EFFECT OF FOOD PLANT ON DEVELOPMENT, REPRODUCTIVE PERFORMANCE, SURVIVAL AND NUTRITIONAL PROFILE OF THE DESERT LOCUST, *Schistocerca gregaria* Forskal (ORTHOPTERA: ACRIDIDAE)

BY

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DECLARATION

This research thesis is my own original work and has not been submitted elsewhere for examination, award of degree or publication to the best of my knowledge.

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DEDICATION

This thesis is dedicated to my parents David Mumo Mukasa, Jenifer Kawali for their love, support and encouragement during my entire study period. I also dedicate it to the rest of my family members Ruth Kithei, Ann Ndinda, Benedict Kithuka, Rosemary Wayua, Alex Mutinda and Lawrence Mutua for their support and understanding.

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

ADF: Acid Detergent Fibre

AOAC: Association of Official Analytical Chemists

DLCO-EA: Desert Locust Control Organization, East Africa

FAO: Food and Agricultural Organization of United Nations

ICIPE: International Centre of Insect Physiology and Ecology

L: D: Light to darkness

NDF: Neutral Detergent Fibre

ABSTRACT

Protein insecurity in the 21st century is an emerging issue in most developing and under developed countries which has prompted search for alternative protein sources such as edible insects. The desert locusts, *Schistocerca gregaria,* Forskal (Orthoptera: acrididae) has been identified as a potential source of cheap protein and consequently mass rearing attempts are underway. The present study evaluated the effect of different food plants on the developmental, reproduction parameters and nutritional composition of *S. gregaria* with a view to mass production and enhancing its protein content. Nymphs and adults of *S. gregaria* were reared on *Zea mays*, *Phaseoulus vulgaris*, *Sorghum bicolor* and *Triticum aestivum* seedlings in the laboratory. Results revealed that development time of nymphs (first instar – young adult) was shortest (16.95 days) when reared on *P. vulgaris* and longest on *Z. mays* (45.06 days). Survival of nymphs to adulthood was highest when maintained on *P. vulgaris* (98.33%), followed by *T. aestivum* (93.33%) and *S. bicolor* (86.67%). No nymphs reared on *Z. mays* survived up to adult. Longevity and reproduction performance of *S. gregaria* was greater for insects reared on *P. vulgaris*, followed by *T. aestivum* as compared to *S. bicolor*. Nutritional profiling revealed significant differences in the crude protein content of *S. gregaria* reared on the different food plants at different adult phases. Ovipositing females raised on *P. vulgaris* contained the highest level of crude protein (86.10%) whereas the lowest was recorded in adults reared on *S. bicolor* (70.47%). These results suggest that *S. gregaria* is a nutrient rich food source for human and animal diets. Its life cycle and nutritional composition can be altered by the type of food plant fed on. *P. vulgaris* is therefore a suitable food plant for mass rearing *S. gregaria* and that this insect species is a good protein source.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Insects play diverse roles in the ecosystem. These roles can be categorized depending on the subject of interest. To humans, insects can be used as food and feed (Vantomme *et al.*, 2012), in addition to benefit accrued through ecosystem services. The use of insects as food or feed is gaining popularity globally due to their high nutritional value. They are reportedly rich in protein, carbohydrate, fat, minerals and vitamins (Ueckert *et al.*, 1972). Acridids, (locusts and grasshoppers), are edible insects that are reportedly palatable. Among these, grasshoppers provide between 52.1% to 77.1 % of proteins (Ramos-Elorduy *et al.*, 1984). Because of this high nutritive value, studies have been undertaken to identify suitable acridid that can be reared and produced in large numbers. In this context, desert locust, *Schistocerca gregaria* (Foskal),(Orthoptera: Acrididae) has been identified and investigated in many different studies (DeFoliart, 1989).

Schistocerca gregaria is a polyphytophagous species and reportedly feeds on more than 400 plant species (Uvarov, 1966) including almost all crop plants. The consumption and utilization of the food plant influence the biology, behavior and other life history aspects such as growth rate, development, survival, fecundity and fertility of the locusts (Sultana and Wagan, 2007). It is the nutritional and pathological value of a given food plant that govern its preference, ingestion, digestibility and assimilation by the acridids (Chapman, 1990). Feeding the acridids on a given food plant singly or as a mixed diet significantly affects different stages of its development. For example, feeding the *Hieroglyphus nigrorepletus* on *Oryza sativa* resulted to shortened nymphal duration in the 5th instar while *Desmostachya bipinnata* caused prolonged 2nd, 5th and 6th instar showing variable developmental rates of the acridids (Sultana and Wagan, 2007). The adult maturation, oocyte formation and egg development of insects can also be determined by the nutritional value of the food plants as observed by Nzekwu and Akingbohungbe (2002). It is therefore evident that the nutritional levels of the host plants are perquisites for growth, development and production of eggs in acridids.

As efforts are underway to rear the desert locust in large numbers and establish colonies, there is need to identify suitable food plants from their local diet spectrum, which can support their mass culture and biomass production. Identification of suitable food plants should facilitate mass rearing under laboratory conditions by promoting maximum nutrients input and high reproduction potential. Such food plant should have positive influence on insect's life history parameters such as rapid growth rate, low mortality levels and high protein manifestation at low costs of production. Rearing of locusts on such food plant, considered to be easily available would ensure sustainable supply of insects to supplement the growing protein demand associated with growing human population. Such information will also be helpful in understanding and designing management strategies to avoid future outbreaks of the desert locust.

2.1 Problem statement

The human population is expected to grow to 9 billion by 2050 according to Food and Agricultural Organization (Alexandratos and Bruinsma, 2012). This implies more consumption of food especially protein from animal origin. As a result, a progressive demand for protein to feed the livestock and fish which are the principal sources of animal protein will exist. Currently, livestock production relies mainly on soybean and fishmeal as the protein source for commercial feeds (Semino *et al.*, 2009). Competition for these protein sources by animals and humans has rendered the availability and sustainability of protein production too scarce and expensive especially for the local farmers.

3.1 Justification of the study

Edible insects such as desert locust, *Schistocerca gregaria*, have been proposed for inclusion in both human and animal nutrition (Anand *et al.*, 2008). The high protein level qualifies the locusts potential supplements for fish and livestock feeds. While the nutritional value of the locusts remains unquestionable, their sustainability and economic feasibility in animal production greatly depends on future opportunities to develop production systems (Veldkamp and Bosch, 2015). Such opportunities entail mass rearing of the locusts under suitable foods to enhance their nutritional value, and optimum environmental conditions. This study aimed at assessing the effect of four food plants on the life history parameters and nutritional composition of desert locust with a view of determining a suitable food plant that can support its mass culture. Identification of such food plant will be a breakthrough in establishment of locust colonies. This would eventually provide an innovative, cheap and sustainable protein-rich raw material for fish and livestock feed production and eventually boost food and feed security.

4.1 Objectives of the study

4.1.1 Broad Objective

To establish the effect of different food plants on the life cycle parameters and nutritive status of the desert locust, *S. gregaria* under laboratory conditions.

5.1.1 Specific objectives

1. To investigate the effect of maintaining *S. gregaria* on maize, beans, sorghum and wheat seedlings on its development, reproductive performance and survival under laboratory conditions.
2. To determine the nutritional profiles of the *S. gregaria* reared on maize, beans, sorghum and wheat seedlings.

CHAPTER TWO

LITERATURE REVIEW

2.1 Entomophagy

The practice of using insects for food is referred to as Entomophagy (Chakravorty *et al.*, 2011). It is emerging strongly in the 21st century because of the global population growth which is causing competition on the conventional food materials by man and livestock (van Huis, 2013). Different species of insects contain different levels of nutrients which are comparable to the conventional animal sources with high protein content (Hanboonsong *et al.*, 2013). Insects such as locusts and grasshoppers have been used in the past for human and animal nutrition as a delicacy especially in the tropics by several ethnic communities (Van Huis, 2003). Jacob *et al.* (2013) suggested that human consumption of the edible insects is a way out of protein deficiency resulting from the often prohibitive prices and overdependence on the inadequate conventional animal protein sources.

The practice of using insects as food is associated with approximately 2 billion people worldwide (van Huis, 2013). According to (Niaba *et al.*, 2012) this practice is deeply rooted in African communities, where thirty six countries are entomophagous. About 15% of meat diet of Gbaya people of Central African Republic consists of insects (Robert, 1989). Some tribes in Venezuela, Colombia and South Africa preferred certain insects to fresh meat (Jacob *et al.*, 2013; Obopile & Seeletso, 2013) , while the people of Madagascar love eating fried grasshoppers (Bodenheimer, 1951). It is worth noting that, although insects are regarded as food for the poor people and backward by some, they are sought and served in the best restaurants in most countries of Asia, Australia and Europe (Yen *et al.*, 2012). Robert, (1989) suggested that, mass production of insects would lead to at least 10% increase in the world's supply of animal protein, a possible strategy of alleviating the global food and feed shortage and reducing overreliance on the conventional protein sources. Studies indicate that, the tissues of acridids (locusts and grasshoppers) comprise high quality protein that can be utilized for animal feeds (Anand *et al.*, 2008). The desert locust *S. gregaria*, a species of short horned grasshoppers (Acridoidea) has been proposed as a potential ingredient for animal feed because of its high nutritional value (Vantomme *et al.*, 2012). Acridids, are therefore potential sources of high proteins and hence mass rearing farms for this nutritive species should be established (Van Huis, 2003) to supplement the upcoming food and feed insecurity (Haldar *et al.*, 1999).

2.2 Insects as animal feed

Different insect species such as locusts, beetles, crickets, fly larvae, grasshoppers and silkworms offer an attractive and nutritive natural food to many vertebrates such as lizards, snakes, birds, and other mammals (Anand *et al.*, 2008). They have been found suitable for feeding domesticated animals such as swine, freshwater fish and poultry while the quality and palatability of the meat remains uncompromised (Khusro *et al.*, 2012).

The bottom line behind the use of insects for feeding animals rests on their high protein content that challenges the ordinary sources like plant foods. The protein levels in the body tissue of edible insects may range from 44 to 70% compared to 9 to 10% for plant foods (Ramos-Elorduy, 1987). The protein content of ants and termites is higher than that in the dried fish (Dufour, 1987). In another study, replacement of soybeans with Mormon cricket in chick feed showed no significant difference the chick weight gain (Finke *et al.*, 1985). Insects can therefore be used to supplement the conventional fish oil, fish meal, soy meal and soy oil ingredients of compound aqua feeds and animal fish (van Huis, 2013). The soybean and the fishmeal have become expensive globally due to the high demand by the increasing of human population and slowed production (Trostle, 2008). This has stimulated some researchers' interest to look for alternative sustainable cheap and safe ingredients for the animal feeds although this field is at infancy (Makkar *et al.*, 2014).

Acridids which comprise the locusts and grasshoppers make nutritious natural protein source to several animals such as lizards, poultry and fish (Anand *et al.*, 2008). A study by Makkar *et al.*, (2014) found the crude protein content of grasshoppers and locusts to range between 42-63% and therefore a potential replacement for soy meal and fish meal in the diets of poultry, pig and fish.

The Chinese grasshopper (*Acarida cinerea)* can replace up to 15% chicken diet made of soy and fish meal (Wang *et al.*, 2007).

2.3 Rearing of Locusts and Grasshoppers in the laboratory

Different species of locusts and grasshoppers have attracted the attention of researchers worldwide due to their economic importance (Hinks and Erlandson, 1994) .This has led to laboratory rearing of these acridids to investigate different parameters related to them. Among the most reared species are; the African migratory locust, *Locusta migratoria migratorioides* and the desert locust, *S. gregaria*. The *Melanoplus sanguipines* species has been subjected to numerous studies hence found to be a convenient classroom insect (Pfadt and Smith, 1972). This species has been used for pesticides screening and also tests for plant resistance (Hinks and Olfert, 1993).

