Sudan University of Science and Technology
College of Graduate Studies

Susceptibility of five pearl millet (*Pennisetum glaucum* L. Ecotypes to the nymphal instars of the Migratory locust *Locusta migratoria migratorioides* (Reiche and Farmaire) infestation.

By

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INCEPTION

قال تعالى:

بسم الله الرحمن الرحيم

(133 : الأعراف)

{خُشعاً أبْصَارُهُمْ يَخْرُجُونَ مِنَ الْأَجْدَاثِ كَأَنهُمْ جَرَادٌ منتَشِرٌ }

(7 : القمر)

DEDICATION

To my beloved mother.

To my dear father.

To my dear and faithful uncle Nassir Elsayed.

To my uncles, aunts, brothers, sisters and cousins.

ACKNOWLEDGEMENTS

In the beginning I render my acknowledgement to the Almighty Allah. I am indebted to and express my deepest thanks, sincere gratitude and appreciation to my supervisor Professor Magzoub Omer Bashir for his continuous guidance, suggestions and encouragement throughout the period of this study. I would like to thank all staff members of Plant Protection Department, Sudan University of Science and Technology and staff members of Crop Protection Department, University of Khartoum. My thanks also extend to my colleague Salih Nurain who helped me in literature, data analysis and thesis preparing. Also thanks to Dr. Jaffar Farah at crop production of (SUST), Dr. Rabei Abdelmagid from Ministry of Agriculture and to my colleague Abdelhakim Shogar. At Last but not least I am greatly indebted to all those whom I may have forgotten, I offer my sincere apologies.

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ABSTRACT

The laboratory experiments were conducted at the unit of biological control, Insectary laboratory of the Department of Crop Protection, Faculty of Agriculture University of Khartoum, Shambat, during the period from the beginning of May 2014 to the beginning of January 2015. The experiments were carried out under semi-field conditions (cage- experiment). The objectives of the study were to study investigation and evaluation the susceptibility of five ecotypes of (Pearl millet *Pennisetum glaucum var.*) on the life system of the solitary African Migratory Locust. The main objective was to detect the most preferred food variety on the development of nymphal instar (3^{rd} & 4^{th} in stars) of the African Migratory Locust *Locusta migratoria migratorioides* (Lin.). Five different experiments with five ecotype varieties of Pearl millet *Pennisetum glaucum* var were setup. Each experiment with three replications were applied topically on the 3^{rd} and 4^{th} nymphal instars. Each treatment replicated 3 times. Each experiment took duration of four days. Millet plants were gown in ground basin and plastic cup to feed the locusts and for experiment application techniques. Data were recorded daily after 24 hours from beginning of experiments and were followed until the fourth day. The food preference and ecotype susceptibility evaluation was based on Amount of food-intake in gram, Weight of food-ingested and digested in gram, percentages, and Amount of weight of feces in gram.

The results showed the significant difference of susceptibility of five varieties ecotype of pearl millet. The susceptibility of feeding by 3^{rd} and 4^{th} nymphal instars was clearly observed in all ecotypes.

According to the study results showed the preference of ecotypes by nymphs was increased according to increasing of application time.

The high one was Bayouda-late maturing compared to four other ecotypes of treatments. Then Kano-late maturing, Wad elahow-late maturing, Bayouda-early maturing and Dembi-early maturing respectively. During the experiments were noticed that the preference of five ecotypes were high in the first reading and third reading of experiments.

However the results revealed that the susceptibility of five ecotypes of pearl millet *Pennisetum glaucum var*, according to remain amount of feces in any ecotype variety. The least amount of reminder feces was in Bayouda-late maturing ecotype, this means that the biggest part of the food-intaken was ingested, digested and assimilated according to the four others ecotypes.

The bigger percentages of ingested amount of food consumption for five ecotypes of pear millet *Pennisetum glaucum var*, with 3rd and 4th instars of African migratory locust ranked as above mentioned.

The research concludes that further works on evaluation of susceptibility of pearl millet varieties with different pest, particularly in migratory locust is recommended, thus the crucial role in order to detect the target palatable variety as a trap in pest management control.

مستخلص الأطروحة

أُجريت هذه التجارب المعملية بمعمل وحدة المكافحة الإحيائية التابع لقسم وقاية المحاصيل بكلية الزراعة - جامعة الخرطوم ، شمبات . في الفترة من بداية مارس 2014م وحتى بداية يناير 2015م. أُجريت التجربة تحت درجة حرارة ورطوبة وضوء النهار العادي أى تحت ظروف جوية مشابهة للحقل (تجربة القفص).

