
37	basil	8.2	3.2	11	1.0	a	0.037	Not normal	total oviposition period	2.9	2	0.240	0.687	Homoscedastic
38	coriander	6.6	4.2	9	1.4	a	0.646	Normal	total oviposition period	2.9	2	0.240	0.687	Homoscedastic
39	maize	9.1	3.2	20	0.7	a	0.706	Normal	total oviposition period	2.9	2	0.240	0.687	Homoscedastic
40	basil	11.2	2.5	26	0.5	a	0.041	Not normal	adult longeivity	21.7	2	0.000	0.537	Homoscedastic
41	coriander	9.8	2.8	19	0.6	a	0.156	Normal	adult longeivity	21.7	2	0.000	0.537	Homoscedastic
42	maize	12.9	2.0	44	0.3	b	0.006	Not normal	adult longeivity	21.7	2	0.000	0.537	Homoscedastic
43	basil	0.2	0.0	28	0.0	a	0.289	Normal	pupa weight	40.0	2	0.000	0.794	Homoscedastic
44	coriander	0.2	0.0	22	0.0	a	0.114	Normal	pupa weight	40.0	2	0.000	0.794	Homoscedastic
45	maize	0.2	0.0	47	0.0	b	0.222	Normal	pupa weight	40.0	2	0.000	0.794	Homoscedastic
46	basil	44.5	3.4	26	0.7	a	0.450	Normal	generation duration	15.5	2	0.000	0.021	Not homoscedastic
47	coriander	45.7	5.3	20	1.2	a	0.408	Normal	generation duration	15.5	2	0.000	0.021	Not homoscedastic
48	maize	42.1	3.0	44	0.5	b	0.058	Normal	generation duration	15.5	2	0.000	0.021	Not homoscedastic

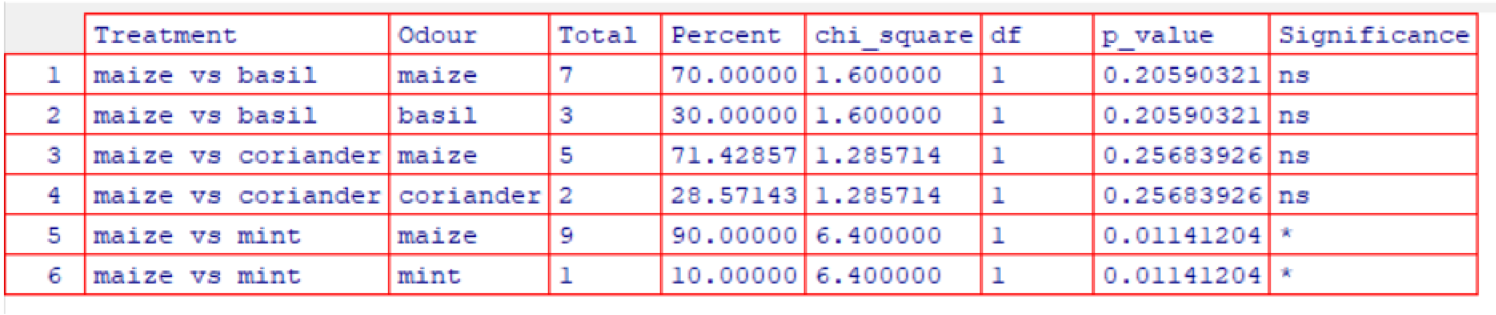
Appendix 5. Y Tube Olfactometer Chi Square Outputs.