2.3.1 Rearing cages

In earlier studies, rearing cages were made of wood and fabric (Barnes 1955). A more secure all metal and glass cages were later developed, which are compatible with stringent cleaning procedures which favour continuous production of healthy insects (Dudley *et al* 1962). Mazuranich (1975) came up with a design that measure 46 x 46 x46 cm, (subsequently referred to as 46 cm cage). The improved model is made of aluminum window fly screens for the sides and a 3mm plexiglass front. The bottom of the cage is a 3 mm perforated zinc mesh attached to the main body by an aluminum angle secured by aluminum metal screws. A 5 x5 cm opening at both right and left sides of the cage are covered by a flexible perforated zinc mesh and provide ventilation and access point to the interior of the cage. This model has proven convenient for rearing experiments and are easily stacked for storage when not in use (Hinks and Erlandson, 1994)

2.3.2 Rearing temperatures for desert locust in the laboratory

Temperature plays important life roles such as growth rate and affects the overall productivity in the life of different poiklotherms such as locusts and grasshoppers (Hinks and Erlandson, 1994). It can affect the rate of biochemical processes such as metabolism, developmental rate, reproduction and the body size. Extreme temperature (temperature outside the insect tolerance range) can cause thermal death due to desiccation and inactivation of enzymes. The extreme sub-optimal temperatures outside the tolerance range can cause decreased body size, extended developmental rate, diapauses, less fecundity and decreased body size on the insects such as locusts and grasshoppers (Amhad, 2014). In a study to investigate the effect of radiant heat on the development and reproduction of *Chirthipus brunneus*, it was observed that the developmental period of the 4th instar reduced 5.6 times than when it was not subjected to radiant heat (Begon, 1983). He also found that, females exposed to the radiant heat source for longer periods laid more eggs than those exposed for shorter durations. In a separate study by Parker (1930), the larval development period of *Melanopus mexicanus* reduced by 27 days, when the temperature for rearing them was increased from 27^0 C to 32^0 C. Most of the studies show that, an increase in temperature has an overall speeded rate of development although, the extent of the increase and the associated benefits are greatly depended on the thermal biology of the insect in question (Thomas and Blanford, 2003).

2.3.3 Feeding the desert locust in the laboratory

The desert locust and grasshoppers represent a group of acridids that are highly polyphagous and therefore have a wide dietary spectrum.(Uvarov, 1966). Despite the numerous studies done on the biology, physiology and biochemistry of grasshoppers and locusts, the precise dietary requirements has not been fully elucidated (Hinks and Erlandson, 1994). Chapman (1990) however argued that, despite the *S. gregaria*, *M. sanguipines*, and many other acridids being highly polyphagous, they have definite dietary requirements. For the polyphagous species, diets consisting of broad-leaved plant foliage and cereals or grass foliage are often the best (Barnes 1955, MacFarlane and Thorsteinson, 1980). For example, (Hinks and Olfert, 1993) observed that, the acceptability and nutritional value of wheat foliage to grasshoppers was evident from the natural growths often leading to their population outbreaks of *M. sanguipines* and *Camnulla pelicida.*

2.4 The Biology of desert locust, *S. gregaria*

The abdomen of the males appear boat-shaped in the tip as opposed to that of the females which has two serrated valves that can be either together or apart can be used in digging the hole for depositing her egg pods (Uvarov, 1966). The ovipositor is used to make a hole in the sand, about 5-10 cm deep where the eggs are laid and covered with a froth that hardens (Maeno *et al.*, 2013; Uvarov, 1966). The eggs are attached onto a pod with 60-100 eggs where each egg is 7-8 mm long and 1.0-1.3 mm broad (Uvarov, 1966). A female may lay up to 4 or 5 of these egg pods (Maeno *et al.*, 2013) if well fed. The eggs do not undergo distinct diapauses although at low soil temperatures and moisture content in the field, some form of temporary arrestment of the eggs has been observed (Meinzingen, 1993). Depending on the temperature and moisture of the sand, the development of the eggs will take two weeks or longer and hatch into first worm like larva which finds their way through the egg pod to the soil surface (Ely, 2015) where they molts and become a ‘hopper’ which undergo five developmental instar before becoming adults (Uvarov, 1977).

2.4.1 The life cycle

The desert locust, *S. gregaria* transforms reversibly between two phases, solitaria and gregaria which are very different morphologically, physiologically and behavior wise (Uvarov, 1966). The most conspicuous difference between the phases is the behavior where the gregarious forms aggregate and forms swarms while the solitarious shy off from each other.

A mature adult locust on this phase is usually pale grey-brownish. A solitary female usually lays 3-4 pods, each pod containing about 100-160 eggs (Uvarov, 1966) where the egg pods are laid at an interval of 7-10 days. Solitarious hoppers have a uniform green colour in early instars, which may become brown in the last two of the six instars (Steedman, 1988).

A gregarious immature adults are usually pink (Loher,1961). When sexually mature, this colour changes to yellow with the males appearing brighter than the females (Loher, 1961). A gregarious female locust usually lays eggs at least three times in its lifetime, at intervals of about 6-11 days. Two egg pods are produced each bearing about 35-70 eggs (Uvarov, 1977). The eggs are laid in sandy soils at a depth of 5-10 centimeters below the surface (Assad *et al.*, 1997).The eggs takes 10-20 days to hatch depending on the moisture content and temperature.

During hatching, the emerging hoppers of the desert locust (the gregarious phase) move up through the froth plug to the surface and immediately moult into the 1^{st} instar (Symmons and Cressman, 2001). The newly hatched hoppers then develop through five instars with a moult in between with the last instar hopper moulting into a young adult known as a fledgling (Symmons and Cressman, 2001). It takes about ten days for the fledglin's wings to harden sufficient enough to sustain a flight. The hoppers develop through five instars in the natural environment (takes about 30-40 days depending on the prevailing temperature and humidity condition) (Lecoq, 2001) as opposed to six weeks for solitarious phase (Steedman, 1988).

After fledging, adults take about three weeks under normal conditions to mature while their longevity ranges within three to five months depending with prevailing ecological and weather conditions. The gregarious locusts have black marks on a yellow background in all instars (Uvarov, 1966).

2.4.2 Locust ecology

The populations of desert locust are low and restricted to Arid and Semi-arid areas in Africa, Middle East and some regions of South-West Asia (Steedman, 1988). During the outbreak moments, the locusts move in large swarms into the invasion areas covering extensive lands. The locusts require certain ecological conditions such as rainfall, topography, soil type, vegetation and temperature for breeding. Adequate rainfall (usually at least 25-50 mm) is required to provide moisture for egg development and for vegetation to germinate or regenerate and provide food and shelter for the hoppers development (Lecoq *et al.*, 2011). Locusts show preference for sandy or silty soils for egg-laying (Steedman, 1988). The presence of vegetation influences where the swarms will deposit eggs and the behavior of newly hatched hopper bands. Healthy vegetation is important for the survival of the hoppers by providing food and shelter. Steedman (1988) observed that temperature is the main factor in determining the rate of egg and hopper development.

2.4.3 Food recognition

Visual cues play important role in locating the food plants from a distance in desert locust and grasshoppers while the acceptance of the specific food plant is facilitated by the olfactory cues (Ely, 2015). In other insects, the cues are also known to influence other behaviors such as mating and aggregation (Barrata and Araujo, 2001). The cues are in form of pheromones and plant odours composed of varied chemical compounds blend and concentrations in different plant species and thus are easily blown by wind in all direction (Barrata and Araujo, 2001). Nearly all plants emit a wide spectrum of odours such as the green leaf volatiles (GLV), present in different levels in the specific plant species (Hansson *et al*.,1999).

2.4.4 Plant-insect relationships

The gregarious desert locust, *S. gregaria*, is termed highly polyphagous (Evans & Bell, 1979).The interaction of this species with food plants is influenced by the volatiles from host plants that are important in food location (Haskell *et al.*, 1962) and non-volatile allelochemicals involved in food recognition and acceptance (Njagi and Torto, 1996). This associations with plants is related to their need for development, reproduction, survival, and growth performance

(Chapman, 1990) and for refuge from unfavorable biotic and abiotic factors. Research has demonstrated that, different food plants have particular chemical constituents (Bernays and Chapman, 1994) and nutrients (McGinnis and Kasting, 1966) important for survival of locusts and grasshoppers life aspects. For example, millet, *Pennisetum typhoides* and *Sorghum bicolor* enhanced gregarious characteristics in a study by Jackson *et al*., (1978) while Halfa grass, *Dipterygium glaucum* accentuated solitarious traits. On the other hand, solitarious desert locusts highly preferred *Heliotropium sp.*, *P. typhoides,* and *D. glaucum* for feeding and oviposition (Bashir *et al.*, 2000).

2.4.5 Effect of food plants on reproduction of insects

Locusts and grasshoppers, require food with high level of and therefore selectively consume a wide variety of food plants with high nitrogen content (Chandra and Williams, 1983). The nutritional value of food plant may affect the fecundity of acridids (Nzekwu and Akingbohungbe, 2002). When *Locusta migratoria migratorioides,* (Acrididae) were subjected to a low protein food, egg production declined (McCaffery, 1975). Similarly, when *Ageneotettix deorum*, was subjected to a more nitrogen diet, its weight and the quantity of eggs produced increased significantly (Joern and Behmer, 1997).

2.4.6 Effect of food plants on growth and development of insect

Food plants influence the growth, development, survival and fecundity of grasshoppers and locusts (Islam and Whitworth, 1988). When these phytophagous insects feed on a given food plant, a prolonged or shorted developmental period may be experienced as reviewed by Uvarov (1977). Abdel *et al.,* (1999) observed shortened nymphal development for the 5th instar, of *H. nigrorepletus,* when feeding on rice *O. sativa* as compared to maize (*Zea mays)*. Contrary to this, feeding of the same acridid on Halfa grass (*D. bipinnata)* led to a longer developmental periods in the 2nd, 5th and 6th instars. This shows possible occurrence of variable developmental periods of grasshoppers and locusts in their natural habitats (Abdel, 1999).

2.5 Proximate analysis of forage

Determination of the nutritional value of a given feed provides basis for establishing the nutritive value of a plant species as a silage, fodder or component of any food. The levels of the major classes of chemical compounds such as the crude protein, fat, nitrogen free extract, ash and moisture forms a reliable relative nutritive value of the target food source for their utilization in animal feeding. The crude protein is estimated using the Kjeldahl Nitrogen analysis and crude fat measured as diethyl ether or petroleum extractable material (Chang, 2010). Igniting samples until free of carbon is used to determine the ash levels while the Nitrogen-free extract is the difference between sum of these constituents and the original dry sample weight (Wall and Blessin, 1970). This information is essential for laying a platform for comparison between different plant species, plant parts and the cultivation conditions. However, it is essential to acknowledge the caution of relying on the proximate analysis data as the only criteria for establishing food value (Van Soest, 1967).

Several factors influence the level of nutrients in the plants. These include developmental stage of the plant, the relative amount of foliage and stalk, the degree of plant maturity and cultivation factors such as soil, fertilizers, climate and plant population. In sorghum, for example, the leaves have a relatively higher crude protein than the stalk at an early stage (12 -18% protein of dry weight) which declines gradually to 5 - 8% as the plant approaches maturity (Wall and Blessin, 1970).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Establishment of the initial *S. gregaria* colony

Rearing was undertaken according to procedure described by Henry (1985) in the insectary of Entomology Research unit, University of Nairobi

The experimental locusts were obtained from *icipe* stock, which had been propagated with a colony from the Desert Locust Control Organization for Eastern Africa (DLCO-EA), Nairobi, Kenya. The eggs were incubated at a temperature of $32\pm1^{\circ}$C and hatched after 10-13 days. Forty newly hatched nymphs were transferred into each of the eight rearing cages and fed on wheat seedlings (wheat grass) and wheat bran to adults (first generation). The rearing temperature in the cages was maintained at $32\pm1^{\circ}$C and 20-40% relative humidity under a continuous illumination. This was done to raise enough eggs that were then incubated at the same temperature to produce sufficient second generation nymphs for the experiment.