هدف الدراسة هو فحص وتقييم قابلية خمس اصناف للدخن المحلي على طور الحورية الثالث والرابع للجراد الأفريقي الرحال الانفرادي . كان الهدف الرئيسي هو اكتشاف أفضل الخمس أصناف للدخن المحلي على نمو طوري الحورية الثالث والرابع للجراد الأفريقي الرحال الانفرادي .

طبقت خمس تجارب مختلفة مع خمس أصناف من الدخن المحلي . كل صنف اعتبر وحدة تجريبية ، كل ربة كررت ثلاث مرات وطبقت نموذجياً على طوري الحورية الثالث والرابع للجراد الأفريقي الرحال الانفرادي.

تمت زراعة نبات الدخن في أحواض وفي أصص بغرض تطبيق تقنية التجربة وتغذية الجراد والحوريات قبل وأثناء التجربة. إستمرت التجارب لمدة أيام .كانت القراءات والتسجيل يومياً بعد مرور 24ساعة من بداية التجارب.

تم تحليل النتائج إحصائياً . أُعتمد تقييم أفضلية الغذاء وقابلية الصنف على أساس كمية الغذاء المتحصل عليها بالجرام ، وزن الغذاء المهضوم والممتص بالجرام ، وزن كمية الفضلات بالجرام ونسبها.

أظهرت النتائج هنالك اختلافات معنوية في قابلية الخمس اصناف للدخن المحلي، ولوحظت قابلية تغذية الأصناف الخمس لطوري الحورية الثالث والرابع بصورة واضحة .

دلت النتائج ان أفضلية الأصناف لتغذية الحوريات ازدادت وفقاً لزيادة فترة تطبيق التجربة. كان الأفضل في صنف بيوضة متأخرة النضج مقارنة بالاصناف الاربعة الاخرى المحلية.

وهي صنف كانو متأخر النضج ، ود اللحو ، بيوضة مبكرة النضج ، واخيراً الصنف دمبي مبكر النضج على التوالي. لوحظ ان معدل الافضلية كانت عالية في القراءة الأولى والأخيرة للتجربة.

أوضحت النتائج ان افضلية الخمس الاصناف المحلية للدخن وأ لكمية بقايا الفضلات، وان اقل كمية من الفضلات كانت في صنف بيوضة متأخرة النضج ، مما يؤكد ان اكبر جزء من الغذاء المهضوم والممتص في هذا الصنف مقارنة بالاربعة الاصناف الاخرى.

كانت نسب الغذاء المستهلك الأكبر للخمس اصناف بواسطة طوري الحورية الثالث والرابع للجراد الأفريقي الرحل الانفرادي كما ذكر في السابق.

يوصي البحث بإجراء المزيد من الدراسات على تقييم اكثرقابلية اصناف الدخن المحلي لآفات الدخن المختلفة كالجراد الصحراوي وبالاخص الجراد الافريقي الرحال لدوره الحاسم في اكتشاف الصنف المستصاغ بأعتباره المصيد المستهدف في ادارة مكافحة الآفات.

CHAPTER ONE

INTRODCUTION

Locusts belong to a large group of insects commonly called short horned grasshoppers which belong to the super family Acridoidea, and the most important locusts are all in the family Acrididae (Anonymous 1966.). They differ from grasshoppers in their behaviour and phase of transformation. An important feature of locusts is their ability to transform reversibly between the two extreme phases of solitaria and gregaria which differ in morphology, physiology and behaviour (Uvarov, 1966). Gregarious locusts have the tendency to stay together in dense groups, march in bands as wingless hoppers or adult swarms over long distances (Steedman, 1988). The locusts are counted among the major pests in the Sahel zone of Africa. The migratory locust *Locusta migratoria*, belonging to a mono specific genus Locusta Linnaeus.

Migratory locust is one of the most important destructive agricultural pests in the world, and its outbreaks were recorded early in the 13^{th} century BC (Fan, 1983, Vijay *et al*, 2013). It is a highly migratory species and has greater distribution than any other locust or grasshopper occurring in all the temperate and tropical regions of the eastern hemisphere (Asia, Europe, Africa and Australia) and also known to occur up to 4600 m above sea level in the Tibet Plateau (Guo *et al*., 1991, Meinzingen , 1993). Like other locust species L. *Migratoria* also has remarkable phase polymorphism ability involving the graded changes in their morphology, physiology and behaviour with transient morphs between solitarious to gregarious phases or vice versa (Uvarov, 1921, 1977). Both nymphs or hoppers (immature) and adults of the migratory locust show density dependent phase polymorphism. At low density both nymphs and adults have cryptic body colouration including green, orange, brown or black and sedentary in nature and show little or no tendency to aggregate. But when their population density increases then both nymphs and adults show strong tendency for aggregation and dispersion, besides having morphological changes. Nymphs march in bands on ground while adults form swarms and migrate over long distances, sometimes several hundred kilometres Uvarov(1977).

