Field Study of Host Plant Preference of solitary Desert Locust Schistocerca gregaria (Forskal) (Orthoptera: Acrididae)

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Chapter one
Introduction

The desert locust, *Schistocerca gregaria* (Forskal) is a hemimetabolous insect. It belongs to the subfamily Cyrtacanthacridinae of the family Acrididae that belongs to the order Orthoptera.

The total distribution area of *Schistocerca gregaria* extends over some 29 million km$^2$ in Africa and southwestern Asia (Uvarov, 1977). It occurs mainly in semi-desert and short grass savannah and is capable of invading nearly all parts of Africa north of the equator, the Middle East, Central and Western regions of the Soviet Union.

The desert locust is one of the most destructive pest feeding on a very wide range of plants, inflicting considerable damage by cutting through stems and leaves and breaking branches by the weight when densely settled (Steedman, 1990).

A major swarm may weigh 100,000 tonnes and eat this much of green vegetation every day (Prior *et al.*, 1992). Both Steedman (1988) and Showler (1995) mentioned that, a swarm, which contains 50 million individuals per km$^2$ might travel a few to over 100km in a day. It therefore invades a vast area due to its ability to fly long distances, the flight speed ranges between 1.5-16km/hr. (Meinzingen, 1993).

Its multiplication rate is very high when the conditions are favourable for breeding within three month or less it can complete one generation from egg laying to the mature adult (Nurien, 1987).
During 1986-1989 a desert locust plague occurred that necessitate the mobilization of resources costing about US $ 300 million and the application of nearly 15 million litres of pesticides over more than 17 million hectares and some of which were applied in ecologically sensitive areas (AbdelRahman, 1999).

Nevertheless, in 1992-94 another major upsurge occurred and a bout US $ 45 million was spent on chemical control over an area of 4 million hectares (AbdelRahman, 1999). Such control strategies of desert locust, by using a broad spectrum of chemical insecticide may certainly affect a wide range of non-target species including beneficial insects, birds, and mammals and to some extent the human beings. Consequently, the current control strategies are directed to control measures that are environmentally safe, economical and effective against the pest.

Although a great deal of information has been gathered on the behaviour and population dynamics of gregarious locusts, yet less is known about solitaria behaviour and population in their habitats.

Solitaria locust lives in fewer varieties of biotopes than swarms.

In general, they occur in open sandy steppes with few or no trees.

However some of the plants with which solitaria desert locusts are often associated with are *Heliotropium spp.*, *Diptyerygium, Tribulus spp.*, *Schouwia purpurea*, *Schouwia thebaica*, *Aerva persica*, *Hyocamus muticus* and among cultivated plants the bulrush millet. In the absence of
these, however, they may show preference for other species (Steedman, 1988)

Ghaout et al. (1991) carried out gut content analysis and demonstrated that, *Schouwia purpurea* and *Boerhavia repens* dominant on the study site and on the strip-transect were found in the feces in the same proportion to their relative abundance. While *Tribulus terrester*, which was rare all over the study site, was consumed more than expected.

Bhatia and Sikka (1956) outlined that, when some plants were singly grown they were eaten by *Schistocerca gregaria*, yet they were totally neglected when found growing side by side with other plants. Moreover, the insect did not eat some plants when grown singly; nevertheless they were devoured when found among some other less favoured plants.

Ba-Angood (1974), reported that although *Schistocerca gregaria* is polyphagous, it showed some preference for dicotyledonous plants compared to monocotyledons.

Although several studies have been carried out on host plant preference, nevertheless, much remained to be done.

Hence, this field study was undertaken with the following ultimate objective:

To identify the host plants preferred by solitary desert locust nymphs and adults under field condition, in the potential breeding and recession area.
Thus, the key aim of this field study is to unravel information on forecasting and prediction of early outbreak and gregarising population pattern in the potential recession and breeding areas. This information is essential for the successful development of the most rational and effective management strategies of desert locust.

However, the study will investigate the following parameters:

1- General plant cover of the area.
2- Plant species cover of the area.
3- Relative number of plant species encountered in the study site.
4- Plant species availability.
5- Plant species frequency.
6- Analysis of the fecal pellets of both the hoppers and the adults collected from the specified transect at the study site.
7- Comparison of the frequency of the epidermal cells in the fecal pellets to the plant frequency and availability in transects, from which the locust individuals were collected.
Chapter Two

Literature review

2.1 Taxonomy

The desert locust belongs to phylum Arthropoda and the class Insecta; the subclass is Pterygota.

The division is Exopterygota, the order of Orthoptera; suborder of Caelifera; family Acrididae and subfamily Cyrtacanthacridinae (Meinzingen, 1993 and Nurien, 1987).

Phase polymorphism is manifested by some species of desert locust. The species *Schistocerca cancellata*, described by Serville (1839), has phase polymorphism in both adults and hoppers. However, the gregarious phase was described as *Acridium paranense* and is frequently referred to in the literature as *Schistocerca paranensis* (Burmeister, 1839).

The species, *Schistocerca piceifrons* (Walker) likewise has phase polymorphism. The solitarious phase is difficult to distinguish from *S. americana* (Drury, 1773).

The desert locust, *Schistocerca gregaria* (Forskal) is the only old world species representing this genus. It was lately classified as a subspecies of *S. americana* (Dirsh). Nevertheless crossing experiments have proved this supposition to be untenable (Jago, *et al.*, 1979). It is regarded as a distinct
species with two subspecies; one is *S. gregaria flaviventris* (Burmeister, 1839), which is known as the South-West African subspecies found especially in Namibia, south Africa, Botswana, Angola and Ascension Island. The other is the well-known desert locust, *Schistocerca gregaria gregaria*, which has not been known to invade Southern Africa.

### 2.2 Identification

The male body length of the desert locust is 60-75mm; female body length is 70-90mm. The pronotum of the desert locust is not crested, but is more constricted and saddle shaped in the gregarious phase. The colour of the gregarious immature adult is pink becoming reddish-brown if it stays more than two months in this stage whilst the mature adult is bright yellow.

The solitarious, immature male is sandy-grey or brownish, often with a coloured median stripe on the pronotum. The solitarious mature male may be yellow. (Meinzingen, 1993)

### 2.3 History and Geographical Distribution

The desert locust exists in two phases, the solitarious and gregarious phases. In its gregarious phase, the desert locust, has caused plague to agriculture from the earliest recorded time; the eighth plague of Egypt recorded in the book of exodus (about 1300 BC) was of this species.
The total distribution area of *S. gregaria* extends over some 29 million km² in Africa and southwestern Asia (Uvarov, 1977), more than half of this area (54%) is infested only by migrating swarms. It occurs mainly in semi-deserts and short grass savannah, and is capable of invading nearly all parts of Africa north of the equator, the Middle East, central and western regions of the Soviet Union.

During the recession periods, it inhabits a broad belt of arid and semi-arid areas covering about 16 million square kilometers (Meinzingen, 1993 and Haskel, 1982).

### 2.4 Economic Importance

In the past, the key factor causing starvation and famine, is the desert locust. For the 9-years the F.A.O. estimate of the total value of crop damage in 12 countries, was $15 million (F.A.O., 1958).

The amount of crops consumed by the desert locust were: 7,000,000 grape vines, i.e. 19% of the total vines cultivated in Libya, in 1944; 55,000 tonnes of grains in Sudan in 1954; 16,000 tonnes of millet and 200 tonnes of other crops in Senegal, 600 tonnes of oranges in Guinea, 167,000 tonnes of grains in Ethiopia, which was sufficient to feed 1,000,000 individuals for one year; 4,000 hectares of cotton valuing for $30,000 in India (Steedman, 1988).
This pest eats about its own weight daily (200mg-1.5g) for hoppers, while an actively migrating adults consumes 2-3g daily and possibly three times as much (Steedman, 1988; Prior et al., 1992).

The desert locusts feed on a very wide range of plants, inflicting considerable damage by cutting through stems and leaves and breaking branches by their weight when densely settled (Steedman, 1990).

A major swarm may weigh 100,000 tonnes and can eat this much of green vegetation everyday (Prior et al., 1992).

Joyce (1977), stated that the damage caused by locusts includes complete destruction, as in young cereals and pulses; defoliation, as in citrus trees, selective destruction of grains at milky stage, barks; fruits, flowers, seeds and growing points; mechanical damage and fouling were caused by weight and excreta respectively.

Analysis of sample records showed that about 8% of the damage is caused by immature hoppers, 69% by the immature adults and 23% by mature adults (Joyce, 1977).

The frequency of occurrence of high-density population is one of the factors contributing to its status as a major pest. COPR (1982) pointed that phase transformation from solitary to gregarious and vice versa occurs rapidly and frequently. Outbreak occurs on average of one year in every six (Joffe, 1995) and the recent examples were outbreaks in 1984-1988 and 1993-1994 (krall, 1995).
Steedman (1988) and Showler (1995) mentioned that a swarm, which contains 50 million individuals per \(\text{Km}^2\), might travel a few to over 100-km in a day in the general direction of the prevailing winds. Whilst bands of nymphs can march about 1.5 Km per a day (Showler, 1995), a swarm can fly this distance per hour (Steedman, 1988).