3.2 Rearing temperature and humidity in the insectary

A growth chamber whose internal dimensions measured 6 x 4 m housed the colony cages on shelves at a working height. The temperature in the insectary was thermostatically maintained at a constant temperature of 27 ± 1^{0} C under continuous illumination but was constantly higher (31±2°C) inside the rearing cages due to the presence of a 40W incandescent light bulb mounted at the middle back wall. The relative humidity in the insectary was maintained between 20 and 40% by constantly pouring water on the concrete floor every morning and evening.

3.3 Rearing cages

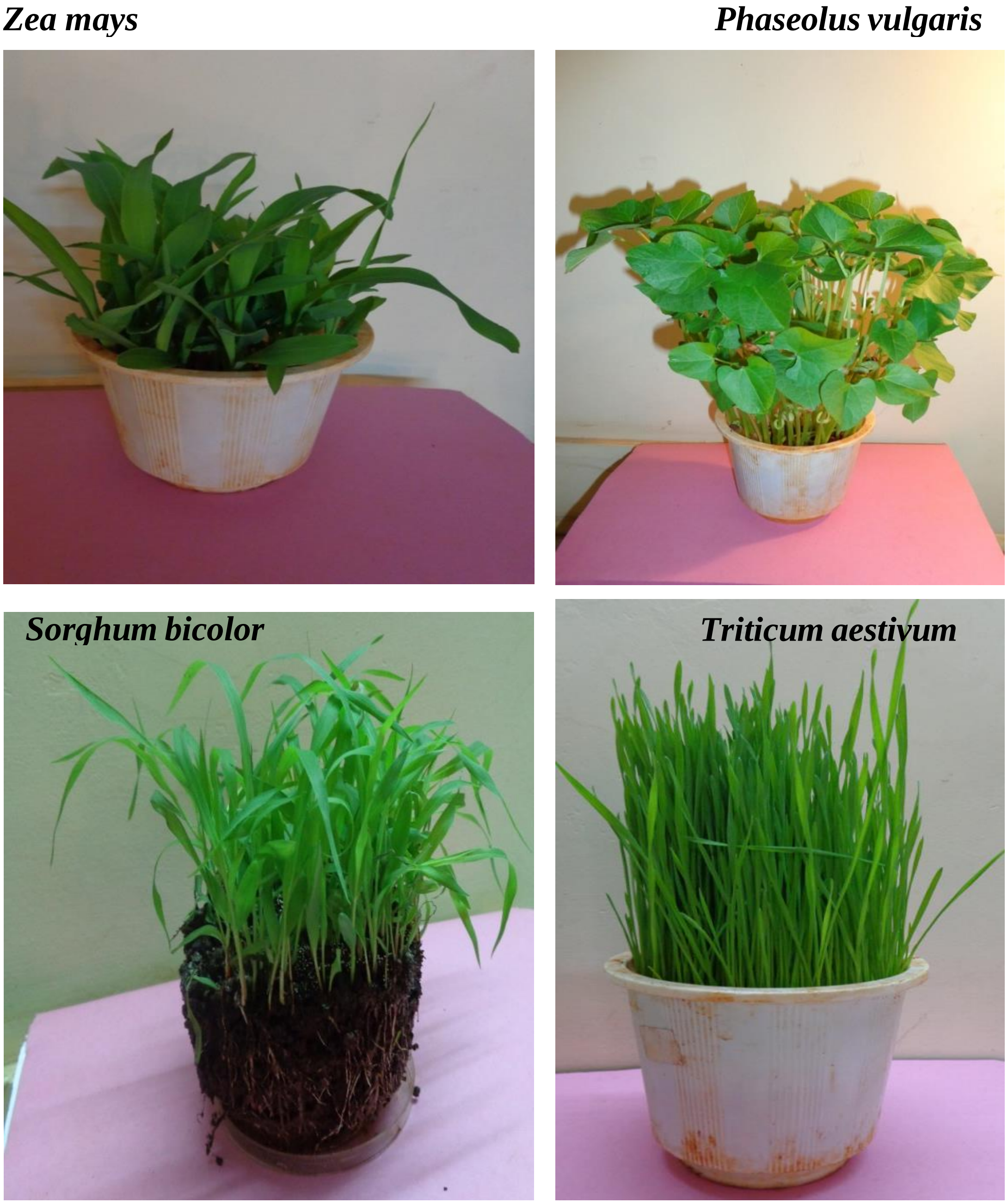
Cages for rearing the locusts were based on slight modification of the design described by Mazuranich (1975), and measured 50 x 40 x 40 cm. They were made of aluminum, a 3mm Plexiglas front and galvanized metal screws (Figure1). A 3mm perforated zinc mesh formed the bottom of each cage and was connected to the main body of the cage by an aluminum angle, secured by galvanized metal screws. A 40W incandescent light bulb was mounted in the middle upper wall of each aluminum cage. This provided radiant heat for locusts basking on a metallic wire mesh standing vertically on the cage. The mesh also provided a surface for the nymphs to attach on while shedding their exoskeleton.

This type of cage is durable and supports standard cleaning procedures; it is more secure and capable of withstanding repeated immersion of corrosive cleaning solutions ensuring production of more healthy insects. When not in use, this design is easily stacked for storage.

3.4 Raising experimental food plants

The selected food plants (*Zea mays*, *Phaseolus vulgaris*, *Sorghum bicolor* and *Triticum aestivum*) were seeded in plastic pots (10cm radius and 14cm height) containing red soil mixed with cattle manure in a ratio of 3:1 v/v (Figure 2). Equal number of seeds were planted and watered until when the seedlings were approximately 15-20 days old, when they were used to feed the locusts in the cages. Once the seedlings were removed from the pots, a fresh stock was immediately planted to ensure a continuous supply of the feed.

Figure 1: Aluminum cage used for rearing *S. gregaria*



Zea mays

Phaseolus vulgaris

Sorghum bicolor

Triticum aestivum

Figure 2: Food plants used for rearing desert locust in laboratory

3.5 Rearing of the *S. gregaria* in the laboratory

Rearing was undertaken according to procedure described by Henry (1985). Four cages were used for the rearing, each containing 20-first instar nymphs fed with each food plant, and replicated three times. The feeding was *ad libitum*, with the food being introduced twice a day at 0900hrs and 1500hrs. Cleaning of the rearing cages was done daily with a regular check of the cages and its surrounding for spiders and other predators. Remains for the previous food and the fecal matter were removed before the next feeding to avoid contamination and maintain hygiene in the cages. The locusts were subjected to their respective food plant for one complete life cycle (figure 3).

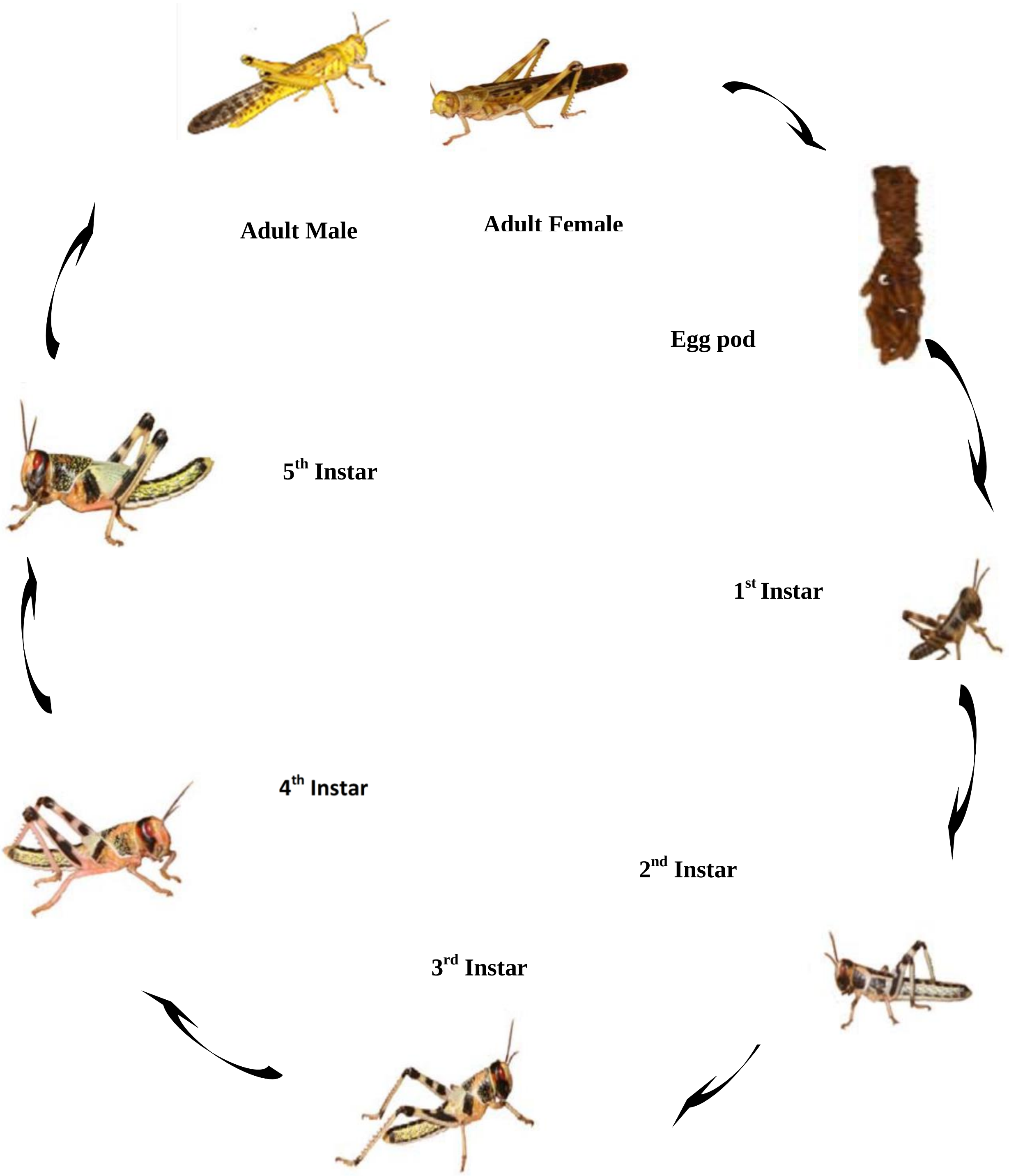


Figure 3: The life cycle of gregarious desert locust; *S. gregaria* (source; Ely, 2015)

3.6 Observation on the life history parameters

The following aspects on the biology of the desert locust, *S. gregaria* were observed during the entire study from the first instar to the laying of the eggs by the adult females and compared across all the treatments.

3.6.1 Nymphal development and survival factors

Twenty newly hatched first instar nymphs were obtained from the stock colony and individually introduced into wire-mesh enclosures (10x10x15cm in the main cage) making a total of 60 replicates for each of the four food plants. The hoppers were then fed on the designated food plant; (*P. vulgaris*, *S. bicolor*, *T. aestivum* and *Z. mays*) *ad libitum* until they attained the adult stage. The individual developmental duration in every instar was observed and recorded up to the adult. The number of the dead individuals was recorded in every developmental stage and the survival rate in a replicate calculated by dividing the number of live hoppers at a given developmental stage by the initial number of the hoppers (n=20) and expressed as percentage.

Weight of individual 5th instar hoppers, fledgling, mating and ovipositing locusts in each replicate was determined using an electronic balance (Model Scout Pro Balance, Ohaus).