Population increases to high density may take several generations. Figure due to the traits change in morphology, colouration, physiology and behaviour in the migratory locust and its wide distribution lead to recognition of different species of this single species. It caused difficulty in identification. Thus, this species was differently named as *L.australis, L. danica, L. gallica, L. rossica*, and *L. solitaria*. At present 7 subspecies are recognized in *Locusta migratori*. Nymphs of *Locusta Migratoria* Feeding on Pasture Grass in Loma-Dumchu Sector, Ladakh.Thus, *a* from various geographical regions, but the validity of the subspecies status is under considerable debate. They are *L. m burmana, L. m capito, L. m cinerascens, L. m migratoria*, L. *m manilensis*, *L. m migratorioides, and L. m tibetensis* (Zheng and Xia 1998; Zhang *et al*., 2009).Some studies have appeared differentiations among various populations of *Locusta migratoria* and three genetically distinct groups viz *L. m migratoria*, *L. m manilensis*) and *L. m tibetensis*. Dispersal routes of the migratory locust show that global populations can be divided into two different lineages, the northern lineage and southern lineage. The outbreak of *Locusta migratoria* has caused serious damage to the pasture land and agriculture besides terrifying people and causing traffic accidents by the swarming locusts (Kumar and Ramamurthy 2009).

Summer breeding takes place in eastern Sudan especially in Elgedaref state, Gezira state, Sinar state, Blue Nile state, Northern state and River Nile state Hamid (2003).

Millet is one of the preferred cereals besides the wheat, rice, and maize attacked by the pest. Millet is a major food sources for millions of people, especially those who live in hot, dry areas of the world. It is grown mostly in marginal areas under agricultural conditions in which major cereals fail to give substantial yields (Adekunle, 2012). Millet is classified with maize, sorghum, and Coix (Job's tears) in the grass sub-family *Panicoideae* (Yang *et al*., 2012).

Millet is an important food in many underdeveloped countries because of its ability to grow under adverse weather conditions like limited rainfall. In contrast, millet is the major source of energy and protein for millions of people in Africa. It has been reported that millet has many nutritious and medical atributes (Obilana and Manyasa, 2002; Yang *et al*., 2012). It is a drought resistant crop and can be stored for a long time without insect damage (Adekunle, 2012); hence, it can be important during famine.

Millets are unique among the cereals because of their richness in calcium, dietary fiber, polyphenols and protein (Devi *et al*., 2011). Millets generally contain significant amounts of essential amino acids particularly the sulphur containing amino acids (methionine and cysteine); they are also high in fat content than maize, rice, and sorghum (Obilana and Manyasa, 2002).They provide, fatty acids, minerals,vitaminsand typical millet protein contains high quantity of essential amino acids.(FAO, 2009).

Millets are subjected to many insect pests and the most dangerous ones are locusts. The locust concentrations are often found to be associated with particular species of food plants.

Among the cultivated crop, find that a close associated between locust and millet crop may be due to the type of variety and cropped area, ecotype or the other factors. There are more than five varieties of *Pennisetum glaucum* var. in the Darfur region, but these five varieties are found frequently in the locust habitat. An advantage of testing this ecotype is that it is possible to know the preferred variety, which will make the survey of locusts more limited. This will save a lot of money, effort and time. Also it helps to suggest and detect any gregarization, which may happen. The locust must be controlled before they come together because it may be too late to stop the damage once they swarm and migrate.

This study investigates and evaluates the susceptibility of five ecotypes of Pearl millet *(Pennisetum glaucum variety*.) to the nymphal instars of the solitary African Migratory Locust *Locusta migratoria migratorioides* and detects the most preferred food variety.