The Sudan has the highest frequency of invasion in the infestation region. The summer breeding in Sudan covers vast plains, while the winter breeding concentrates in the Red Sea coastal area. According to studies carried by Waloff and Cornners (1964) during the period from 1937 to 1963, the desert locust swarms invaded the Sudan in 25 years and it was the country with the highest frequency of swarm invasion.

During 1988 plague, Sudan had been invaded with the most serious plague ever since 1958. The plant Protection Directorate of the Sudan reported that 3.7 million ha were infested (Abbas and Shahata, 1991).

The desert locust economic importance stems from the following:

1-It invades a vast area due to its ability to fly long distances, the flight speed ranges between 1.5-16 km/hr (Meinzingen, 1993).

2-Its multiplication rate is very high when the conditions are favourable for breeding. Within three months or less it can complete one generation from egg laying to the mature adult. (Nurien, 1987)
3-The species has two phases, which can change from solitary to gregarious phase according to ecological conditions. Those changes are known as phase transformation (Uvarov, 1966)

**2.5 Habitat of Solitarious Desert Locust**

The important locust habitats are all man made, created by the practice of shifting cultivation mainly in wadi areas. When the original vegetation is cleared and *Pennisetum* (millet) is planted this provides a suitable locust habitat, especially when left unweeded. Solitarious locusts live in restricted types of habitats than swarms. In general, they occur in open sandy steppes with few or no trees. The vegetation, with which solitarious locust associates generally consist of perennial bushes, herbs and annual plants. If the pattern of vegetation is fairly uniform the locusts will probably remain scattered, but when it is patchy, groups will be formed because the locusts prefer certain plants for food and shelter (Steedman, 1988).

El Bashir, *et al.* (1993) observed during a survey of the Red Sea coast of Sudan, which is a major desert locust recession and breeding site that gregarious locusts take shelter in *Panicum turgidum*, *Salsola forskalii* and *Leptadenia pyrotechnica*.

Some of the plants with which solitarious desert locusts are often associated are *Heliotropium spp.*, *Dipterygium*, *Tribulus sp.*, *Hyocamys muticus*; and among cultivated plants the bulrush millet. In the absence of
these, however, they may show preference for other species (Steedman, 1988).

During summer in Pakistan, Iran and India locusts tend to concentrate in open steppes vegetation where there are patches of bare ground on dune crests and slope. There is good vegetation cover after the first rain and patches of bare ground suitable for laying are restricted to sites such as bare dune crests. Whereas in winter and spring in the lowlands of Pakistan, Baluchistan and Iran, the vegetation of which is of the open steppe type with low cover, containing such species as *Heliotropium undulatum*, *Sericostoma pauciflorum*, *Sphaerocoma*, *Aerva persica* and *Panicum turgidum* (Steedman, 1988).

The desert locust breeds regularly in these areas in the winter and spring, but no important concentration seems to occur. Moreover in Arabia when it rains, the sand dunes of Southern Arabia become suitable habitats for desert locust and small concentrations can be found in patches of plants such as *Chrozophora oblongifolia*, *Tribulus sp.*, *Dipterygium glaucum* and *Aerva persica* (Steedman, 1988).

Abdel Rahman (1999) demonstrated that out of the tested 22 food plants only the following five species *Launea capitata*, *Heliotropium undulatum*, *pennisetum typhoidium*, *Crotalaria microphylla* and *Dipterygium glaucum* proved to sustain appreciable development of the species.
Uvarov (1966) stated that the reproductive capacity of the desert locust is impaired by a monospecific diet, even if it is adequate for non-reproductive growth.

2.6 Host Plant Preference And Feeding Habit

Host plant preference is a behavioural sequence used to describe the insect predilection to select some plants in preference to others within its host plant range (Maxwell and Jenning, 1979).

In a field study of the food eaten by *S. gregaria*, carried out in a winter breeding area in Mauritania, Ghaout, *et al.* (1991), revealed that Although *Schouwia purpurea* and *Boerhavia repens* were dominant at the study site, nevertheless they were consumed in the same proportion to their relative abundance. Whereas *Tribulus terrestris*, which was rare on the strip, transect was consumed more than its frequency.

However, Lambley, *et al.*, (1972) stated that, feeding preference in *M. Sanguinipes* on cultivated plants generally corresponds with plant abundance.

Similarly, dietary discrimination between plants by polyphagous grasshoppers appears to be correlated with the relative abundance of the plants in that community (Lambley, *et al.*, 1972 and Mitchell, 1975), although some plants are obviously avoided (Lambley *et al.*, 1956; Pfad and Lavingne, 1982).
Bhatia and Sikka (1956) proved that some plants when found singly were eaten by *Schistocerca gregaria*, yet they were totally neglected when found growing side by side with other plants.

Furthermore, Chandra (1981) carried out laboratory studies and reported that, *Anacridium rubrispinum* (Bei-Beinko) preferred cauliflower, potato, castor and the wild plant *Heliotropium undulatum*. Four other kinds of plants were completely rejected and the remaining seven were intermediate.

According to Johnson (1932) food preference is clear, particularly in older hoppers of *Anacridium melanorhodon*. He observed that while hatchlings fed readily on grasses and sedges for the first few days, they later ceased eating them and have to be given leaves of *Acacia* and *Zizyphus*. He also found that where *Acacia enhrenbergiana* and *Zizyphus spina christi* were growing together only the latter was eaten, while in absence of *Zizyphus*, *Acacia* was eaten.

Similarly, Tigani (1965), revealed that, the solitary phase of *Anacridium melanorhodon var.melanorhodon* (Walker) in only one locality, was found on one or two species of trees although there may be in the same area, several other species on which they feed. Swarms of *A. m. melanorhodon* appear to be far less selective. Thus, at Abu Tabar, the swarm was found feeding on all trees in the area including *Commiphora africana* and *Grewia*. He also pointed that the habit in solitary individuals
of feeding on restricted number of trees is probably one of the reasons for the development of swarms in areas where there is only a few scattered trees of these species.

According to El Khidir (1975), *Truxalis grandis grandis* (Klug) proved to be polyphagous but preferred the monocotyledonous plants to the dicotyledonous ones. They showed marked preference for the two common grasses *Cyprus rotundus* and *Cynodon dactylon*, while *Euphorbia heterophylla* and *Calotropis procera*, were rejected. Conversely, Ba-Angood (1977) reported that, although *S. gregaria* was polyphagous it showed some preference for dicotyledonous plants, eating 11.8g *Medicago sativa* and 9.8g *sesamum orientale* compared with only 2.4g *pennisetum typhodeum* and 1.8g *sorghum Vulgare* over a period six days. *Locusta migratoria migratorioides* was found to prefer graminaceous plants. *Poekilocerus hieroglyphicus* preferred *calotrops procera* and ate 11.77g of it compared with 4.04g *Vicia faba*, 4.11g *Cucumis melo* and 6.02g *Euphorbia heterophylla* over a period of six days.

In India, Chandra (1985) investigated the feeding preferences of hatchlings and 5th instars hoppers of *S. gregaria* to fresh leaves and leaf powders of wheat, Chives, umbrella plant (*Cyprus alternifolius*) and lemon grass (*Cymbopogon citralus*), wheat –*cyprus* mixture (8:2) and wheat leaf powder diluted with cellulose in 3 different proportions. Fresh
and leaf powders of wheat and the wheat- *cyprus* mixture were the most nutritious and effected highest growth rates and efficiency of conversion of ingested food, while lemon grass was the least nutritious. In tests conducted under single, dual and multiple choice conditions in short-term (half hour) or long term (24hr) feeding trials, there was a positive correlation between the nutritive values of food plant and their selection by the locusts. The locust always displayed partial preference when the diet is a mixture of two or more food plants in proportion to their nutritional values. Further more, under single-choice condition, meals taken on nutritionally superior food(s) were far greater than those on unsuitable one. The protein content of plant seemed to be a major factor determining its nutritional suitability and hence selection by locust.

Grasshoppers detect and preferentially feed on Grasses with higher proline and valine (Haglund, 1980), which increase in concentration in drought-stressed plants. Similarly, the leaf-cutting ants, show preference for high levels of common constituents such as carbohydrates, amino acids and glycerides and they are repelled by such chemicals as the oils from citrus rinds (Hsiao, 1973)

Chandra (1987) in a laboratory study tested the feeding responses of the 5.th instars hoppers of *Schistocerca gregaria* to an increasing abundance of wheat and *Cyprus* leaves in a 50:50 ratio. Although wheat has a higher nutritive value to the locust than *Cyprus*, preference of wheat remained
more or less similar irrespective of the absolute densities of the two food mixtures. The desert locusts showed no tendency to reject even reduce the intake of Cyprus at higher densities of wheat, indicating that it prefers a mixed diet.

In Canada, the binary choice experiment conducted by Hinks, et al. (1990) using growing plants or cut leaves indicated that M. sangunipes preferred wheat and Kochia (Kochia scoparia) to oats. The biotic potential of the insect was highest on wheat and lowest on Kochia.