5.1 Scenario 1



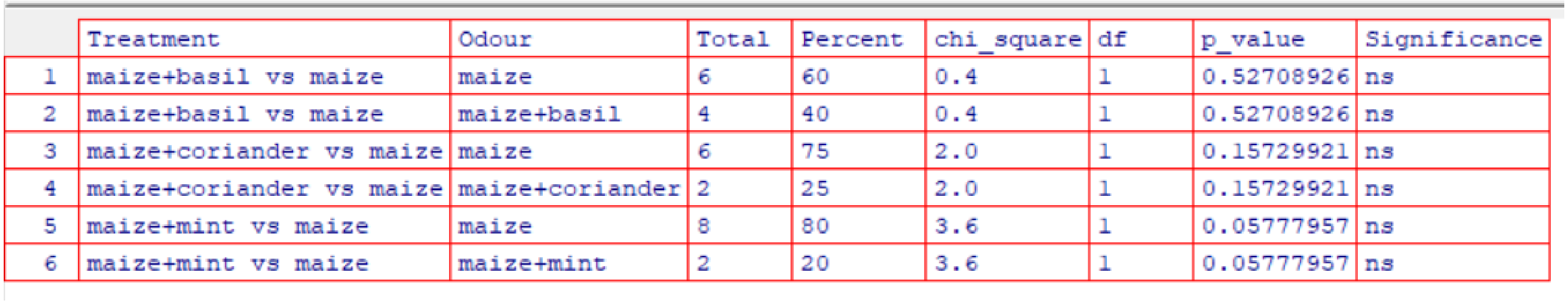
	Treatment	Odour	Total	Percent	Scenario	p_value.x	Significance.x	p_value.y	Significance.y
1	basil vs air	air	2	25.00000	Potential Repellent Plant vs Air	0.15729921	ns	0.9237827	ns
2	basil vs air	basil	6	75.00000	Potential Repellent Plant vs Air	0.15729921	ns	0.9237827	ns
3	coriander vs air	air	3	42.85714	Potential Repellent Plant vs Air	0.70545699	ns	0.9021516	ns
4	coriander vs air	coriander	4	57.14286	Potential Repellent Plant vs Air	0.70545699	ns	0.9021516	ns
5	maize vs air	air	1	11.11111	Potential Repellent Plant vs Air	0.01963066	*	0.9402618	ns
6	maize vs air	maize	8	88.88889	Potential Repellent Plant vs Air	0.01963066	*	0.9402618	ns
7	mint vs air	air	6	85.71429	Potential Repellent Plant vs Air	0.05878172	ns	0.9021516	ns
8	mint vs air	mint	1	14.28571	Potential Repellent Plant vs Air	0.05878172	ns	0.9021516	ns

5.2 Scenario 2



	Treatment	Odour	Total	Percent	chi_square	df	p_value	Significance
1	maize vs basil	maize	7	70.00000	1.600000	1	0.20590321	ns
2	maize vs basil	basil	3	30.00000	1.600000	1	0.20590321	ns
3	maize vs coriander	maize	5	71.42857	1.285714	1	0.25683926	ns
4	maize vs coriander	coriander	2	28.57143	1.285714	1	0.25683926	ns
5	maize vs mint	maize	9	90.00000	6.400000	1	0.01141204	*
6	maize vs mint	mint	1	10.00000	6.400000	1	0.01141204	*

5.3 Scenario 3



	Treatment	Odour	Total	Percent	chi_square	df	p_value	Significance
1	maize+basil vs maize	maize	6	60	0.4	1	0.52708926	ns
2	maize+basil vs maize	maize+basil	4	40	0.4	1	0.52708926	ns
3	maize+coriander vs maize	maize	6	75	2.0	1	0.15729921	ns
4	maize+coriander vs maize	maize+coriander	2	25	2.0	1	0.15729921	ns
5	maize+mint vs maize	maize	8	80	3.6	1	0.05777957	ns
6	maize+mint vs maize	maize+mint	2	20	3.6	1	0.05777957	ns

Appendix 6. Experimental setup for FAW developmental duration and survival assessment.

Survival and development of FAW on various treatments.. (A) FAW incubated eggs on basil, maize, coriander and mint, (B) plastic vials with filter papers, (C) random separation of hatched FAW larvae, (D) basil treatment FAW colony, (E) coriander and mint FAW colony, (F) Maize treatment FAW colony, (G) Pupa from the colonies, (H) Weighing of pupa, (I) sex determination of pupa, (J) pairing for concurrent pupa in plastic cups for adult emergence and oviposition, (K) counting of eggs in microscope (L,M) oviposition test of emerged adults on coriander and basil test for F_1 generation.