CHAPTER TWO

2- LITERATURE REVIEW

2.1. Host plant (Pearl millet).

Cereals are important food crops, among which millet is the sixth most important cereal in the world. Pearl millet is grown as a stable cereal on an estimated area of 25-36.9 million hectares (ICRISAT, 1991 and FAO, 1999). In Sudan pearl millet locally known as Dukhun, is one of the important cereal crops, ranks after sorghum in both area and total production. It contributes the stable food of the majority of inhabitants of Western parts of Sudan (Darfur and Kordofan) where it occupies an area of 1.2- 2.938 million hectares (Abuelgasim and Jain, 1987; ICRISAT, 1987; Maranville, 1992 and FAO, 1999). Most of the millet area in the Sudan (95%) is cultivated and harvested under traditional rain fed agriculture using local varieties. Some farmers in the mechanized clay plain of central Sudan started to grow pearl millet instead of sorghum (Elmahi *et al*., 1995).The grain is consumed as human food, the stalks can be used as forage and as building material or fuel. A number of local varieties could be identified and named by farmers in Sudan according to time of maturity, plant height and grain color. The most widely cultivated varieties include Kano, mayoa, Abusoof or abushara, Dembi, Drmsa, Bayouda, Sharoba, Aish Bernu, Hammer and Wad elahow (Hamid, 2013 and Siddig *et al* 2013). In Darfur Dembi is relatively a dwarf short day to maturity, red seeded variety. A taller longer season white seeded type has different names in different places (Abuelgasim, 1989; Sabil, 1991 and Abuelgasim 2011).

2.1. Classification of the pest (The African Migratory Locust)

Kingdom : Animalia

Phylum : Arthropoda

Class : Insecta

Order : Orthoptera

Suborder : Caelifera

Family : Acrididae

Genus : *Locusta*

Species : *migratoria*

Sup species : *migratorioides*

Scientific Name: *Locusta migratoria migratorioides*. Reiche and Farmaire (COPR.1982).

Locusts belong to a large group of insects commonly called grasshopper. They belong to the super family Acridoidea. The most important locusts are found in the family Acrididae. The African migratory locust, *(Locusta migratoria migratorioides* Reiche and Farmaire) is one of the most economically important species of locusts in Africa, especially in areas where continuous irrigation is practiced. The middle Niger flood plains are considered the main out break area where four or five generations may occur annually. However in the other tropical African countries, particularly the southern part of the continent, generally two generations per year are produced. Survival rates of eggs, hoppers and adults are affected by climatic factors. The major ones being the degree of desiccations as a result of high temperatures, low humidity, dry winds and drought (Shoemaker 1997 and Balanca *et al*. 1999).

2.2. Ecology, habitats and Behavior:

Some observations on the relationship between ecology of locusts and structures of the habitat are those of Guichard (1955), who recorded that ephemeral vegetation may inhibit gregarisation while it remains dense and lush, but would favour it when drying up. There is, thus, a close connection between the conditions favouring growth of the main ephemerals, *Schouwia* and *Tribulus* and also *Locusta migratoria migratorioides*.

The Migratory Locust is mainly graminivorous, occupying the grass cover near the ground. River, lake and sea banks with planting of reeds and sedges, particularly *Phragmites communis* form its main habitat. Such regions are often surrounded by steppe and desert areas. Most outbreak areas are in the deltas of rivers flowing into the banks .Most migratory flights are local and oviposition takes place in the same general area but occasionally, depending on weather condition, massive movement of swarms occurs, spreading over hundreds of kilometers into the surrounding territories (Launois,M. 1978).