Hierarchy of preference exists for desert locust, despite its polyphagous nature. Some plants are preferred for shelter and moulting site and generally solitarious females prefer to oviposit close to Heliotropium sp. and millet (Bashir et al., 1991; 1995).

In Tempe, Arizona, Barnes (1955) reported that, order of food plants preference of the lesser migratory grasshopper nymphs was hedge mustard, alfalfa, Johnson grass, nettle-leaf (goosefoot) and Bermuda grasses.

On the other hand, inhibitory chemicals play a considerable part in host plants selection by a wide range of phytophagous insects from several orders, some of them amongst the normal constituents of plants (Chapman, 1974). Detailed studies have demonstrated the importance of particular chemical constituents in the host plants to grasshoppers survival including both defensive secondary chemicals (Mulkern et al.,
1972; Bernays et al., 1974, -1980) and nutrients. El Khidir (1975) indicated that *Calotropis procera* and *Euphorbia heterophylla* were never approached by *Truxalis grandis grandis*. This suggested that, these two plants contain repellent principals, which may belong to certain fraction of secondary plant substances. Furthermore, Abushama and El Khidir (1976) tested the food selection by *Truxalis grandis grandis* among twelve plant species. Marked preference was shown for the grasses *Cyprus rotundus* and *Cynodon dactylon*. According to them, neither leaves shapes nor starvation appeared to influence food preference. They concluded that, a few chemical differences were found between attractant and repellent plant extract.

Similarly, Williams (1954), carried out study on the effect of physical properties on food selection. He confirmed that, leaf shape, surface texture and depth of the colour appear to be of little importance but toughness and moisture are probably governing factors. Toughness was shown to influence the feeding of young hoppers of *Locusta sp.* but have little effect on the habits of the older nymphs and adults, whereas grasshoppers deprived of water as well as food could be induced to feed on a number of succulent plants which previously, they would only slightly nibble.

### 2.7 Effect of the Host Plants on Development
It is clear that, some insects can recognize nutritionally superior foods. If the larvae of the fly, *Agria affinis* are given a choice of four synthetic foods, which differ in balance between amino acid mixture and glucose, they show the same order of preference for the foods as the order in which the food plants are ranked in promoting larval growth and development. Likewise in lepidopterous larvae food plant preference appears to be related to the previous experience. When the larvae are reared on given host plants for several days, they develop a marked preference for the food plants on which they had fed previously (Maxwell and Jennings, 1979).

There is a general tendency for herbivores to avoid C4 species, that C4 species are inferior food sources in terms of survival and reproduction. When *Melanoplus biliteratus* were reared on a C4 species survival to the adult stage was only 27% whereas, with C3 species survival ranged from 37-53%. Fecundity was also greatly reduced from 97-256 eggs per female fed on C3 species to only 22 eggs per female fed on a C4 species (Peter, 1975).

Rao (1960), demonstrated that, with the desert locust, *Tribulus terrestris* allowed rapid maturation, while *Panicum* delayed it. Similarly, the shortage of certain nutrient, notably gibberellins and monoterpenoids in senescent vegetation lead to delayed maturation (ellis and Carlisle, 1965).
Toye (1973) investigated the effect of food plants on development of the desert locust. He found that, the rate of development, feeding activity of nymphs and the morphometrics of adults, *S. gregaria* was more successfully reared on grasses (*Agropyron repens* and *Poa annua*), than on the other plant species like lime, privet and spinach. The former (*A. repens*) gave well-fed mature adults, while the later (*Spinach oleracea*) gave brachypterous adults.

Warlaugh, *et al.* (1969) studied the incubation and hopper development periods of the desert locust under various conditions typical of the Tihama and Hejaz of Saudi Arabia. He found no statistical significant difference between the developmental rates of hoppers fed on different species of plants, though the result did suggest that, hoppers reared on either barley or sorghum developed rapidly to adult than those reared on either millet or lucerne.

In Arkansas, Sanderson (1939) reported that, the mean nymphal developmental period for the differential grasshopper, *Melanoplus differentials*, when reared on soybeans was 69.13 days, whereas on cotton, development was much slower, about 102.37 days. He also found that mortality was especially high in the early instars and the grasshopper would not develop beyond the first instar when fed only on Bermuda grass. Many of the grasshoppers fed on both wheat and soya beans, reached maturity, whilst few of those fed exclusively on cotton attained
maturity. It had a higher survival rate and laid more eggs when reared on soya bean plants 304 eggs per female than when reared on wheat 208 eggs/female, whilst the only female that reached maturity on cotton deposited a single egg pod containing 73 eggs. Infestation of the differential grasshopper *M. differentials* increased in Arkansas areas where soyabeans largely replaced cotton.

According to Jackson *et al.* (1978) food plants have a marked effect on growth and development of desert locust. The *Pennisetum typhoideum, Dipterygium glaucum, Tribulus longipetalus* and *Chrozophora oblingifolia* are shown to support rapid growth and development. A pure diet of Sorghum sp. allows some hoppers to reach the adult stage in normal period but many are retarded. They also reported that the reproductive capacity of this insect is affected by monospecific diet, even when it is adequate for non-reproductive growth.

Tauber *et al.* (1945) found that adult of the grasshopper *M. bivittatus*, tested on 29 different types of plants produced eight times as many eggs on some plants as on others. He concluded that, the egg output might vary with the species of plant, even on those belonging to the same genus.

In Tempe, Arizona, Barnes (1955) studied the effect of various food plants on the lesser migratory grasshopper, *melanoplus mexicanus mexicana*. He reported that egg produced per female, was 221 on mixed diet, 196 on hedge mustard, 89 on Johnson grass, 43 on nettle-leaf (
goosefoot) and 13 on alfalfa. He also reported that, the percentages of survival were as follows: hedge mustard; 41, Johnson grass; 40, alfalfa; 8, mixed diet; 53 and Bermuda; 0. The average length in days of nymphal period was 34 for hedge mustard, 36 for Johnson grass, 50 for alfalfa and 30 for mixed diet.

Hinks, et al., (1990) in Canada, studied the performance of the grasshopper, Melanoplus sanguinipes, in binary choice experiment with Kochia (Kochia scoparia), Oats (Avena sativa) and wheat (Triticum aestirum). He found that, the percentage of survival of grasshoppers to the adult stage was highest on wheat (48.4), followed by oats (16.4) and Kochia (10.4). Rate of development was the same in both sexes and was in the same order as survival ranging from 33 days on wheat to 50 days on Kochia. Mean adult weight was affected by diet more in females than in males and was greater in wheat followed by oats and Kochia. Degree of development of the ovaries in surviving adults was affected also by diet and was in the order of better performance exemplified by wheat >oat>kochia and showed the greatest variance of any parameter measured. The average number of eggs per female was 18.4 when grasshoppers were reared on wheat, 7.9 on oats and 4.7 on Kochia. Grasshoppers fed on Kochia had the highest percentage of egg viability (70.7), followed by those fed on oats (66.1) and wheat (53.1).

2.8 Effect of the host Plants on Phase
The study carried by Barns (1956) on the effect of different diets comprising alfalfa (*Medicago sp.*), Johnson grass (*Chenopodium murale*), Hedge mustard (*Sisymbrium irio*) and a mixture of the three on morphometric of adult lesser migratory grasshopper, *Melanoplus mexicanus*, confirmed that, adults which were reared on hedge mustard or mixed diet showed greater degree of gregarisation than those reared on Johnson grass. Moreover, those raised on alfalfa showed little or no change towards the gregarious phase, maintaining typical solitarious characteristics.

Paradoxically, Abdel Rahman (1999) demonstrated that, the type of the food plants did not affect the morphometric in both phases.

Jackson *et al.*, (1978) studied the effect of seven of food plants on the phase status of the desert locust and monitored changes in colour, morphometrics, number of eye stripes and fecundity. Their results revealed that *pennisetum typhoideum* (Burm. f.) and *sorghum bicolor* enhanced gregarious characteristics, while *Dipterygium glaucum* (Oecn) accentuated solitary traits.

Dadd (1961) stated that, colouration may be affected by nutrition either through the absence of some constituents of pigments or through interference with pigment metabolism. He also found that the absence of B-carotene has both effects in *Schistocerca gregaria*. The carotene is an
essential constituent of the yellow carotenoid giving the background colour, but in absence of carotene melanization is reduced.
Chapter Three

Materials and Methods

3.1 Field Survey

3.1.1 Collection of Plant Species and their Identification.

In the course of the four-month field study in Gob area, from January to April 2000, approximately over 46 species of plants were identified and herbarized for the International Centre of Insect Physiology and Ecology (I.C.I.P.E.) Port Sudan field station. The investigation was carried out under the auspices and supervision of the International Centre of Insect Physiology and Ecology and was conducted in the winter breeding area of the Red Sea coast at Khor Gob, which lies 13.2 Km. South of Suakin on longitude 37° 14 and latitude 19° 23. Nearly all the area where the study was conducted was mainly used for growing millet (Pennisetum spp.), although there were patches of land where millet did not grow and were heavily infested by weeds, forming patches of layer of herbs and scattered bushes within millet. Although farmers in this area exerted much effort in weeding, several species of weeds heavily grow, forming mat of vegetation under millet.