3.7 Reproduction parameters of the adult female locusts

A single newly emerged adult female together with one adult male were individually placed in five small cages (225 cm^2 each) in the main cage and maintained on a specific food plant supplemented with wheat bran until death. Fifteen replicates were made for each food plant. Oviposition tubes (9cm long x 4.5cm diameter) filled with moist sterilized silica sand was placed at the bottom of the cages. Sterilization of the sand and the tubes was done in an oven model MMERT B30, Germany, at 80^oC for 48 hours. After every two days, the tubes containing egg-pods were recovered and replaced with fresh ones. The following parameters were scored: pre-oviposition time, oviposition duration, longevity and the total number of eggs.

3.8 Proximate Analysis of food plants

The proximate analysis of the four experimental food plants was conducted using Association of Official Analytical Chemists standard protocol (AOAC, 2000). Briefly, fresh food plant samples were harvested from the pots and immediately oven-dried at 65^o C for 48hrs. After drying, they were ground and the crude protein of each sample determined using Kjeldahl method at Chemistry Department Laboratory, *icipe*, Nairobi, Kenya.

The nutritional analysis of the insects materials was done according to the procedure employed by Association of Analytical Chemists (Helrich, 1990). Locusts at the 5th instar, mating and ovipositing stages from each diet type were frozen to kill, dried in hot air oven at 80^o C for 24 hours. They were then made into a fine powder for analysis. Crude protein was established following the Kjeldahl method using Micro Kjeltech Apparatus. Soxhlet apparatus were used to estimate the level of crude lipid. The ash level was estimated by heating the samples overnight in a Muffle furnace at 550^0 C. The organic matter (OM) was then established by subtracting the ash content from 100. The Acid Detergent Fibre (ADF) and Neutral Detergent Fibre (NDF) were analyzed in the Velp fibre analyzer (FIWE 6) (VELP Scientifica, Usmate Velate, Italy) using reagents described (Van Soest *et al.*, 1991)

3.9 Data management and statistical Analysis

Insects that did not complete a specific developmental stage due to mortality were excluded from the analysis in that particular life stage. Individuals from *Z. mays* didn't survive past the 5th instar and therefore were not included in the subsequent analysis. Data obtained from the experiments were subjected to normality test using Shapiro-Wilk's test. Data on survival rate were arcsine transformed while longevity and developmental durations were log-transformed to achieve normality. They were then back transformed and recorded in the results. Data on nymphs' development duration, survival rates, longevity, fecundity and nutritional composition were subjected to analysis of Variance (ANOVA) in R statistical software version 3.0.1. Means were separated using Tukey's HSD.

CHAPTER FOUR

RESULTS

4.1 Effect of food plant on the development of desert locust nymphs'

Development time of *S. gregaria* varied depending on the type of food plants (Table 1). Nymphs developed successfully on all experimental food plants except *Z. mays* where none survived beyond the fifth instar. Food plants influenced the developmental duration significantly and the effect varied in respective stage. In the first instar, developmental period varied significantly among the nymphs fed on different food plants ($F_{3,236}$=539.80, p<0.001). It was shortest (4.1 days) in the nymphs reared on *P. vulgaris*, *T. aestivum* and *S. bicolor* but differed significantly from those reared on *Z. mays* (12.5 days), which was more than three times longer. Similarly, in the second instar, development period varied significantly among the nymphs fed on different food plants ($F_{3,219}$=914.50, p<0.001), with nymphs fed on *P. vulgaris*, *T. aestivum* and *S. bicolor* completing their development in about 3.2 days, which was about half the time taken by nymphs raised on *Z. mays* (7.2 days).

Developmental periods of the third instar nymphs fed on different food plants varied significantly ($F_{3,201}$=18.50, p<0.001). The nymphs fed on *P. vulgaris* had a mean developmental period of 3.2 days, compared to those fed on *S. bicolor* (4.5 days) or *T. aestivum* (4.7 days) and although these were not significantly different, they differed significantly from the developmental period of the nymphs reared on *Z. mays* (9.4 days), which was twice as long (Table 1). In the fourth instar, developmental periods of nymphs fed on different food plants varied significantly ($F_{3,184}$=53.88, p<0.001). Nymphs fed on *S. bicolor* had the shortest developmental period (3.0 days) which was significantly different from those reared on *P. vulgaris* (3.3 days), *T. aestivum* (3.5 days) and *Z. mays* (5.3 days). Comparatively, in the fifth instar, there were significant variations in developmental periods among nymphs fed on different food plants ($F_{2,177}$=78.23, p<0.001). Nymphs reared on *P. vulgaris* took the shortest duration (3.2 days) to moult into adults, which was significantly different from those reared on *T. aestivum* (3.5 days) and *S. bicolor* (4.5 days). The total developmental duration varied significantly ($F_{2,177}$=6.238, p<0.0022) on hoppers fed on four different food plants. Nymphs reared on *P. vulgaris* took the shortest period to mature to adults (16.96 days) significantly different from those reared on *T. aestivum* (18.8 days) and those reared on *S. bicolor* (19.17 days).

Table 1: Effect of food plant on development duration of *S. gregaria* nymphs.

Food plant	Mean (± S.E.) developmental period in days					
	Instars					
	i	ii	iii	iv	v	Total duration
Z. mays	12.50 ± 7.10^{a}	7.22 ± 3.71^{a}	9.42 ± 6.47^{a}	5.30 ± 0.94^{a}	-	-
P. vulgaris	4.10 ± 0.34^{b}	3.15 ± 0.45^{b}	3.19 ± 0.39^{b}	3.26 ± 0.74^{b}	3.19 ± 0.39^{c}	16.96 ± 1.26^{b}
T. aestivum	4.11 ± 0.23^{b}	3.29 ± 0.28^{b}	4.65 ± 1.87^{b}	3.49 ± 1.37^{b}	3.49 ± 1.8^{b}	18.88 ± 19.60^{a}
S. bicolor	4.11 ± 0.32^{b}	3.22 ± 0.30^{b}	4.45 ± 1.80^{b}	3.01 ± 0.31^{c}	4.45 ± 2.5^{a}	19.17 ± 3.59^{a}
F value	539.80	914.50	18.50	53.88	78.23	6.238
D.F	3,236	3,219	3,201	3,184	2,177	2,177
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0022

Means in the same column followed by the same letters are not significantly different from one another at 5% significance level of probability (Tukey's HSD).

4.2 Effect of food plant on the survival of *S. gregaria* nymphs and immature adults.

The survival of *S. gregaria* nymphs reared on four different food plants varied in every developmental stage except for the 1st instar (Fig. 4). The survival for the hoppers reared on *P. vulgaris*, *T. aestivum* and *S. bicolor* was 100% in the 1st, 2nd, 3rd and 4th instars. In the fifth instar, the survival of nymphs reared on *P. vulgaris* (98.3%), *T. aestivum* (98.3%) and *S. bicolor* (86. 7%) was not significantly different ($F_{3,8}$=5.898, p<0.001) but was significantly lower in hoppers fed on *Z. mays* (8.3%). None of the hoppers reared on *Z. mays* survived to the adult stage.

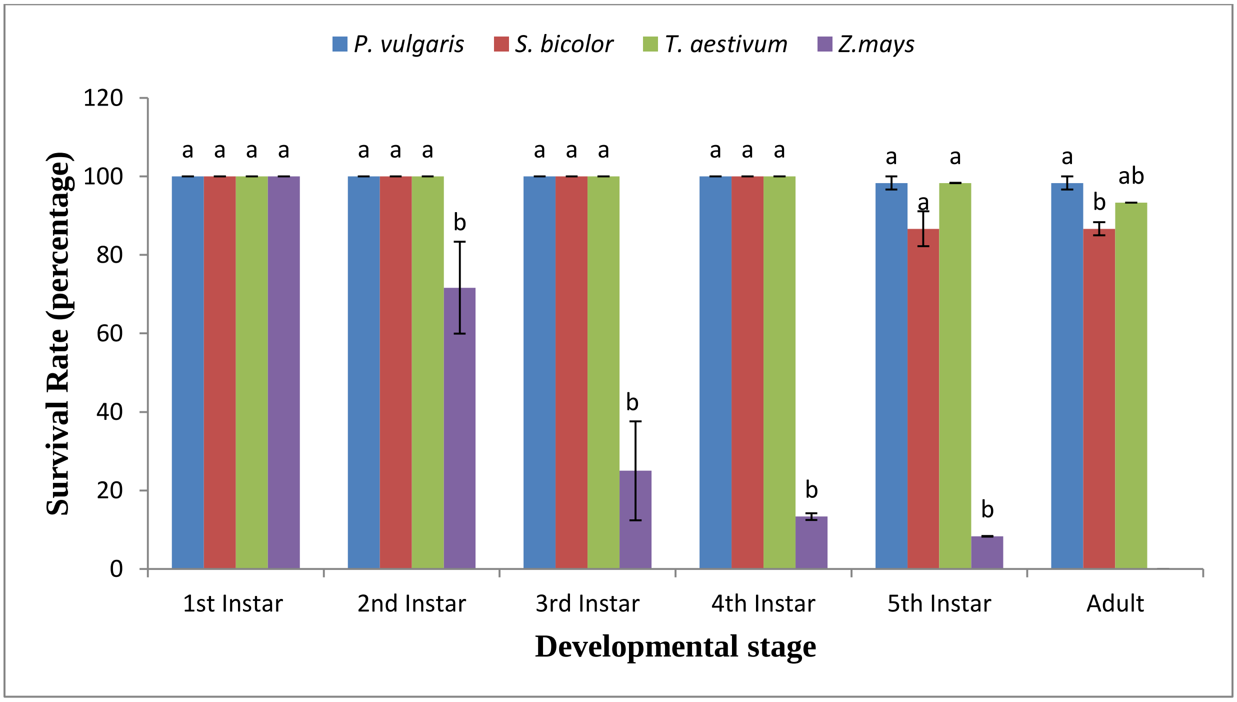


Figure 4: Effect of food plant on survival rate of the desert locust, *S. gregaria*.

Bar graphs marked with different small letters are significantly different from one another at 5% significance level of probability (Tukey's HSD).

4.3 Effect of food plant on the life history parameters of adult *S. gregaria*

There was evidence on the variation of fecundity parameters; pre-oviposition duration, oviposition period, longevity and the total number of eggs laid by female desert locust reared on food types (Table 2). Longevity varied significantly ($F_{2,85}$=23.83, p<0.001) among the females reared on the different food plants. Females reared on *S. bicolor* lived longest (106.4 days) which was significantly different from those reared on *T. aestivum* (79.7 days) or *P. vulgaris* (81.9 days). Pre-oviposition period differed significantly ($F_{2,86}$=81.17, p<0.001) on the females reared on the various food plants. The shortest pre-ovipositioin period was observed on adults feeding on *P. vulgaris* (18.6 days), but this was not significantly different from those fed on *T. aestivum* (19.1 days). Females reared on *S. bicolor* took the longest duration (45.00 days) to start ovipositing significantly different from those fed on the other food plants ($F_{2,86}$=81.17, p<0.001). There was a significant variation on the number of eggs deposited by females reared on the different food plants ($F_{2,75}$=17.21, p<0.001). Females reared on *P. vulgaris* deposited the highest number of eggs (566.3) which was significantly different ($F_{2,75}$=17.21, p<0.001) from those laid by females reared on *T. aestivum* (424.0 eggs) and *S. bicolor* (224.5 eggs). The ovipositing duration did not vary significantly ($F_{2,58}$=0.286, p=0.752) in females reared on different food plants (Table 2). Females raised on *S. bicolor* oviposited for the longest period (53.7 days) followed by those of *T. aestivum* and was shortest on those from *P. vulgaris* (49.6 days).