During the few days after hatching, gregarious hoppers start forming groups, whose density can reach 80,000 hoppers/m2 for 1st instar and 7,000 hoppers /m2 for 5th instar. These groups can move for relatively long distances .Inside poor vegetation cover, 5th instar hoppers can march up to 3km per day. Gregarious adults form swarms about 10 days after fledging. Despite its food preference, the Migratory Locust can eat plants of many families after leaving its outbreak areas or when its favourite grasses are missing .Each individual eats from 300to500g of forge during its life .Population dynamics is intimately connected with changes in water balance in breeding areas, alternation of seasonal flood and dry periods in reed beds causing reduction or spreading of food supply and oviposition. The Migratory locust seeks heat (optimal temperatures of 20°-25°C), average humidity environments (optimal rainfall of 50-100 mm/month) and colonizes steppes and savannahs with little or no tree cover. It is quite a strict graminivore that is able of causing considerable damage to grain crops and even plantations during outbreak periods. In temperate regions, the Migratory locusts undergo embryonic diapause in response to the harsh winters. In such conditions there are 1 or 2 generations per year. This obligatory developmental arrest does not occur in subtropical and tropical subspecies such as *Locusta migratoria migratorioides* which is able to breed continuously by migrating hundreds of kilometers to encounter ecological conditions that will enable them to survive. This locust can produce 3 to 5 generations per year by utilizing seasonally complementary ecological areas. Hence, their life cycle is rapid when the weather is hot and wet. The migratory locust is highly sensitive and able of switching from solitarious to gregarious phase once the critical density threshold is surpassed (estimated at 2 000 adults/hectare in subtropical zones). Phase polymorphism is shown by morphological, anatomical, physiological, ecological and behavioural differences. Solitary adults are characterized by an arched non saddle-shaped pronotum, they are green or brown depending on the seasonal atmospheric humidity levels and males are substantially larger than females. Gregarious males and females are almost the same size with very dark markings. There are 5 to 7 instars in the solitarious phase and only 5 in the gregarious phase. Gregarious forms develop more slowly and produce fewer generations than solitarious forms. Gregarious Migratory locusts are excellent flyers. Swarms migrate diurnally and are able to reach further and fly longer than solitary locusts which migrate just after nightfall using different wind systems. Phase transformation takes place in outbreak centers which often have more suitable and longer-lasting breeding and densation conditions than elsewhere. In south-Saharan Africa, these outbreak centers are located in moist zones with high residual humidity in the dry season (central Niger River delta in Mali, around Lake Chad and the Blue Nile Region in Sudan). These gregarisation sites are located in enclosed bush clearings in the southwestern part of the island. In Africa, the last serious widespread plague of *Locusta migratoria migratorioides* took place from 1928 to 1942. Since then, the spatiotemporal rainfall patterns and anthropogenic modifications in the largest and most important West African outbreak zone of central Niger and River delta in Mali (COPR, 1982).

2.3. Geographical distribution

Migratory Locust has the largest world distribution area among all locusts and grasshoppers, comprising practically all temperate and tropical parts of the eastern hemisphere and throughout Old World grasslands, i.e. Europe, Africa incl. Madagascar, Arabian and Indo-Pakistan peninsulas, Caucasus, Central and South-eastern Asia, China, Japan, Australia, Papua New Guinea and New Zealand. The northern limit of this huge distribution area corresponds roughly with the southern edge of the coniferous forest zone of Europe and Asia. Southern extension reaches New-Zealand. The western limit corresponds to the Azores, in the Atlantic Ocean, and the eastern one to at least the Fiji, in the Pacific Ocean and in Africa south of the Sahara (Uvarov1966, 1977; 1980; Meinzingen, 1993 and Chen, 1999, Plate 1).

The altitudinal distribution of the species is also amazingly wide, from sea-level to more than 4,000 m in Central Asian Mountains. Therefore, the species is present in a wide range of habitats presenting very different climatic and environmental conditions; this results in different biological responses fitting with local conditions and a number of geographical subspecies.