The identification of plants was made primarily by using the following references; Flora of Saudi Arabia and Common Weeds of Central Sudan, all of which encompassed several illustrated flora, their genus and
species. Although the genus was adequately and clearly described, unfortunately, many species occurring in the area were not included.

3.1.2 Strip- transects.
Diet determination and feeding preferences were studied where the hoppers and adults could be encountered.
Six transects were randomly located in the experimental site. Each transect was 100 m long and 10 m wide. A quadrat was randomly thrown ten times within each transect to determine the plant samples. In each square metre, the following parameters were estimated in percentage: general plant cover and relative plant species cover. However, the number of plant species was determined by counting.
The desert plant encountered on the strip transect were considered as dominant plants in the experimental area and were labelled as (table 1), whilst those which were not found on transect were considered as rare plants in the study site and were labelled as (Table 2). However, the rare plants in the experimental site were sought for thoroughly throughout the experimental site to find out the diversity of the plant species available in the study site.

**Dominant plants in the study site** (Table 1)

<table>
<thead>
<tr>
<th>Family</th>
<th>Botanical name</th>
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<tr>
<td>Boraginaceae</td>
<td><em>Heliotropium</em> spp.</td>
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<tr>
<td>Family</td>
<td>Botanical name</td>
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<tr>
<td>Asteraceae</td>
<td>Launea capitata</td>
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<td>Amaranthaceae</td>
<td>Amaranthus spp.</td>
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<tr>
<td>Caryophyllaceae</td>
<td>Robbeira delileana</td>
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<tr>
<td>Asclepiadaceae</td>
<td>Calotropis procera</td>
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<td>Crotalaria microphylla</td>
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<tr>
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<td>Euphorbia spp.</td>
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<tr>
<td>Cucurbitaceae</td>
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<td>Convolvulaceae</td>
<td>Convolvulus sp.</td>
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**Rare plants in the study site** (Table 2)

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<tr>
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<th>Botanical name</th>
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<tbody>
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<td>Species</td>
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<td>--------------</td>
<td>----------------------------------</td>
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<tr>
<td>Leguminosae</td>
<td><em>Tephrosia appollinea</em></td>
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<td>Leguminosae</td>
<td><em>Indigofera spinosa</em></td>
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<tr>
<td>Acanthaceae</td>
<td><em>Blepharis persica</em></td>
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<td>Graminae</td>
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<td>Graminae</td>
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<td>Polygonaceae</td>
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<tr>
<td>Ceasalpiniaceae</td>
<td><em>Cassia senna</em></td>
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</table>
3.2 Laboratory work.

3.2.1 Fecal Pellets Collection

Desert locust adults and hoppers were caught from the experimental transects in the study site. Each individual was kept without food in a separate cell of the wooden cages until the next morning so as to collect the feces. This method gave locust enough time to complete their meal overnight rest; therefore the probability of obtaining individuals with a full alimentary tract was higher. The feces collected were what the insects had eaten before being caught.

Fecal pellets were then collected and wrapped in aluminium foil, folded in papers, placed in plastic bag and stored in the laboratory under room temperature until they were examined.

3.2.2 Preparation Of Plant Epidermis For Identification.

Collection of plant epidermis was prepared for identification purpose by giving only known host plant, which were encountered in the strip-
transect to each locust. The fecal pellets were then collected from each individual locust fed with a known plant and were examined by the microscope and these serve as specimen for identification purpose.

The host plant such as *Colothynthis vulgaris*, which was rejected by locust, were prepared by peeling the epidermal layer from its leaves and examined by the microscope.

### 3.2.3 Fecal Treatment And Microscopic Analysis

The feces (fecal pellets), collected from each individual solitary desert locust were hydrated for 24hrs in water contained in petri dish. The pellets were then thoroughly shredded until all the plant materials were separated from each other into fragments, and then they were treated for 8-10 minutes in sodium hypo chlorite (Chlorox).

Only five mounted slides were prepared for each individual locust. Drops of water were used as a medium for mounting the slides. Finally, the mounted slides were carefully examined through a microscope.

### 3.3 Statistical Analysis

The following parameters, general plant cover and the percentage of the plant species cover were estimated in percentage from the area under the square metre. However the relative plant species number was obtained by counting the number of the plant species within the square metre.
On the other hand, the calculation of the plant species availability was obtained by the multiplication of the percentage cover of the individual plant species by 100 and divided by the total sum of all the plant species cover in the square metre, whilst plant species frequency was calculated by the multiplication of the number of the individual plant species by 100 and divided by the total sum of all the plant species number within the square metre. Finally, the frequency of the plant tissues in the feces (fecal frequency) was obtained by the multiplication of the individual plant species eaten from transect by 100 and divided by the total sum of all plant species eaten by the desert locust from the strip transect (modified Ghaout methods).
CHAPTER FOUR
RESULTS

The experimental results obtained from this study were organized systematically according to the six transects studied. The six transects, which were randomly selected were arranged ascendingly in order of their serial number, starting from transect No. 1 up to transect No. 6. In each transect, data were presented in the following order: the mean percentage of plant availability, plant species frequency and fecal pellet frequency.

4.1 transect No. 1
4.1.1 Plant species
The mean percentages of the plant species availability are summarized in Table (3).
The plant species encountered in this strip transect were: *Heliotropium* spp., grasses, *Launea capitata*, *Amaranthus* spp., *Robbeira delileana*, *Calotropis procera*, *Crotalaria microphylla*, *Pennisetum typhoidenum*, *Chorchorus olitorius*, *Prosopis chilensis*, *Convolvulus* spp., *Euphorbia* spp., *Zygophyllum simplex*, *Colothynthis vulgaris* and *Trianthema* spp.
Their availability were: 26.63%, 12.20%, 7.83%, 3.00%, 3.67%, 3.70%, 1.80%, 18.33%, 1.80%, 6.00%, 4.07%, 1.80%, 8.17%, 0.33%, and 0.67% respectively. It is very clear from the table that the plant species with the highest availability was *Heliotropium* spp. followed by *Pennisetum typhoidenum* and the lowest was *Colothynthis vulgaris*.
The total pant species cover of this transect was 24.70%

4.1.2 Plant species frequency
Table (4): Presents the mean percentages of the plant species frequency. The plant species frequency of the above-mentioned species respectively were: 19.52%, 30.28%, 2.46%, 5.45%, 10.96%, 7.96%, 4.11%, 9.28%, 4.76%, 0.83%, 4.07%, 1.77%, 5.14%, 0.59%, and 0.31%.
The desert plant species with the highest frequency was grasses the desert plant with the highest frequency was grasses followed by *Heliotropium* spp.
and the lowest was *Trianthema* spp.

4.1.1.1 Fecal pellets Analysis.
Fig. (1): represents the percentage frequency of desert plants tissues in the fecal pellets of adults desert locust caught from transect No. 1.
The fecal pellet analysis revealed that *Heliotropium* spp. represents 100% of the diet eaten by solitary phase and no other plant from the plant species encountered in the strip transect was eaten.
4.2 Transect No. 2
4.2.1 Plant species
The mean percentage of the plant species availability is summarized in Table (5):

The plant species found in the transect were: *Heliotropium spp.*, *Tephrosia spp.*, *Calotropis procera*, *Convolvulus spp.*, *Pennisetum typhoidium grasses Sueda spp.*, *Trianthema spp.*, *Launea capitata*, *Euphorbia spp.*, *Amaranthus spp.*, *Tribulus longipetalus*, *Crotalaria microphylla*, dry leaves and *Robbeira delileana*.

The following values 68.26%, 1.575%, 1.28%, 1.50%, 1.10%, 4.39%, 0.22%, 3.03%1.80%, 0.93%, 1.07%, 3.03%, 1.33%, 10.00% and 0.50% were their percentage availability respectively.

The total plant species cover of this transect was 61.40%. *Heliotropium spp.* had the greatest availability compared to all plant species encountered in the strip transect. The lowest value was recorded to *Sueda spp.*

4.2.2 Plant species frequency.
The frequency of the plant species encountered in this strip transect as mentioned above respectively were: 53.06%, 2.90%,
3.76%, 3.35%, 1.08%, 9.48%, 0.73%, 2.45%, 1.67%, 2.11%, 2.24%, 3.17%, 1.00%, 10.00% and 3.00%.
The mean percentages of plant species frequency are indicated in Tab.(6).
The highest frequency was shown by *Heliotropium spp.* followed by the dry leaves of *Calotropis sp.* and the lowest was *Sueda sp.*

### 4.2.3 Fecal pellets analysis.
The percentage of frequency of desert plants tissues in the fecal pellets of desert locust nymphs and adults collected from the transect No.2 is shown in Fig. (2):
As indicated in the figure, *Heliotropium spp.* had the highest percentage of frequency of the desert plants tissues in the fecal pellets examined, followed by *Tribulus longipetalus*, *Pennisetum typhoideum*, grasses, *Robbeira delileana* and the lowest was *Euphorbia spp.*
The values of the percentage of the frequency of the above desert plants tissues observed in the fecal pellets were: 51.6%, 16.12%, 12.90%, 9.68%, 6.45% and 3.22% respectively.
The comparison of the fecal pellet frequency, the plant species availability and frequency of the desert plants eaten from the transect gave the following ratio: 3:1:1, 5:1:1, 1:2:1, 1:1:3, 11:6:1, 4:1:2 respectively.