Table 2: Effect of different food plant on reproduction parameters of female *S. gregaria*

	Mean duration (days ±S.E).			
Food plant	Pre-ovipositing	Ovipositing	Longevity	No. of eggs
P. vulgaris	18.63 ± 0.19^{b}	49.61 ± 4.24^{a}	81.89 ± 4.05^{b}	566.32 ± 50.62^{a}
S. bicolor	45.00 ± 2.85^{a}	53.86 ± 3.44^{a}	106.40 ± 4.09^{a}	224.54 ± 28.83^{c}
T. aestivum	19.06 ± 0.19^{b}	51.50 ± 3.74^{a}	79.74 ± 3.44^{b}	424.00 ± 37.28^{b}
D.f	2,86	2,58	2,85	2,75
F-value	81.17	0.286	23.83	17.21
P-value	<0.001	0.752	<0.001	<0.001

Means in the same column followed by the same letters are not significantly different from one another at 5% significance level of probability (Tukey's HSD).

4.4 Effect of food plant on the mean weight of 5th instar hoppers and adults of *S. gregaria*

Food plant used to rear the hoppers significantly influenced their weight at different life stages (Table 3). Generally, females weighed more than the males and the weight varied with the type of food plant. In the fifth instar, the pooled weight of both sexes fed on *P. vulgaris* and *T. aestivum* (1.4g) was not significantly different ($F_{3,168}$=6.978, p=0.00123) but was significantly different from that of males and females fed on *S. bicolor* (1.2g) or *Z. mays* (1.1g).

In the immature adults (fledglings), there were no individuals reared on *Z. mays* for comparison due to mortality. There were no significant differences in the weight of females reared on *T. aestivum* (2.9g) *or P. vulgaris* (2.7g) ($F_{2,76}$=12.31, p<0.001), both of which had significantly higher weight than those fed on *S. bicolor* higher (2.4g). Similarly, weight of males reared on different food plants varied significantly ($F_{2,85}$=4.765, p<0.001). The highest weight was recorded in males reared on *T. aestivum* (2.0g). However, this was not significantly different from the weight in males fed on *P. vulgaris* (1.9g) but differed significantly from fed on *S. bicolor* (1.8 g).

In the mating stage, the highest weight was observed in females reared on *P. vulgaris* (3.6 g) which was significantly different from those reared on *T. aestivum* (3.2g) or *S. bicolor* (2.4g) ($F_{2,72}$=42.94, p<0.001). Males reared on *T. aestivum* or *P. vulgaris* had a similar mean weight (2.0g) which was significantly different from those reared on *S. bicolor* (1.7g). In the ovipositing stage, there were no significant variations on the mean weight of the males raised on the three food plants ($F_{2,73}$=0.917, p=0.404). However, those reared on *P. vulgaris* weighed slightly higher (1.69g), followed by those fed on *S. bicolor* (1.65g) with those reared on *T. aestivum* having the lowest weight (1.61g). Females reared on *P. vulgaris* weighed significantly higher (3.2g) compared to those reared on both *T. aestivum* (2.8 g) and *S. bicolor* (2.7g) ($F_{2,59}$=10.15, p<0.001).

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Table 3: Mean weight (± SE) of 5th instar hoppers and adult stages of *S. gregaria* reared on different food plant.

Feed	5th instar nymphs	Immature adults		Mating adults		Ovipositing adults	
	Male and Female	Male	Female	Male	Female	Male	Female
P. vulgaris	1.40 ± 0.04^{b}	1.86 ± 0.04^{ab}	2.67 ± 0.08^{a}	1.93 ± 0.04^{a}	3.56 ± 0.11^{a}	1.69 ± 0.03	3.24 ± 0.13^{a}
S. bicolor	1.19 ± 0.04^{a}	1.78 ± 0.03^{b}	2.40 ± 0.07^{b}	1.69 ± 0.04^{b}	2.44 ± 0.08^{c}	1.65 ± 0.03	2.73 ± 0.05^{b}
T. aestivum	1.35 ± 0.05^{b}	1.97 ± 0.05^{a}	2.92 ± 0.08^{a}	2.03 ± 0.07^{a}	3.19 ± 0.07^{b}	1.61 ± 0.05	2.75 ± 0.08^{b}
Z. mays	1.05 ± 0.05^{c}	-	-	-	-	-	-
F value	6.978	4.765	12.31	10.48	42.94	0.917	10.15
D.f	2,168	2,85	2,76	2,82	2,72	2,73	2,59
P value	0.00123	0.0109	<0.001	<0.001	<0.001	0.404	<0.001

Means in the same column followed by the same letters are not significantly different from one another at 5% significance level of probability (Tukey's HSD).

4.5 Proximate analysis of food plants.

There were significant variations in the mean levels of the dry matter in the experimental food plants ($F_{3,4}$=60, p=0.00088) (Table 4). Dry matter levels were not significantly high in *Z. mays* (90.2%) and *S. bicolor* (90.0%). However, they differed significantly ($F_{3,4}$=60, p=0.00088) in *T. aestivum* (88.0%) and *P. vulgaris* (85.0%). Crude protein level of the experimental food plants was not significantly differently among the three food plants: *P. vulgaris* (32.0%), *T. aestivum* (31.6%) and *S. bicolor* (31.3 %) but significantly low in *Z. mays* (30.5 %) ($F_{3,4}$=8.93, p=0.0302).

The ash content was not significantly different in all the food plants ($F_{3,4}$=2.312, p=0.218), although it was highest in *S. bicolor* (17.0%) followed by *Z. mays* (15.8%), *P. vulgaris* (15.0%) and least in *T. aestivum* (10.6%). There were no significant variations in the levels of organic matter in all the four food plants ($F_{3,4}$=2.312, p=0.227) (Table 4). However, the highest level of organic matter was recorded in *T. aestivum* (89.0%) followed by *P. vulgaris* (85.0%), *Z. mays* (84.2%) and lowest in *S. bicolor* (83.0%).

Fat content was highest in *Z. mays* (7.5%) but not significantly different from *T. aestivum* (6.0%) ($F_{3,4}$=2.312; p=0.0034) both of which were significantly different from *P. vulgaris* (2.7%) and *S. bicolor* (3.4%). The Neutral Detergent Fibre (NDF) significantly varied in all the experimental food plants ($F_{3,4}$=65.02; p=0.00075) (Fig 5). The highest level of NDF (41.2%) was recorded in *S. bicolor* although this was not significantly different from *T. aestivum* (39.2%) or *Z. mays* (38.8%) but differed significantly from *P. vulgaris* (20.0%). The Acid Detergent Fibre (ADF) level did not differ significantly on *T. aestivum* (20.2%) and *Z. mays* (21.7%) ($F_{3,4}$=55.16, P=0.00104) but it varied significantly from *P. vulgaris* (15.0%) or *S. bicolor* (24.6%).

Table 4: Nutritional composition (% DM) of the experimental food plants (mean ± S.E)

Food plant	Dry matter	Ash	Organic matter	Crude Protein	Fat	ADF	NDF
P. vulgaris	85.00 ± 0.00^{c}	15.00 ± 2.31^{a}	85.00 ± 3.24^{a}	32.03 ± 0.31^{a}	2.65 ± 0.00^{b}	14.95 ± 0.50^{c}	19.98 ± 0.43^{b}
T. aestivum	88.00 ± 0.50^{b}	10.59 ± 1.27^{a}	89.00 ± 1.27^{a}	31.61 ± 0.22^{ab}	5.98 ± 0.03^{a}	20.24 ± 0.11^{b}	39.17 ± 2.42^{a}
S. bicolor	89.75 ± 0.25^{ab}	16.99 ± 0.78^{a}	$83.00 \pm 0.^{79a}$	31.30 ± 0.07^{ab}	3.35 ± 0.83^{b}	24.64 ± 0.00^{a}	41.17 ± 0.00^{a}
Z.mays	90.25 ± 0.25^{a}	15.79 ± 0.87^{a}	84.21 ± 0.87^{a}	30.53 ± 0.17^{b}	7.50 ± 0.02^{a}	21.66 ± 0.96^{ab}	38.81 ± 0.11^{a}
F value	60	2.312	2.312	8.93	2.312	55.16	65.02
D.F	3,4	3,4	3,4	3,4	3,4	3,4	3,4
P value	0.00088	0.218	0.227	0.0302	0.0034	0.00104	0.00075

Mean in the same column followed by the same letter(s) are not significantly different from one another at 5% significance level of probability (Tukey's HSD)

4.6 Nutrient composition of the 5th instar hoppers, *S. gregaria* reared on different food plants.

The nutritional composition (% Dry Matter) of the 5th instar hoppers varied according to the food plant used to rear them (Table 5). Individuals reared on *Z. mays* were not analyzed because of high mortality since those who survived to 5th instar couldn't provide enough quantity for analysis.

Fat content did not vary significantly in hoppers reared on the three food plants ($F_{2,3}$=0.332, p=0.741). However, it was highest in individuals reared on *S. bicolor* (15.2%) followed by those raised on *P. vulgaris* (13.6%) and lowest in hoppers reared on *T. aestivum* (13.6 %). Similarly NDF levels did not vary significantly ($F_{2,3}$=9.07, p=0.0535), although it was highest in hoppers raised on *S. bicolor* (19.4%), followed by those of *T. aestivum* (12.9%) and lowest in *P. vulgaris* (11.6%). Hoppers raised on *S. bicolor* had the highest level (12.03%) of ADF significantly different from those of *T. aestivum* (9.1%) and *P. vulgaris* (7.3%) ($F_{2,3}$=43.33, p=0.00612).

The quantity of organic matter was highest in *P. vulgaris* (92.2 %) and lowest in *T. aestivum* (82.3%) but the variation was not significant ($F_{2,3}$=0.449; p=0.675). The ash content did not vary significantly in the hoppers reared on the three food plants ($F_{2,3}$=0.449; p=0.675) although it was highest in hoppers reared on *S. bicolor* (10.8%), followed by those reared on *T. aestivum* (10.7%) and lowest in those reared on *P. vulgaris* (7.9%). Hoppers reared on *P. vulgaris* were found to contain high levels of dry matter (15.0%) compared to those of *T. aestivum* (12.0%) though the difference was not significant, however, both differed significantly from those raised on *S. bicolor* (7.5%) ($F_{2,3}$=644.4, p=0.000112).

Table 5: The proximate profile (% DM) of 5th instar hoppers (mean ± S.E).

Food plant	Dry matter	Ash	Organic matter	Fat	ADF	NDF
P. vulgaris	15.00 ± 0.00^{a}	7.85 ± 1.45^{a}	92.15 ± 1.45^{a}	13.65 ± 2.20^{a}	7.31 ± 0.43^{b}	11.61 ± 1.29^{a}
T. aestivum	12.00 ± 0.50^{a}	10.72 ± 1.12^{a}	82.28 ± 1.42^{a}	13.62 ± 1.36^{a}	9.06 ± 0.46^{b}	12.94 ± 0.83^{a}
S. bicolor	7.46 ± 0.25^{b}	10.77 ± 3.82^{a}	89.22 ± 3.82^{a}	15.15 ± 0.04^{a}	12.03 ± 0.01^{a}	19.43 ± 1.86^{a}
F value	644.4	0.449	0.449	0.332	43.33	9.07
D.F	2,3	2,3	2,3	2,3	2,3	2,3
P value	0.000112	0.675	0.675	0.741	0.00612	0.0535

Mean in the same column followed by the same letter(s) are not significantly different from one another at 5% significance level of probability (Tukey’s HSD)

4.7 Nutrient composition of the mating *S. gregaria* adults reared on different food plants.

The proximate analysis conducted on mating adults revealed significant variations in percentage dry matter of the adult reared on different food plants (Table 6). Adults raised on *T. aestivum* had the lowest dry matter content (88.1%) which differed significantly from those reared on *S. bicolor* (90.3%) and *P. vulgaris* (89.7%) ($F_{2,3}$=28.24, p=0.0113). There were no significant differences in the ash levels on all adults reared on the three food plants ($F_{2,3}$=2.389, p=0.21). However, the ash content was highest in adults raised on *P. vulgaris* (10.4%) followed by those on *T. aestivum* (9.0%) and lowest in those reared on *S. bicolor* (5.5%). Organic matter did not vary significantly in the adults reared on the three food plants ($F_{2,3}$=1.426, p=0.367). It was however highest in adults reared on *S. bicolor* (94.5%) and least in *P. vulgaris* (89.7%). There were significant variations in fat levels ($F_{2,3}$=78.21, p=0.00258) where the highest quantity was observed in individuals fed on *T. aestivum* (21.8%) which differed significantly with those from *S. bicolor* (16.0 %) and *P. vulgaris* (14.8 %).

NDF varied significantly in all the adults reared on the different experimental food plants ($F_{2,3}$=60.12, p=0.038). Adults raised on *S. bicolor* contained the highest levels of NDF (30.7%) which was significantly different from other adults from both *P. vulgaris* (21.5%) and *T. aestivum* (23.3%). On the other hand, the ADF level in locust fed on *S. bicolor* was significantly high (16.03%) compared to those of *T. aestivum* (13.7%) and *P. vulgaris* (11.7%) ($F_{2,3}$=14.2, p=0.0287).

Table 6: The proximate profile (% DM) of mating *S. gregaria* adults. (mean ± S.E)

Food plant	Dry matter	Ash	Organic matter	Fat	ADF	NDF
P. vulgaris	89.72 ± 0.27^{a}	10.35 ± 2.38^{a}	89.65 ± 2.50^{a}	14.77 ± 0.24^{b}	11.66 ± 0.04^{b}	21.53 ± 0.28^{b}
T. aestivum	88.06 ± 0.00^{b}	9.04 ± 2.26^{a}	90.96 ± 2.26^{a}	21.78 ± 0.65^{a}	13.65 ± 0.44^{b}	23.33 ± 0.44^{b}
S. bicolor	90.25 ± 0.25^{a}	5.54 ± 1.12^{a}	1.12 ± 1.59^{a}	16.01 ± 0.23^{b}	16.25 ± 0.95^{a}	30.69 ± 0.99^{a}
F value	28.24	2.389	1.426	78.21	14.5	60.12
D.F	2,3	2,3	2,3	2,3	2,3	2,3
P value	0.0113	0.21	0.367	0.00258	0.0287	0.0038

Mean in the same column followed by the same letter(s) are not significantly different from one another at 5% significance level of probability (Tukey's HSD.

4.8 Nutrient composition of the ovipositing *S. gregaria* adults reared on different food plants.

The different food plants used to rear ovipositing adults of *S. gregaria* impacted the locusts differently as revealed by their nutritional composition (Table 7). Adults reared on *T. aestivum* accumulated the highest level of dry matter (90.3%) which was not significantly different from those reared on *S. bicolor* (90.0%), but differed significantly from those raised on *P. vulgaris* (88.5%) ($F_{2,3}$=50.17, p=0.00495). There were no significant variations on the ash content for individuals reared on the three food plants ($F_{2,3}$=0.266, p=0.783). However, adults reared on *S. bicolor* had the highest level of ash (6.1%) followed by those of *T. aestivum* (5.8%) and lowest in individuals reared on *P. vulgaris* (5.6%).

There were no significant differences on the levels of organic matter in adults reared on the different experimental food plants ($F_{2,3}$=0.266, p=0.783). The organic matter was however highest in adults reared on *P. vulgaris* (94.4%), followed by those reared on *T. aestivum* (94.2%) and lowest in individuals raised on *S. bicolor* (93.9%).Fat levels differed significantly on the adults reared on all the experimental food plants ($F_{2,3}$=801.8, p=0.0000807). Adults reared on *S. bicolor* had the highest level of fat (16.8%) which differed significantly from those raised on *T. aestivum* (5.9%) and *P. vulgaris* (3.9%). NDF level was high (39.7 %) in the adults fed on *T. aestivum* and the variation was significantly different from the adults raised on *P. vulgaris* (38.2%) and *S. bicolor* (27.0%) ($F_{2,3}$=208, p=0.000606). The level of ADF was highest in individuals reared on *P. vulgaris* (20.8 %) which differed significantly from adults reared on *T. aestivum* (17.5%) and *S. bicolor* (14.0 %) ($F_{2,3}$=18.77, p=0.0201).

Table 7: The Nutritional profile (% DM) of Ovipositing *S. gregaria* adults (mean ± S.E) adults reared on different food plants

Food plant	Dry matter	Ash	Organic matter	Fat	ADF	NDF
P. vulgaris	88.53 ± 0.03^{b}	5.64 ± 0.58^{a}	94.36 ± 0.58^{a}	3.85 ± 0.43^{c}	20.80 ± 0.45^{a}	38.32 ± 0.24^{a}
T. aestivum	90.27 ± 0.23^{a}	5.80 ± 0.58^{a}	94.20 ± 0.28^{a}	5.92 ± 0.01^{b}	17.51 ± 1.22^{ab}	39.72 ± 0.80^{a}
S. bicolor	89.97 ± 0.03^{a}	6.13 ± 0.54^{a}	93.87 ± 0.28^{a}	16.84 ± 0.004^{a}	13.95 ± 0.4^{b}	26.99 ± 0.01^{a}
F value	50.17	0.266	0.266	801.8	18.77	208
D.F	2,3	2,3	2,3	2,3	2,3	2,3
P value	0.00495	0.783	0.783	0.0000807	0.0201	0.000606

Mean in the same column followed by the same letter(s) are not significantly different from one another at 5% significance level of probability (Tukey’s HSD)

4.9 The crude protein content of 5th instar hoppers and adults of *S. gregaria* reared on different food plants.

The nutritional analysis conducted on *S. gregaria* reared on different food plants revealed variations on the level of crude protein which also differed according to developmental stage (Table 8).

In the fifth instar, hoppers reared on *P. vulgaris* had the highest crude protein level (71.5%), which differed significantly from hoppers raised on *T. aestivum* (64.4%) and *S. bicolor* (62.2%) ($F_{2,3}$=42.24, p=0.00635). Mating adults reared on *P. vulgaris* accumulated the highest protein (73.3%) followed by those raised on *S. bicolor* (69.3%) and *T. aestivum* (65.4%). However, these crude protein levels were not significantly different ($F_{2,3}$=6.978, p=0.0744). For the ovipositing females, individuals maintained on *P. vulgaris* had highest crude protein (86.1%), which differed significantly from adults raised on *T. aestivum* (80.8%) or *S. bicolor* (70.5%) ($F_{2,3}$=25.32, p=0.0495).

Crude protein generally accumulated with the age of the locust reared on all the experimental food plants (Table 8). When reared on *P. vulgaris*, the ovipositing adults accumulated the highest proteins (86.1%) significantly different ($F_{2,3}$=27.79, p=0.0116) from the mating adults (73.3%) and the fifth instar hoppers (71.5%). When the locusts were reared on *T. aestivum*, the crude protein was significantly high ($F_{2,3}$=35.55, p=0.00815) in ovipositing adults (80.8%) as compared to the mating adults (65.4%) and 5th instar nymphs (64.4%). Similar trend was observed in individuals reared on *S. bicolor* whereby the highest crude protein level was recorded in ovipositing adults (70.5%) followed by the mating adults (69.3%) but varied significantly ($F_{2,3}$=29.94; p=0.0104) from the 5th instar hoppers (62.2%).

Table 8: Crude protein (% DM) of *S. gregaria* reared on different food plants (mean ± S.E).

	Fifth Instar hoppers	Mating adults	Ovipositing adults			
Food plant				F value	D.F	P. value
P. vulgaris	71.51 ± 0.31^{aB}	73.33 ± 2.54^{aB}	86.10 ± 0.03^{aA}	27.79	2,3	0.0116
T. aestivum	64.43 ± 0.40^{bB}	65.39 ± 0.07^{aB}	80.77 ± 2.63^{bA}	35.55	2,3	0.00815
S. bicolor	62.18 ± 1.18^{bB}	69.28 ± 0.54^{aA}	70.47 ± 0.56^{bA}	29.94	2,3	0.0104
F value	42.24	6.978	25.32			
D.F	2,3	2,3	2,3			
P value	0.00635	0.0744	0.00495			

Values in the same column with different small letters are significantly different ($P<0.005$) and values in the same column with different capital letters are significantly different ($P<0.05$) (Tukey's HSD).

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

This study aimed at investigating suitable food plants with positive impact on the life cycle of desert locust; *S. gregaria* in the laboratory. Locusts and grasshoppers represent a group of acridids that are highly polyphagous and hence capable of feeding on a wide variety of plants. Food plants have variable effects on the life aspects of grasshoppers and locusts such as growth and development, survival and fecundity (Finke, 2013). Other studies have shown that, the quality of a diet can greatly affect the growth and survival of an insect (Behmer and Joern, 1993). The insects require nutrients such as proteins, carbohydrates, fats, water and micro-nutrients for their growth, reproduction and for other metabolic activities (Ghosh *et al.*, 2014).

The ability of an insect to ingest, digest, and assimilate a food substance into the body ensures maximum growth rate, fosters weight input and increased survival chances to the adulthood (Abdel, 1999). From our study, it was noted that the developmental periods of the *S. gregaria* nymphs were highly varied when reared on different food plants. These revelations are in agreement with other studies by (Das *et al.*, 2012) who found that different food plants contain nutrients and particular chemicals that are responsible for varied growth and survival of grasshoppers and locusts. Superior food plants with respect to nutrition shorten nymphs development period and increases the chances of insect' survival to adulthood (Ghosh *et al.*, 2014).

From our study, the shortest nymphal development was observed on *S. gregaria* hoppers reared on *P. vulgaris* insignificantly followed by *T. aestivum.* These findings suggest that, both food plants contained nutrients that fostered the growth of the nymphs compared to *S. bicolor* and *Z. mays.*

In 2013, similar results were reported by Ganguly, that the shortest nymphal durations were observed on Oe*daleus abruptus* when fed on *T. aestivum* and *Sorghum prasiniferum* than when reared on *S. halepense*. Rearing of the *S. gregaria* nymphs on *Z. mays* resulted to a significantly longer development phase between the 1st and 2nd instar thrice the time taken by similar nymphs feeding on *P. vulgaris*, *S. bicolor* and *T. aestivum*. This delayed development implies some nutritional inadequacy of *Z. mays* plants for newly hatched *S. gregaria* hoppers.

Longer developmental periods were also observed in hoppers feeding on *Z. mays* for the 3rd and 4th instars which doubled in other food plants. It was noted that, in *Z. mays* nymphs, the number in each instar gradually declined in the successive developmental stages and consequently, the longest surviving individual lived up to the 5th instar. The hoppers were hesitant to feed on either the young leaves or the stems of the maize and could be seen foraging on the remains of the germinated seeds. This implied that, the food plant lacked essential nutrients that are needed for survival and growth of the hoppers and maybe therefore led to the high mortality. In natural environments; varied developmental rates are also possible resulting from the nutritional diversity of food plants (Abdel, 1999).

Feeding the *S. gregaria* nymphs on *P. vulgaris*, *S. bicolor* and *T. aestivum* revealed insignificantly shortest developmental durations for 1st, 2nd, and 3rd instars.

In the 4th and 5th instar, the shortest nymphal developmental duration was observed in nymphs fed on *P. vulgaris* significantly different from *S. bicolor* and *T. aestivum*. This observation is in line with other studies by Abdel (1999) and Uvarov (1977) that variable developmental periods are possible to occur in grasshoppers and locusts in the same localities due to variable food plants nutritional content. Generally, *P. vulgaris* appeared superior to other test food plants since it led to shortest total development from the 1st instar to the adult stage.