### 4.2.4 Gut content analysis.
The gut content analysis of feces collected, showed that both hoppers and adults had eaten only one plant (47.06%), however, about (35.29%) had eaten 2 plants (11.76) had eaten 3 plants and (5.88%) ate 5 plants.
4.1.3 Transect No. 3

4.1.3.1 Plant species cover
The mean percentage of plant species availability and total plants covers are summarized in Table (7).
The plant species recorded in the transect were: Calotropis procera, Heliotropium spp., Pennisetum typhoides, Tephrosia spp., Tribulus longipetalus, Launea capitata, Robbeira delileana, Colothynthis vulgaris, Amaranthus spp., Abutilon pannosum, Trianthema spp., Zygophyllum spp. and grasses spp.
The calculated mean percentage of their plant species availability were: 20.49%, 21.68%, 14.88%, 2.32%, 3.97%, 0.39%, 0.11%, 3.44%, 2.21%, 8.57%, 1.79%, 6.67% and 3.50% respectively, while the mean percentage of the total plant cover of the transect was 41.10%.
Fig. (7): presents the mean percentage of the plant species availability. The figure clearly shows that, Heliotropium spp. had the highest availability and lowest was Robbeira delileana.

4.1.3.2 plant species frequency
The frequency in percentage of the recorded plant species in the strip transect is shown in Table (8).
The following percentage: 27.73%, 24.45%, 11.86%, 5.43%, 3.02%, 0.57%, 3.75%, 1.79%, 1.08%, 2.67% and 6.67% were respectively the frequencies of the plant species encountered in this strip transect.
The relative plant species frequency is shown in Fig (8). It is very interesting that, Calotropis Procera had the highest frequency followed by Heliotropium spp.

4.1.3.3 Fecal pellet analysis
The percentage of frequency of desert plants in the fecal pellets of the solitary desert locust nymphs and adults collected from the transect are shown in Fig (9):

On the examination of the feces of nymphs and adults, the results revealed that only seven plant species were observed in the fecal pellets examined. The seven plants species were: *Heliotropium* spp., *Tribulus longipetalus*, grasses spp., *Tephrosia* spp., *Pennisetum typhoideum*, *Launea capitata*, and *Zygophyllum sp.* and the percentages of their frequency in the fecal pellets were: 44%, 16%, 12%, 12%, 8%, 4%, 4% respectively. While the comparison of the fecal frequency to the plant species availability produced the following ratio: 2:1:1, 5:1:1, 3:1:2, 10:1:2, 5:1:2, 1:2:2, 2:2:1 for *Heliotropium* spp., *Tribulus longipetalus*, grasses spp, *Launea capitata*, *Tephrosia* spp., *Pennisetum* spp. and *Zygophyllum sp.* respectively.

**4.1.3.4 Gut content analysis.**

The analysis of the gut content revealed that most of the nymphs and adults collected from the transect had eaten only one plant species (42.86%), (35.7%) ate two plants and (21.43%) had eaten 3 plant species.

![Fig. (3): Frequency of desert plants tissues in the fecal pellets of DL nymphs and adults collected from transect No.3](image)

**4.1.4 Transect No.4**

**4.1.4.1 Plant species cover**

Table (9): summarized the mean percentage of the plant species availability and total plant covers of the transect.

The total plant species found in this transect were: *Panicum turgidum*, *Calotropis procera*, *Heliotropium* spp., *Launea capitata*, *Colothynthis vulgaris*, *Euphorbia* spp., *Chorchorus olitorius*, *Tribulus longipetalus*, *Zygophyllum* spp.
Robbeira delileana, Convolvulus spp., Sueda sp., Grasses spp., Solanum dubium, Zygophyllum spp., and Argemone mexicana. Their respective percentage of availability being: 8.5%, 4.84%, 38.57%, 3.73%, 6.00%, 0.51%, 0.40%, 0.21%, 0.60%, 1.00%, 2.00%, 0.31%, 13.33%, 1.67%, 16.98%, and 1.33%, while the value of the mean percentage of the total plant cover of the transect was 35.90%. Fig. (10): presents the percentages of availability of the plant species encountered in the strip transect. The data revealed that Heliotropium spp., had the highest plant species cover followed by Pennisetum typhoideum and lowest was Tribulus longipetalus.

4.1.4.2 Plant species frequency.
The values of frequencies of the plant species encountered in this transect respectively were: 8.52%, 15.83%, 27.08%, 3.53%, 0.20%, 0.77%, 0.77%, 0.65%, 1.50%, 1.76%, 5.00%, 1.14%, 14.70%, 1.25%, 15.31% and 2.50% (Table 10).
The relative plant species frequency is indicated in Fig. (11). Obviously from the figure it is clear that, Heliotropium spp. had the highest frequency. Followed by Calotropis procera. The desert plants with the lowest value of frequency were: Euphorbia sp., Chorchorus olitorius, Tribulus longipetalus and Colothynthis vulgaris.

4.1.4.3 Fecal pellet analysis.
Fig. (12): represents the percentage of frequency of desert plants in the fecal pellets of desert locust nymphs and adults collected from the transect.
The data obtained from the examination of the fecal pellets revealed that, of all the desert plants recorded in the strip transect only six plants were observed in the fecal pellets examined. The fecal pellets frequency of Heliotropium spp., Tribulus longipetalus, grasses spp., Robbeira delileana, Chorchorus olitorius, and Launea capitata were: 44%, 24%, 20%, 4%, 4% and 4% respectively.
These results undoubtedly showed that, of all the plant species eaten from the strip transect, Heliotropium spp. had the highest frequency followed by Tribulus longipetalus, the grasses spp. were intermediate whereas Robbeira delileana, Chorchorus olitorius and Launea capitata had the same fecal frequency and were the least of all.
The comparison of the fecal pellets frequency to the plant species availability and frequency in the transect, resulted in the following ratio: 2:1:1, 114:1:3, 64:1:4, 7:1:3, 10:1:2, 1:1:1 for Heliotropium spp., Tribulus longipetalus, grasses spp, Robbeira delileana, Chorchorus olitorious and Launea capitata respectively.

4.1.4.4 Gut content analysis.
The fecal pellets of the individual solitary phase of the desert locust caught from the transect, clearly demonstrated that (61.11%) of the...
individual desert locust caught had eaten only one plant whilst (38.89%) had eaten 2 plant species.

![Fig. (4): Frequency of desert plants tissues in the fecal pellets of DL nymphs and adults collected from transect No.4](image)

**4.5 Transect No.**

**4.5.1 Plant species.**
The mean percentages of the plant species availability of the transect are summarized in Table (11).
The percentages of availability of *Convovulus sp.*, *Calotropis procera*, grasses, *Chorchorus prostrata*.; *Heliotropium spp.*, *Tribulus longipetalus*, *Panicum turgidum*, *Launea capitata*, *Euphorbia spp.*, *Amaranthus spp.*, *Tephrosia spp.*, *Pennisetum typhoideum* and *Colothynthis vulgaris* respectively were: 4.14%, 1.42%, 1.02%, 0.27%, 82.97%, 1.89%, 0.1%0.62%, 0.1%, 0.52%, 0.20%, 4.74%, and 2.00%.
The mean percentage of the total cover of the transect was 81.20%.
The results indicated that *Heliotropium spp.* had significantly the highest availability followed by *Pennisetum typhoideum* and the lowest were *Panicum turgidum* and *Euphorbia spp.*

**4.1.5.2 Plant species frequency.**
The mean percentages of the plant species frequency are indicated in Table (12).
The values of the mean percentage frequencies of the plant species encountered in the transect mentioned above respectively were:7.80%. 3.53%, 1.81%, 0.81%, 76.33%, 2.62%, 0.18%, 0.54%, 0.54%, 1.75%, 0.36%, 2.31% and 1.43%.
The host plant with highest frequency was *Heliotropium spp.* and the lowest value was revealed by *Panicum turgidum*. 
4.5.3 Fecal pellet analysis.
The percentage of frequency of desert plants tissues in the fecal pellets of the seven desert locust nymphs and ten adults collected from this transect, are shown in Fig. (5).
The results obtained from the analysis of the fecal pellets clearly demonstrated that, although 13 plant species were encountered in the strip transect, only seven plants species were eaten by the locust caught from the transect.
The following were the values of the desert plants observed in the fecal pellets: *Heliotropium* spp.; 51.72%, *Tribulus longipetalus*; 17.24, grasses.;10.34%, *Launea capitata*.; 10.34, *Pennisetum typhoideum*; 3.45%, *Tephrosia sp*; 3.45% and *Amaranthus* spp.; 3.45%.