Besides the developmental durations, the superiority and suitability of the food plant was also reflected on high survival rates of locusts reared on *P. vulgaris*. On the other hand, *Z. mays* emerged to be nutritionally inadequately for the growth and development of *S. gregaria* hoppers. This was supported by the low survival rates and longer time taken by the hoppers to switch from one life stage to the other dragging the entire time from newly hatched hoppers to adult maturation. All the experimental individuals raised on *Z. mays* died before attaining the adult stage. Other studies showed that, polyphagous grasshoppers were able to adjust to other food plant if nutritionally appropriate as a complement (Bernays and Bright, 1991) and this may explain the decline of *Z. mays* individuals**.**

There were significant variations on the weight gain of the *S. gregaria* at different life stages as a result of the different food plants. The weight increased steadily from the 5th instar and was highest in mating adults in all the tested food plants indicating maximum accumulation of nutrients in the body masses except for *Z. mays* whose individuals failed to survive to adult. In the mating stage, the females are preparing for ovipositing and there is rapid formation of eggs. *S. gregaria* adults fed on *T. aestivum* promoted the highest weight gain insignificantly different from the *P. vulgaris.* This can partially be attributed to the nitrogen content from the food plants. This observation is in agreement with other studies done by Joern and Behmer (1997) that, when grasshopper *Ageneotettix deorum*, was subjected to a more nitrogen diet, the weight significantly increased. Individuals reared on *Z. mays* completely declined at the 5th instar and therefore no data was available for comparisons. In the 5th instar, individuals raised on *P. vulgaris* gained the highest weight and generally appeared active and physically huge in size than those of *Z. mays.*

At this stage, the hoppers are preparing for fledgling and therefore a lot of growth and development of body structures and physiological maturity.

This study revealed significant variations in the survivorship of the *S. gregaria* hoppers subjected to different food plants. The survival rate for hoppers reared on *P. vulgaris*, *T. aestivum* and *S. bicolor* was highest compared to those for *Z. mays* in the 2nd instar. This observation agrees with studies that a decline of quality food plants led to reduced survivorship and reproductive allocations in *M. sanguinipes* (Branson, 2008*)*

From the experiment, the survivorship was highest in the initial developmental stages and declined in the successive stages implying that, survivorship was a function of nutritional strength of the forage plants. In *Leptocorisa chinensis* (Hemiptera: Alydidae) the survival rate was high in young instars and declined towards the adulthood when reared on some selected summer and spring plants. In upper instars, it can be considered that more than one different food plant is required for proper development of the polyphagous *S. gregaria* hoppers.

In the 5th instar the highest survival rate was observed in both *P. vulgaris* and *T. aestivum* followed by *S. bicolor* and was least in *Z. mays*. The number of nymphs that molted to adulthood was significantly highest in *P. vulgaris* suggesting that it was more suitable nutritionally than all other food plants. On the other hand, almost no hoppers molted to adulthood on *Z. mays* besides their small sized bodies and poor health suggesting the plant lacked sufficient nutrients for nymphal development. Poor survival performance in *Z. mays* can also be attributed to absence of fundamental but unidentified factors for the development of *S. gregaria* hoppers. Our results are constituent with other studies which argued that chemicals such as specific amino acids present in the food plants acts as phagostimulants and stimulate the locusts to feed on the best food that is able to foster its growth hence high survivorship (Behmer and Joern 1993).

Generally, *P. vulgaris* and *T. aestivum* promoted the highest survival suggesting that the food plants contained nutrients, water levels and were more palatable than *S. bicolor*. On the other hand, *Z. mays* was less eaten by the hoppers and perhaps contained deterrent chemicals that could be behind high mortality and less weight gain as compared to other food plants. The low mortalities may also attributed to the low nitrogen level in the *Z. mays*. Other studies by White (1976) showed that the survival of *S. gregaria* nymphs in desert environments was high at elevated leaf nitrogen. From this study, *P. vulgaris* and *T. aestivum* are appeared more suitable food plants for *S. gregaria* nymphs with regard to high survival and short developmental. The existence and mechanisms of chemical factors that stimulated feeding behavior in *P. vulgaris* plants and other noxious deterrents in *Z. mays* for the hoppers remain to be a subject for future studies.

Adults feeding on *P. vulgaris* and *T. aestivum* took the shortest pre-ovipositing duration than all other food plants. The experimental food plants showed significant effects on the total number of eggs in the entire life span of female locust. Locusts reared on *P. vulgaris* deposited the highest number of eggs indicating improved fertility. The right quantities of nutrients in the insects play an important role in triggering the endocrine system in preparation for egg cells formation (Engelmann, 1979). Increased feeding of the female locusts on a suitable food stimulates the foregut receptors to stretch and consequently, invoke the endocrine system (Branson *et al.*, 2006)**.** This phenomenon may be supported by investigation by Uvarov (1977) that, ingestion of less than 80mg (of dry weight grass) per female per day didn’t initiate oocyte formation in desert locusts. There was a conspicuous difference between the pre-oviposition and oviposition duration among the adult locusts reared on different food plants which may be attributed to qualitative and quantitative factors within the food plants.

The prolonged pre-oviposition duration and lower number of eggs in *S. bicolor* may be an indication of poor nutritional value that may have delayed ovarian development. (R. F. Chapman, 1998) argued that, grasshoppers are able to reduce significant resources to reproduction when resources are limiting lowering vitellogenesis. This statement agrees with the experimental results and (McCaffery *et al.*, 1978) that the total quality of food taken influenced the oviposition status during vitellogenesis. When female adult *Locusta migratoria migratorioides* were fed with a low-protein *Agropyrons repens*, oocyte development failed to initiate (Bashir, 2000)

Insects' tissues contain protein essential for various structural and physiological functions in their bodies. Edible insects such as *S. gregaria* have been found to contain relatively higher protein content than most conventional sources such as soybeans. The nutritional quality of an insect can be manipulated by the type of diet taken. Our experiment aimed at assessing how the selected food plants impact the nutritional composition of *S. gregaria*. The crude protein level was found to be highest when the adults were ovipositing and old and when fed on *P. vulgaris* as compared to *T. aestivum* and *S. bicolor.* The crude protein level (86.10%) from the experiment was slightly higher than the previous reports in the literature (61.75%-62%) (FAO, 2012; Cheseto *et al*., 2015) indicating *P. vulgaris* is more suitable than the conventional *T. aestivum* seedlings.

Most edible insects have 10 and 50% fat content (Ying *et al*., 2001; DeFoliart, 1991) which is in agreement with our experimental outcome. The highest fat content was observed in the mating adults of *S. gregaria* reared on *T. aestivum* (21.78%). This results are also consistent with available data on edible insects (Finke *et al.*, 1985). Fat significantly contribute to the energy requirements at this stage where the locusts are very active chasing one another during the mating exercises. The fats greatly contribute to the structural and biological functioning of cells through energy provisions. Ash content in a food sample is an indicator of mineral presence (Adeyeye, 2000). *S. gregaria* was therefore found to be a potential source of minerals although in low levels. There were no significant differences in the ash levels for the hoppers and adults fed on all the food plants. However, the ash level was highest in the 5th instar hoppers. These findings are consistent to other published reports that edible insects contain small amounts of ash due to absence of internal calcified skeleton present in most vertebrates (Mohamed, 2016)

Fibre in a food material can be estimated by the crude fibre (CF), acid detergent (ADF) and neutral detergent fiber (ADF) (Finke, 1984). Lignin, cellulose as well as hemicellulose collectively comprise the NDF in plants (Van Soest, 1977) while ADF consist of lignin and cellulose. In the *S. gregaria* tissue, ADF and NDF are indications of chitin level which is structurally similar to cellulose in plants. In this study the fibre content of the insects reared on different host plants was moderate as reflected in ADF and NDF values of the insects analyzed. The ADF and NDF obtained from our experiments are similar to those of termites (29.58%) as reported by Adeduntan (2005). High NDF and ADF could be due to the chitin found in the insect's exoskeleton although it was comparable to the levels in the food plant. Fibre in the diet improves food digestion by providing bulk to the food and enhancing the peristaltic movements during digestion. From our experiment, the highest levels of NDF and ADF were observed in the oviposting adults especially those reared on *T. aestivum* although comparable to other host plants. This implies that, *S. gregaria* adults fed on wheat seedlings could be the best source of dietary fibre.

The nutritional value of edible insects can vary even within the same species due metamorphic stage on the insect, the habitat and also due to the nutritional content of the diet (Joern, 1997). The content of the crude protein of *S. gregaria* was found to be highest in the ovipositing adults fed on *P. vulgaris*. This tends to point out that, the crude protein (% DM) increased with age and that *P. vulgaris* fostered the highest protein gain. However, this value is slightly above the values popular in the literature for edible Orthopterans 23-65% per dry matter (van Huis, 2013) may be because of the fertility of the soil for raising the host plants and the age when the locusts were analyzed and also due to the host plants. This study aimed at finding out if different host plants influenced the life cycle and nutritional composition of *S. gregaria* as part of the ongoing mission of addressing the scarce information on the dietary and environmental effects on the nutritional value of the edible insects.

5.2 Conclusion

P. vulgaris, T. aestivum and *S. bicolor* are potential food plants for rearing *S. gregaria*. However, *P. vulgaris* is the most suitable food plant for desert locust nymphs and the adults since it fostered the shortest nymph development, highest survival, and highest crude protein manifestation. Rearing the locust on *P. vulgaris* can ultimately lead to a large locust biomass in acridid farms which could be supplied to the poultry feed-producing companies as a high-protein low-cost alternative feed for poultry and other livestock. In addition, since acridids may perform better when fed on mixed food plants, further experiments are needed to investigate the effect of mixed diets and *P. vulgaris* on the performance of *S. gregaria.* The edible *S. gregaria* is therefore a nutrient rich food source for humans and animal diets and its life cycle and nutritional composition can be altered by the type of food plant fed on.

5.3 Recommendations

1. I would recommend the use of *P. vulgaris* as a suitable food plant for the rearing *S. gregaria* in laboratory and its mass production.
2. There is need for further studies on how to integrate *S. gregaria* into fish feeds, livestock feeds as well as human diet due to its protein value when reared on *P. vulgaris*
3. Further analysis on amino acids of the insect tissue raised on *P. vulgaris* ought to be done to ascertain their profile.
4. Further investigations should be carried out to establish the factors that contributed to poor performance of *Z. mays* on the growth and reproduction parameters of *S. gregaria*.

5. I encourage more research on the effect of other leguminous plants and the use of mixed food plants on the nutritional status on the *S. gregaria*.

REFERENCES

Abdel, H., (1999). *Studies on the effect of different food plant species on the life system of the desert locust, Schistocerca gregaria Forskal (Orthoptera: Acrididae).* PhD thesis. University of Khartoum, Sudan.

Alexandratos, N., & Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision. *ESA Work. Pap, 3*.

Anand, H., Ganguly, A., & Haldar, P. (2008). Potential value of acridids as high protein supplement for poultry feed. *International Journal of Poultry Science, 7*(7), 722-725.

Assad, Y., Torto, B., Hassanali, A., Njagi, P., Bashir, N., & Mahamat, H. (1997). Seasonal variation in the essential oil composition of Commiphora quadricincta and its effect on the maturation of immature adults of the desert locust, Schistocerca gregaria. *Phytochemistry, 44*(5), 833-841.

Bashir, M., Hassanali, A., Rai, M., & Saini, R. (2000). Changing oviposition preferences of the desert locust, Schistocerca gregaria, suggest a strong species predisposition for gregarization. *Journal of Chemical Ecology, 26*(7), 1721-1733.

Behmer, S., & Joern, A. (1993). Diet choice by a grass-feeding grasshopper based on the need for a limiting nutrient. *Functional Ecology*, 522-527.