Gut content analysis.
The fecal pellets analysis of the diet of the individual desert locust caught from the transect was carried out to determine the diversity of the host plant eaten by solitary desert locust individuals. The results obtained indicated that (47.06%) had eaten one plant, (41.18%) had eaten 2 plants species (5.89%) ate 3 plant species and 5.89% had eaten 4 plant species.

![Fig. (5): Frequency of desert plants tissues in the fecal pellets of DL nymphs and adults collected from transect No.5](image_url)
4.6 Transect No.6

4.6.1 Plant species cover.

Table (13): presents the mean percentage of the plant species availability of the strip transect.

The percentage of the availability of the desert plants encountered in the transect were: *Heliotropium* spp.; 38.28%, *Pennisetum typhoides*; 12.39%, *Amaranthus* spp.; 5.17%, *Euphorbia* spp.; 0.83%, *Colothynthis vulgaris*; 0.53%, *Convolvulus* sp.; 0.21%, *Calotropis procera*; 0.76%, *Sueda* sp.; 2.36, *Panicum turgidum*; 9.76%, *Robbeira delileana*; 10.00%, *Zygophyllum* spp.; 1.00%, *Trianthema* spp.; 3.50%, *Tephrosia* spp.; 3.33%, grasses spp.; 1.33%, and *Tribulus longipetalus*; 0.56%.

The total plant species cover of the transect in percentage was 45.80%

It is evident from the table that, *Heliotropium* spp. had the highest relative availability whilst *Convvolvulus* sp. had the lowest value.

4.1.5.2 Plant species frequency.

The values of the mean percentages of the plant species frequency are presented in Table (14).

The plant species frequency of the following plants encountered in the strip transect were: *Heliotropium* spp.; 40.35%, *Pennisetum typhoides*; 7.21%, *Amaranthus* spp.; 7.38%, *Euphorbia* spp.; 1.39%, *Colothynthis vulgaris*; 0.51%, *Convolvulus* sp.; 3.10%, *Calotropis procera*; 0.77%, *Sueda* spp.; 3.10%, *Panicum turgidum*; 8.59%, *Robbeira delileana*; 10.00%, *Zygophyllum* spp.; 1.43%, *Trianthema* spp.; 2.86%, *Tephrosia* spp.; 3.00%, grasses; 2.00% and *Tribulus longipetalus*; 1.15%.

The data indicated that *Heliotropium* spp. had the highest relative frequency followed by *Robbeira delileana* and the lowest value was scored by *Convvolvulus* sp.

4.6.3 Fecal pellets frequency.

The mean percentage of the frequency of the desert plants tissues in the fecal pellets of the five desert locust nymphs and six adults collected from this transect are presented in Fig. (6).

On the examination of the fecal pellets to determine the diet of the individual solitary desert locust nymphs and adults caught, the results obtained showed that, only 4 host plants were found in the fecal pellets examined.
The 4 host plants observed in the fecal pellets were: *Heliotropium spp.*, grasses, *Pennisetum typhoideum* and *Tribulus longipetalus* and the values of their percentage being: 60%, 20%, 13.33% and 6.67% respectively.

The results of the fecal frequency were compared to the plant species availability and frequency of the host plant encountered in the strip transect. The results of the comparison revealed the following ratio: 2:1:1, 15:1:2, 2:2:1, 12:1:2 for *Heliotropium spp.*, grasses spp., *Pennisetum sp.*, *Tribulus longipetalus* respectively.

**Gut content analysis.**

The analysis of the gut content of the individual desert locust caught from the strip transect indicated that, 72.73% of the individual locust caught had eaten 1 plant species, 18.18% had eaten 2 plants whilst 9.09% had eaten 3 plants.

![Fig. (6): Frequency of desert plants tissues in the fecal pellets of DL nymphs and adults collected from transect No. 6](image-url)
CHAPTER FIVE
DISCUSSION

The polymorphic desert locust, *Schistocerca gregaria* is able to transform between two phases; gregaria that lives gregariously at high population density in large swarms, causing economic losses in agriculture and solitaria which lives at low population density in a recession area. In the recession areas, locust of different nymphal stages and adults live and feed on a few plant species. Culmsee (1997), highlighted that, the development and growth of the desert locust is determined by composition and density of the vegetation together with a number of other biotic and abiotic factors. In this case, the crucial role is played by the annual plants, which emerge after the rainy season. Several of these plants are clearly preferred as food plants and others equally avoided.

The current field study was carried out to cast light over the host plants preferred by the solitary phase.

The vegetation complex encountered in strip transect No.1 was composed of 15 plants (Table 3). The mean percentage of the total plant species cover of this transect was very low (24.70%). This implies that the general plant species cover of this transect was sparse. Hence, the probability of locust to be in contact with all host-plants in this site might also be very low.

The examination of the fecal pellets of the locust caught from the this transect showed that *Heliotropium spp.* was consumed preferentially.
compared to the other 14 plants encountered in this strip transect. It represented 100% (Fig.1) of the diet eaten by solitary desert locust. This means that the entire individual desert locusts caught from the transect had eaten only *Heliotropium spp.*, whereas the other 14 plant species might have been either avoided. This is in line with the findings of Bhatia and Sikka (1956), who mentioned that some plant species, which were found growing side by side with other plants, were totally neglected. The observations of the diet eaten by solitary phase in the transect, demonstrated that all the individuals (100%) caught from this transect had only eaten one plant.

The plant community encountered in transect No.2 was also composed of 15 plant species. The total plant species cover of this transect was above the average (61.40%). This indicates the greater probability of finding considerable number of locusts within the transect. Of these plant species, which occurred in this transect, *Heliotropium spp.* was significantly dominant, having the highest plant species availability and frequency (Table 5 and 6), followed by dry leaves of *Calotropis procera* whilst the other plant species sparsely prevailed in the strip transect. The 15 plant species found in the strip transect, only six were observed in the fecal pellets were: *Heliotropium spp*, *Tribulus longipetalus*, *Pennisetum typhoideum*, grasses, *Robbeira delileana* and *Euphorbia sp.*

Analysis of nymphs and adults feces revealed that *Heliotropium spp.* had the highest frequency (51.6%)(Fig:2) in the fecal pellets of the locust caught from the strip transect. Presumably, this high level of occurrence of *Heliotropium spp* in the fecal pellets could be attributed to its relative abundance in the strip transect. These results resemble those of Lambley, *et al.*, (1972), who mentioned that feeding preference in *Melanoplus sanguinipes* on cultivated plants generally corresponds with plant abundance. Furthermore, in a field study of the food eaten by *S. gregaria*, carried out in a winter breeding area in Mauritania, Ghaout, *et al.*, (1991) proved that, *Schouwia purpurea*, dominant in the study site, was well represented (70%) in the diet of the species as evident from the examination of the fecal pellets for the plant epidermis.

With view to the comparison of the fecal pellets frequency to the plant species availability and frequency (table 5 and 6), the results revealed that the proportion of *Heliotropium spp* consumed, is 3 times as much as its relative plant species availability and frequency which is lower than *Tribulus longipetalus* that has lower fecal frequency (16.12%) than *Heliotropium spp* but had higher proportion consumed approximately 5 times as much as its availability and frequency in the strip transect. This result indicates that, there is a well marked preference for *Tribulus longipetalus* since it was extremely rare in the site but had the highest quantity consumed compared to the plant species eaten. Similarly,
Ghaout, et al., (1991), examined the adult feces and found that, *Tribulus terrester* was more frequently encountered than expected, although it was recorded only twice on the strip transect but was observed twelve times in the feces.

Although *Pennisetum typhoidexium* had higher fecal frequency (12.90%) (fig.2) than grasses and *Robbeira delileana*, nevertheless the percentage consumed was half its relative availability and the same proportion as its frequency in the transect, whereas grasses and *Robbeira delileana* were eaten in the same proportion to their relative availability and one third of their frequency in the strip transect.

The gut content analysis of the feces collected from the strip transect, showed that 47.06% of both hoppers and adults had eaten only one plant, 35.29% had eaten 2 plants, 11.76% had eaten 3 plants and 5.88% ate 5 plants. It then follows that generally most locusts had the tendency to diversify their diet. These results confirmed the views of Chandra (1987) who in a laboratory study, tested the feeding responses of 5th instars of *Schistocerca gregaria* to wheat and *Cyprus* leaves in a 50:50 ratio and found that although wheat has higher nutritive value to locust than *Cyprus*, preference of wheat remained more or less the same, irrespective of the absolute densities of the 2 food mixtures. The locust showed no tendency to reject or even reduce the intake of *Cyprus* at higher densities of wheat, indicating that it prefers a mixed diet.

In strip transect No.3, 13 plant species (Table 7), making the total plant cover of 41.10% were encountered. The most dominant plant species was *Heliotropium spp.* followed by young plants of latex-containing (*Asclepiadaceae*) *Calotropis procera* which sprout, forming small community. The two plant species were more frequent (Table 8), even forming very vigorous dominant stand. Other plant species such as *Launea capitata* and *Robbeira Delileana* had low frequency and cover. Despite the fact that many plant species were found in this transect, only seven were observed in the diet eaten by individual locusts caught. The seven plant species eaten were: *Heliotrpium spp.*, *Tribulus longipetalus*, grasses, *Tephrosia spp.*, *Pennisetum typhoideum*, *Zygophillum simplex* and *Launea capitata*.

The results of the fecal observation revealed that, solitary desert locust has a definite preference for *Heliotropium spp.* In the frass pellets observed, *Heliotropium spp.* represents (44%)(Fig.3) of the total diet which is the highest eaten by solitary phase, followed by *Tribulus longipetalus* which represents (16%) of the diet. This marked preference for *Heliotropium spp.* could be attributed to the ability of this desert plant to strongly support the larval growth and development of desert locust. This is consistent with the findings of Maxwell and Jennings (1979), who mentioned that, if the larva of the fly, *Agria affinis* are given a choice of
four synthetic foods which differ in balance between amino acid mixture and glucose, they show the same order of preference for the foods as the order in which the foods are ranked in promoting larval growth and development.

Although *Heliotropium spp.* had the highest fecal frequency (Fig. 3), nevertheless, the proportion consumed was only twice as much as its relative plant species availability and frequency, whereas *Tribulus longipetalus* which ranked the second to *Heliotropium spp.* in regard to the frequency in the fecal pellets, was comparatively consumed 5 times; this high consumption could be due to some phagostimulants which rendered this plant palatable. This is in line with Maxwell and Jennings (1979) who mentioned that leaf-cutting ants, show preference for high levels of the feeding stimulants such as carbohydrates, amino acids and glycerides. Furthermore, Haglund (1980) recommended that, grasshoppers detect and preferentially feed on grasses with high proline and valine.

Irrespective of the fact that grasses and *Tephrosia spp* had the same fecal frequency, however, the proportion of *Tephrosia spp* eaten by solitary phase in regard to its plant species availability and frequency is relatively higher than grasses. The quantity of *Tephrosia spp* eaten was 5 times as much as the percentage of its availability whereas grasses was 3 times; while the proportion of *Tephrosia spp* consumed in relation to its frequency was 3 times whereas the grasses was twice.

It could then be concluded that *Tephrosia spp* was consumed more than grasses.

Notwithstanding the higher frequency of *Pennisetum typhoideum* compared to *Zygophyllum spp.*, the proportion of *Pennisetum typhoideum* consumed compared to plant species availability and frequency was lower than *Zygophyllum spp*.

The quantity of *Pennisetum typhoideum* consumed was half the percentage of its availability and frequency. Whereas the amount of *Zygophyllum spp*. eaten was in the same proportion to its plant species availability and twice its frequency in the strip transect. In spite of the fact that *Launea capitata* had the lowest fecal frequency of all the plant species eaten from the strip transect, nevertheless it had the highest percentage of the proportion consumed relative to its plant species availability and frequency. The quantity of this desert plant consumed was 10 times the percentage of its relative plant species availability and 5 times the percentage value of its frequency in the transect. Hence, *Launea capitata* is the most consumed plant species compared to all the plants eaten from the transect. This results suggests a marked preference for *Launea capitata*. The high consumption of this desert plant could be attributed to the softness of its leaves and the moisture content. This
finding is similar to the views of Criddle (1935) who drew attention to the fact that certain plants, at some times, especially during hot weather, are selected and more readily consumed because of their high moisture content.

The analysis of gut contents demonstrated that over half of the individual desert locusts caught, had diversified their diet, eating 2 to 3 plants species, while the rest of the locusts had eaten only one plant species. Approximately, 16 plant species were encountered in transect No.4. The most dominant was *Heliotropium spp.* followed by *Pennisetum typhoideum* and *Solanum dubium*. The other plant species: *Euphorbia sp.*, *Tribulus longipetalus*, *Chorchorus sp.*, *Robbeira delileana* have very low coverage and frequency (Table 9 & 10). The total plant species cover of this transect was 35.90%. Although many plant species were encountered only six of them were eaten by the solitary desert locust. The following: *Heliotropium spp.*, *Tribulus longipetalus*, grasses, *Robbeira delileana*, *Chorchorus spp.* and *Launea capitata* were the plant species observed in the fecal pellets examined.

*Heliotropium spp.* which was the most prevalent in the strip transect was as well significantly represented in the frass pellet examined. It had the highest fecal pellets frequency (Fig. 4) compared to all the plant species eaten from the transect. The high percentage of *Heliotropium spp.* consumed could be related to its ability to effect significant maturation and fecundity. These results are consistent with the findings of Abdel Rahman (1999) who carried out a study on 22 food plants and demonstrated that, fecundity and maturation on *Heliotropium spp.*, exceeded the rest of the potential food plants. Furthermore, another reason for preference, could be due to the capacity of *Heliotropium spp.* to induce phase transition. According to Jackson, *et al.*, (1978), after monitoring the changes in colour, morphometric, number of eye stripes and fecundity of desert locust, concluded that, natural food plants affect the phase status of the locust.

As far as the comparison of the fecal pellets frequency to the plant species availability and frequency (Table 9 & 10) are concerned, the proportion of *Heliotropium spp.* consumed was twice as much as its relative plant availability and frequency. While *Tribulus longipetalus* which had lower fecal frequency than *Heliotropium spp.* and higher than all other host plants eaten by the solitary phase from the transect, had the highest proportion consumed. The percentage eaten was 114 times as much as the percentage of its relative plant species availability and 38 times as much as its plant species frequency in the strip transect. This high consumption of *Tribulus longipetalus*, could reflect its superiority in terms of nutritional value. Chandra (1985) proved that, there is a positive correlation between the nutritive values of food plants
and their selection by the locust. Alternatively, the high proportion of *Tribulus longipetalus* eaten relative to its abundance in the transect might be correlated with the presence of some stimulatory chemical compounds. This agreed with Njagi, *et al.*, (1996) who detected the chemical compound (E, Z)-2,6-Nonadienal in stimulatory amounts as a component in the volatiles of *Tribulus terrestris*. Although grasses had lower value of fecal frequency than *Heliotropium* *spp.*, nevertheless, the amount eaten by solitary desert locust compared to its availability and frequency in the transect is higher than that of *Heliotropium* *spp*. The proportion consumed is 64 times as much as its plant species availability and 24 times its frequency. Possibly, there is a definite preference for grasses. These results confirmed the views of Haglund (1980) who demonstrated that grasshoppers feed preferentially on grasses.

The other plant species namely: *Launea capitata*, *Chorchorus* *spp.*, and *Robbeira delileana*, had the same level of fecal frequency. However, the percentage of *Chorchorus* *spp.* eaten is 10 times as much as its relative availability and 5 times its frequency while the percentage of *Robbeira delileana* consumed is 7 times as much as its relative availability and twice its frequency. In case of *Launea capitata* the percentage consumed is in the same proportion to its availability and frequency.

The fecal pellets of the individual solitary phase caught from the transect, revealed that most of the locust (61.11%) had eaten only a single plant while the rest (38.89%) ate two plant species. Transect No.5 was heterogeneously structured with about 13 plant species. The plant community in this transect is characterized by *Heliotropium* *spp.* which exceedingly showed an extreme abundance in comparison to the other plant species encountered in the strip transect. Although *Heliotropium* *spp.* dominated the transect, the other plant species sparsely interspersed the transect. However, the plant species which were less represented in the transect were: *Panicum turgidum*, *Launea capitata*, *Euphorbia sp.*, *Amaranthus sp.*, *Tephrosia sp.* (Tab.11). Dense vegetation form, mostly composed of *Heliotropium* *spp.* was found in this transect making the total coverage of 81.20%.

El Bashir and Abdel Rahman (1995) concluded that, despite the polyphagous nature of the desert locust, a hierarchy of preference for host plants exist. During this study, the examination of the fecal pellets showed that *Heliotropium* *spp.* had the highest fecal frequency (51%) followed by *Tribulus longipetalus* (17.24%), grasses (10.34%), *Launea capitata* (10.34), *Amaranthus sp.* (3.45%), *Tephrosia sp.* (3.45%) and *Pennisetum typhoides* (3.45%) (Fig. 15).