Bernays, E. & Bright, K. (1991). Dietary mixing in grasshoppers: switching induced by nutritional imbalances in foods. *Entomologia experimentalis et applicata, 61*(3), 247-253.

Bernays, E. & Chapman, R. (1994). Behavior: the process of host-plant selection. *Host-plant selection by phytophagous insects*, 95-165.

Branson, D. H. (2003). Reproduction and survival in Melanoplus sanguinipes (Orthoptera: Acrididae) in response to resource availability and population density: the role of exploitative competition. *The Canadian Entomologist, 135*(03), 415-426.

Branson, D. H., Joern, A., & Sword, G. A. (2006). Sustainable management of insect herbivores in grassland ecosystems: new perspectives in grasshopper control. *Bioscience, 56*(9), 743-755.

Chakravorty, J., Ghosh, S., & Meyer-Rochow, V. B. (2011). Practices of entomophagy and entomotherapy by members of the Nyishi and Galo tribes, two ethnic groups of the state of Arunachal Pradesh (North-East India). *Journal of Ethnobiology and Ethnomedicine, 7*(5), 1-14.

Chandra, S., & Williams, G. (1983). Frequency-dependent selection in the grazing behaviour of the desert locust Schistocerca gregaria. *Ecological Entomology, 8*(1), 13-21.

Chang, S. K. (2010). Protein analysis *Food analysis* (pp. 133-146): Springer.

Chapman, R. (1990). Food selection. *Biology of grasshoppers. Wiley, New York*, 39-72.

Chapman, R. F. (1998). *The insects: structure and function*: Cambridge university press.

Das, M., Ganguly, A., & Haldar, P. (2012). Effect of food plants on nutritional ecology of two acridids (Orthoptera: Acrididae) to provide alternative protein supplement for poultry. *Turkish Journal of Zoology, 36*, 699-718.

DeFoliart, G. R. (1989). The human use of insects as food and as animal feed. *Bulletin of the Entomological Society of America, 35*(1), 22-36.

Dufour, D. L. (1987). Insects as food: a case study from the northwest Amazon. *American Anthropologist, 89*(2) 383-397.

Ely, S. O. (2015). *Reproductive Behaviour Of The Solitarious Desert Locust, Schistocerca Gregaria (Forskål), In Relation To Semiochemical Attributes Of Desert Plants.* UOFK.

Engelmann, F. (1979). Insect vitellogenin: identification, biosynthesis, and role in vitellogenesis. *Advances in Insect Physiology, 14*, 49-108.

Evans, C. S., & Bell, E. A. (1979). Non-protein amino acids of Acacia species and their effect on the feeding of the acridids Anacridium melanorhodon and Locusta migratoria. *Phytochemistry, 18*(11), 1807-1810.

Finke, M., Sunde, M., & DeFoliart, G. (1985). An evaluation of the protein quality of Mormon crickets (Anabrus simplex Haldeman) when used as a high protein feedstuff for poultry. *Poultry Science*, *64*(4), 708-712.

Finke, M. D. (2013). Complete nutrient content of four species of feeder insects. *Zoo biology, 32*(1), 27-36.

Ghosh, S., Haldar, P., & Mandal, D. K. (2014). Suitable food plants for mass rearing of the short-horn grasshopper Oxya hyla hyla (Orthoptera: Acrididae). *European Journal of Entomology*, *111*(3), 448.

Haldar, P., Das, A., & Gupta, R. K. (1999). A laboratory based study on farming of an Indian grasshopper Oxya fuscovittata (Marschall)(Orthoptera: Acrididae). *Journal of Orthoptera Research*, 93-97.

Hanboonsong, Y., Jamjanya, T., & Durst, P. B. (2013). *Six-legged livestock: edible insect farming, collection and marketing in Thailand*.

Haskell, P., Paskin, M., & Moorhouse, J. (1962). Laboratory observations on factors affecting the movements of hoppers of the desert locust. *Journal of Insect Physiology, 8*(1), 53-78.

Helrich, K. (1990). *Official methods of Analysis of the AOAC. Volume 2*: Association of Official Analytical Chemists Inc.

Hinks, C., & Erlandson, M. (1994). Rearing grasshoppers and locusts: review, rationale and update. *Journal of Orthoptera Research*, 1-10.

Hinks, C., & Olfert, O. (1993). Growth and survival to the second instar of neonate grasshopper nymphs, Melanoplus sanguinipes (F.) fed cultivars ancestral to hard red spring wheat. *Journal of Agricultural Entomology, 10*(3), 171-180.

Ishizaki, M., Yasuda, T., & Watanabe, T. (2008). Effect of plant species on survivorship and duration of nymphal stage in Leptocorisa chinensis (Hemiptera: Alydidae). *Annals of the Entomological Society of America, 101*(3), 558-564.

Jacob, A. A., Emenike, A. F., Kayode, A., Olusegun, O., Uzoma, A., & Rukayat, K. Q. (2013). Entomophagy: A Panacea for Protein-Deficient-Malnutrition and Food Insecurity in Nigeria. *Journal of Agricultural Science, 5*(6), p25.

Joern, A., & Behmer, S. T. (1997). Importance of dietary nitrogen and carbohydrates to survival, growth, and reproduction in adults of the grasshopper Ageneotettix deorum (Orthoptera: Acrididae). *Oecologia, 112*(2), 201-208.

Khusro, M., Andrew, N. R., & Nicholas, A. (2012). Insects as poultry feed: a scoping study for poultry production systems in Australia. *World's Poultry Science Journal, 68*(03), 435-446.

Lecoq, M., Andriamaroahina, T. R., Solofonaina, H., & Gay, P.-E. (2011). Ecology and population dynamics of solitary Red Locusts in southern Madagascar. *Journal of Orthoptera Research, 20*(2), 141-158.

Loher, W. (1961). The chemical acceleration of the maturation process and its hormonal control in the male of the desert locust. *Proceedings of the Royal Society of London B: Biological Sciences, 153*(952), 380-397.

Maeno, K. O., Piou, C., Babah, M. A. O., & Nakamura, S. (2013). Eggs and hatchlings variations in desert locusts: phase related characteristics and starvation tolerance. *Frontiers in physiology, 4*.

Makkar, H. P., Tran, G., Heuzé, V., & Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology, 197*, 1-33.

McCaffery, A. (1975). Food quality and quantity in relation to egg production in Locusta migratoria migratorioides. *Journal of Insect Physiology, 21*(9), 1551-1558.

McCaffery, A., Cook, A., Page, W., & Perfect, T. (1978). Utilisation of food by Zonocerus variegatus (L.)(Orthoptera: Pyrgomor phidae). *Bulletin of Entomological Research, 68*(04), 589-606.

McGinnis, A., & Kasting, R. (1966). Comparison of tissues from solid-and hollow-stemmed spring wheats during growth—IV. Apparent dry matter utilization and nitrogen balance in the two-striped grasshopper, Melanoplus bivittatus (Say). *Journal of Insect Physiology, 12*(6), 671-678.

Meinzingen, W. (1993). *A guide to migrant pest management in Africa*: FAO.

Mohamed, E. H. (2016). Determination of nutritive value of the edible migratory locust Locusta migratoria, Linnaeus, 1758 (Orthoptera: Acrididae).

Niaba, K., Atchibri, L., Gbassi, K., Beugre, A., Adou, M., & Anon, A. (2012). Consumption survey of edible winged termites in Cote d'Ivoire. *International Journal of Agrictural Food Science, 2*, 149-152.

Njagi, P. G. N., & Torto, B. (1996). Responses of nymphs of desert locust, Schistocerca gregaria to volatiles of plants used as rearing diet. *Chemoecology, 7*(4), 172-178.

Nzekwu, A., & Akingbohungbe, A. (2002). The effects of various host plants on nymphal development and egg production in Oedaleus nigeriensis Uvarov (Orthoptera: Acrididae). *Journal of Orthoptera Research, 11*(2), 185-188.

Obopile, M., & Seeletso, T. G. (2013). Eat or not eat: an analysis of the status of entomophagy in Botswana. *Food security, 5*(6), 817-824.

Pfadt, R., & Smith, D. (1972). Net reproductive rate and capacity for increase of the migratory grasshopper, Melanoplus sanguinipes sanguinipes (F.). *Acrida, 1*(2), 149-165.

Ramos-Elorduy, J. (1987). Are insects edible? Man's attitude towards the eating of insects. *Food Deficiency Studies and Perspectives*, 78-93.

Ramos-Elorduy, J., Pino, J., Márquez, C., Rincón, F., Alvarado, M., Escamilla, E., & Bourges, H. (1984). Protein content of some edible insects in Mexico. *Journal of Ethnobiology, 4*(6).

Robert, K. (1989). The application of industrial technology for production of insects as food. *The food Insect Newsletter, 3*(3).

Semino, S., Paul, H., Tomei, J., Joensen, L., Monti, M., & Jelsøe, E. (2009). *Soybean biomass produced in Argentina: Myths and realities.* Paper presented at the IOP Conference Series: Earth and Environmental Science.

Steedman, A. (1988). Locust handbook 2nd ed. Overseas Development. *Natural Resource Institute London*.

Sultana, R., & Wagan, M. S. (2007). The effect of food plants on the growth rate, fecundity and survivability of grasshopper Hieroglyphus nigrorepletus I. Bolivar (orthoperta: Acrididae) a major paddy pest in Pakistan. *Journal of Biological Sciences*, *7*(7), 1282-1286.

Symmons, P., & Cressman, K. (2001). Desert locust guidelines: biology and behaviour. *Rome: Food and Agriculture organization (FAO) of the United Nations*.

Thomas, M. B., & Blanford, S. (2003). Thermal biology in insect-parasite interactions. *Trends in Ecology & Evolution, 18*(7), 344-350.

Trostle, R. (2008). Global agricultural supply and demand. *Factors contributing to the recent increase in food commodity prices. Washington, DC: US Department of Agriculture*.

Ueckert, D., Yang, S., & Albin, R. (1972). Biological value of rangeland grasshoppers as a protein concentrate. *Journal of Economic Entomology, 65*(5), 1286-1288.

Uvarov. (1966). Grasshoppers and locusts. A handbook of general acridology. Volume I. Anatomy, physiology, development, phase polymorphism, introduction to taxonomy. *Grasshoppers and locusts. A handbook of general acridology. Volume I. Anatomy, physiology, development, phase polymorphism, introduction to taxonomy.*

Uvarov. (1977). *Grasshoppers and locusts. A handbook of general acridology. Volume 2. Behaviour, ecology, biogeography, population dynamics*: Centre for Overseas Pest Research.

Van Huis. (2013). Potential of insects as food and feed in assuring food security. *Annual Review of Entomology, 58*, 563-583.

Van Huis, A. (2003). Insects as food in sub-Saharan Africa. *International Journal of Tropical Insect Science, 23*(03), 163-185.

Van Soest, P. (1967). Development of a comprehensive system of feed analyses and its application to forages. *Journal of Animal Science, 26*(1), 119-128.

Van Soest, P., Robertson, J., & Lewis, B. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science, 74*(10), 3583-3597.

Vantomme, P., Mertens, E., van Huis, A., & Klunder, H. (2012). Assessing the Potential of Insects as Food and Feed in assuring Food Security. *Rome, Italy: United Nations Food and Agricultural Organization*.

Veldkamp, T., & Bosch, G. (2015). Insects: a protein-rich feed ingredient in pig and poultry diets. *Anim. Frontiers, 5*(2), 45-50.

Wang, D., Zhai, S.-W., Zhang, C.-X., Zhang, Q., & Chen, H. (2007). Nutrition value of the Chinese grasshopper Acrida cinerea (Thunberg) for broilers. *Animal Feed Science and Technology, 135*(1), 66-74.

Yen, A. L., Hanboonsong, Y., van Huis, A., (2012). The role of edible insects in human recreation and tourism. *The Management of Insects in Recreation and Tourism*, 169-185.