The comparison of the fecal frequency of the plants eaten to their relative availability and frequency in the strip transect, revealed that the
proportion of the *Heliotropium spp.* eaten is half its availability and frequency, although it was the most predominant in the transect. In regard to *Tribulus longipetalus* the proportion consumed is 9 times as much as its availability and frequency. Despite the fact that it is lower than *Heliotropium spp.* in regard to the fecal frequency, nevertheless the percentage consumed is higher compared to *Heliotropium spp.* In case of *Launea capitata*, the proportion consumed is approximately 19 times its relative availability and frequency. It is then obvious that *Launea capitata* had the highest proportion eaten compared to all the plants eaten from the transect. The high consumption of this species could be attributed to its capacity to enhance the biotic potential of the locust. These results are consistent with Hinks, *et al.* (1990) who confirmed that, *Melanoplus Sanguinipes* preferred food plants that give high biotic potential. Furthermore, Abdel Rahman (1999) clearly demonstrated that the total development period of the female and male nymphs was shorter, while weight gained by solitary phase was higher on *Launea capitata.* Though the following: *Tephrosia spp.*, *Amaranthus spp.* and *Pennisetum typhoideum* had the same value of fecal frequency (Fig. 5); nevertheless, the proportion of *Tephrosia spp.* eaten is higher than the other two host plants. The proportion of *Tephrosia spp.* eaten was 17 times as much as its relative availability and about 8 times its frequency. In case of *Amaranthus spp.*, the proportion consumed is 7 times as much as its relative availability and about twice as much as its frequency. However, *Pennisetum typhoideum,* was consumed in the same proportion to its availability and twice as much as its frequency in the strip transect. Even though the fecal frequency of grasses is higher than *Tephrosia spp.* the percentage consumed is lower and was 10 times its relative availability and about 5 times as much as its relative frequency. Analysis of the diet eaten by solitary phase encountered in the transect, revealed that less than average (47.06%) had eaten only one plant while more than the average (52.94%) diversified their diet, eating either two or more plant species. The species spectrum in transect No.6 was very wide containing about 15 plant species. Some occurring at high abundance and consequently dominating the transect while others could be found sparsely interspersing the predominant plant species in the transect. The most dominant plant species was *Heliotropium spp.* occurring at the frequency of about 40.35% and the availability of 38.28% (Table 13 and14). The other plant species such as *Convolvulus spp.*, *Colothynthis vulgaris*, *Tribulus longipetalus*, *Calotropis procera* and *Euphorbia spp.* had sparse cover and lower frequency. The total plant species cover of the transect was 45.80%.
Although the transect was composed of a variety of plant species, nevertheless only 4 plant species were found in the fecal pellets examined. The 4 plant species observed were: *Heliotropium spp.*, grasses, *Pennisetum typhoideum* and *Tribulus longipetalus*. Based on the frequency of the host plant in the fecal pellets, the order of the preference for host plants by solitary desert locust in this transect was *Heliotropium spp.* (60%), grasses (20%), *Pennisetum typhoideum* (13.33%), *Tribulus longipetalus* (6.67%) (Fig.6). Hence it is then obvious from this analysis that *Heliotropium spp.* is markedly preferred by solitary desert locust. These results agreed with the findings of (Bashir, O. personal communication) who mentioned that, the percentage of *Heliotropium spp.* consumed by adult solitary desert locusts was 65% and nymphs 40% of the total provided food plants which included the following: *Crotalaria microphylla*, *Tribulus longipetalus*, *Sorghum sp.*, *Zygophyllum simplex* and *Abutilon spp.* However, in regard to the frequency of *Heliotropium spp.* in the fecal pellets compared to its availability and frequency in the strip transect, the proportion of *Heliotropium spp.* eaten was only twice as much as its availability and frequency. Whereas grasses, which had lower frequency in fecal pellets than *Heliotropium spp.*, was consumed 15 times as much as its relative availability and nearly 8 times as much as its frequency; it hence implies that there is a definite preference for grasses. This situation is consistent with Williams (1954) who demonstrated that, when grasshoppers were given choice of herbs and grasses, they showed preference for grasses, sedges and rushes and their allies, although signs of nibbling at the edges of the leaves of some plants other than grasses could show an attempts of feeding. Besides this, He also mentioned that, laboratory experiments showed that apart from sedges, rushes and their allies, plants other than grasses were seldom eaten by grasshoppers under normal condition. Irrespective of the fact that *Pennisetum typhoideum* had higher fecal frequency than *Tribulus longipetalus*, nevertheless the proportion consumed compared to its relative availability and frequency was lower than the proportion of *Tribulus longipetalus* eaten. The quantity of *Pennisetum typhoideum* eaten was in the same proportion as its relative availability and twice its frequency whereas *Tribulus longipetalus* was consumed 12 times as much as its availability and 6 times as much as its frequency in the strip transect. This implies that there is more preference for *Tribulus longipetalus* compared to *Pennisetum typhoideum*. The clear-cut preference for *Tribulus longipetalus* could be due to the quality and quantity of the volatiles possessed by this plant species. This is in line with Njagi (1996) who outlined that quantitative and qualitative
differences in the components of the volatiles may affect the preference hierarchy for host plants in the field. The feces examined demonstrated that most of the solitary desert locust caught from the transect, (72.7%) had eaten one plant species and the rest (27.3%) had eaten 2 and more plant species.

Summary

The grand mean percentage of the total plant species cover of all the six transect studied was 48.35% which reflects the total cover of the plant species in the area studied. *Heliotropium spp.*, which had the highest frequency (55.28%) in the fecal pelletets, was also dominant in the area with the grand mean percentage availability of 46.07% and frequency of 40.13% Tab. (15). This is followed by *Tribulus longipetalus* which has the mean percentage frequency of 13.34% in the fecal pellets Tab.(15). However, the availability and frequency of *Tribulus longipetala* in the area was 1.5% and 1.91% respectively, which is much more less than *Heliotropium spp*. The gut content analysis, also proved that grasses ranked after *Tribulus longipetala* sp. having the mean percentage frequency of 12% and the grand mean percentage availability of 6.00% whilst its frequency was 10.82%. The hierarchy of preference which is indicated by frequency of the desert plants in the fecal pellets, clearly revealed that *Pennisetum typhoideum* followed the above-mentioned plant species scoring the frequency of 6.20% in the fecal pellets whilst its grand mean percentage availability and frequency were 8.57% and 5.30% respectively. Based on diet determination of solitary nymphs and adults, the mean percentage frequency of *Launca capitata* in the fecal pellets was 3.06% and the values of their availability and frequency were: 2.31% and 1.46% respectively. The results of the analysis of the feces obtained from the solitary desert locusts also showed that, the mean percentage frequency of *Robbeira delileana* in the fecal pellets was 1.74% and the following values: 2.55% and 4.91% were recorded as its grand mean percentage availability and frequency respectively.
The following *Chorchorus spp.* and *Zygophillum simplex* had the same frequency (0.67%) in the fecal pellets but they showed different grand mean percentage availability and frequency. *Zygophillum simplex* had higher availability (5.70%) and frequency (4.09%) than *Chorchorus spp.*, which has the availability of (0.41%) and its frequency value was (1.06%). *Amaranthus spp.* and *Euphorbia spp.* had 0.58% and 0.54% mean percentage frequency in fecal pellets examined and they constituted the group of plants which are least preferred by solitary desert locust nymphs and adults.

The other group of plant species which were frequently encountered in the strip transect but were not found in the feces of the desert locust collected from the field during study were: *Calotropis, Crotalaria, Prosopis, Convovulus, Colothynthis, Trianthema, Suaeda*, dry leaves of *Calotropis*, *Abutilon, Panicum, Argemon* and *Solanum spp.* Tab. (15).

Although some of these desert plants have higher grand mean percentage availability and frequency than those mentioned above, yet they were not frequently encountered in the fecal pellets of the solitary desert locust nymphs and adults.

Conclusion

Although this study of the host plant preference cannot provide complete information on host plants, yet it can be concluded that, *Heliotropium spp.*, which was abundant in the experimental site, and appeared most frequently in the fecal pellets examined, was the most preferred under the field condition, followed by *Tribulus longipetalus*. Grasses were also frequently encountered in the frass and ranked after *Tribulus longipetalus* followed by *Pennisetum typhoideum*, *Launea spp.*, *Tephrosia spp.* and *Robbeira delileana*.

The following host plants namely: *Zygophillum, Chorchorus* *Amaranthus* and *Euphorbia spp.* were the least preferred.

However, host plants such as *Solanum, Argemon, panicum, Abutilon, Calotropis, Trianthema, Colothynthis, Convovulus, Prosopis* and *Crotalaria spp.*, did not appear in the fecal pellets of the solitary desert locust examined by the microscope and this suggests that they are not preferred.

SUGGESTED LINES FOR FUTURE WORK
This current field study and analysis of the host plant preference in solitary desert locust was carried out with ultimate aim to find out host plant species preferred by solitary phase.

The results of this study outlined some of the desert plants preferred by the solitary locust, nevertheless this could not yet unravel and provide the wholehearted information on desert plant species and plant communities in the breeding and recession area of the Red Sea coast in Sudan.

Therefore, in order to investigate the complex relationships of solitary phase of *Schistocerca gregaria* and the vegetation complex comprehensively, the following information is worthwhile:

1- More investigation on field study and analysis of the host plant preference in solitary desert locust should be continued on wider dimension including determination of the feeding preference of all the nymphal developmental stages, immature and mature adults, right from the commencement of the breeding season until the end of the season.

2- Chemical analysis of the desert plants preferred by solitary phase to find out the chemical components which act as phagostimulant to enhance feeding habit in solitary phase.

3- Mapping and description of the plants and plant communities in the breeding and recession areas of the desert locust so that, the potential sites where locust occur can therefore be characterized.

4- Study has to be carried on the biotic potential and feeding rate of the solitary phase on the preferred plant species under laboratory condition to find out the plant species that give higher biotic potential.

5- Comprehensive research is necessary to unravel information on the role of various desert plants in sustaining the life system of the solitary desert locust.
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