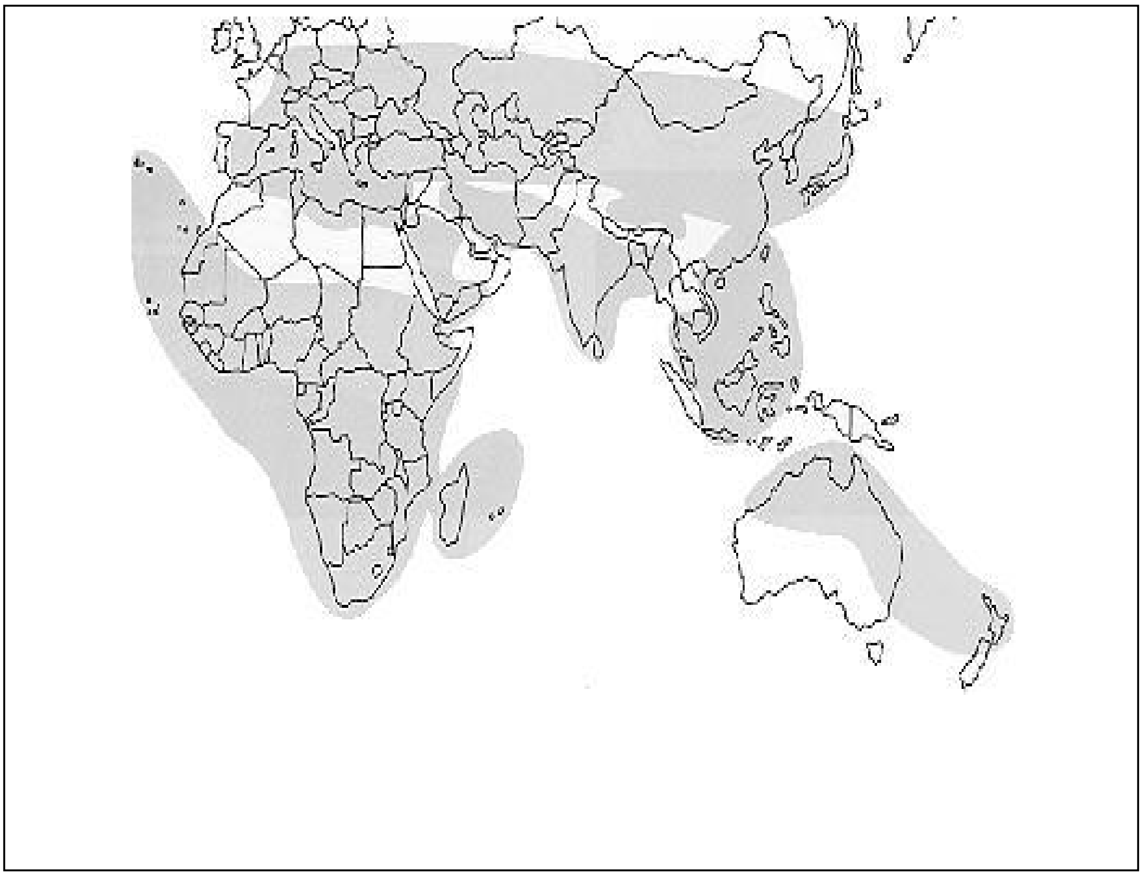

Plate 1: Geographical distribution areas of Migratory locust Meinzingen, (1993).

The main recognized outbreak area of the African Migratory Locust is the flood plains of middle Niger River in Mali. It is from this outbreak area that major swarms originated in a plague which spread over the whole of Africa south of the Sahara. It is thought that the African Migratory Locust is indigenous to the Lake Chad basin .However; populations of solitarious African Migratory Locusts have been recorded in many African countries south of the Sahara .Apart from the main breeding areas, high density populations occurs in the Sudan, Angola and lake Chad Basin. Also small populations of African migratory locust are known to occur in many other types of grassland throughout Africa south of the Sahara and sometimes in crops, particularly cereals and in sugar cane fields. The solitary African Migratory locusts have been recorded in Zimbabwe and in the south – eastern and northern parts of Botswana and in the north-east of Namibia (Kassimatis, 2000, Xiao and Kang, 2003).

2.4. The African Migratory Locust in the Sudan

Although this species reached plague proportions in 1985 and 1986, it has been of very limited concern in Sudan in recent years. In the summer of 1989, a small swarm was reported attacking sugarcane near Kosti, and was successfully controlled. It would appear that environmental conditions in Sudan are only occasionally conducive to large-scale breeding of the species. The principal breeding areas for in Sudan are the black cracking clay vertisols on the boundary between the short grass and tall grass savannahs from El Geneina to Damazin, and thence up to Kassala, (i.e., between the 500 and 600 mm isohyets). The Gash Delta and Gezira are also favored breeding areas.The sugarcane plantations and the Gdarif mechanized farming projects, also the Blue Nile region are invasion area.All these tend to have wet soil and vegetation that remains green for extended periods (SEA, 1990).

2.5. Morphology

The Migratory Locust is a large insect, with body length varying from 35 to 50 mm for males and from 45 to 55 mm for females. Mandibles are blue. Elytra are shining and long: 43.5-56.0 (males), 49.0-61.0 mm (females), exceeding clearly beyond the abdominal extremity. Wings are colorless, except smoky tint and black veins previously mentioned. The bottom of internal side of hind femora are brownish, bluish to black. The length of hind femur is of 22.0-26.0 mm (males) and 20.0-32.0 mm (females). Hind tibia is yellowish, beige or red. There is a dense pilosity of the inferior face of thorax. The colour can vary, but is usually green, brown, yellowish-green or grey. The pronotum is curved in solitary adults and saddle-shaped in gregarious ones, with convex or straight to slightly concave median keel respectively. The transversal furrow is well marked for gregarious individuals. The hoppers also differ, being green in solitary phase (plate2) but grey in the 1st instar, then darkening and becoming orange and black in the later instars when grangerizing (plate3,Simpson and Sword 2008) .

Plate 2: Solitarious hopper of the Migratory locust.

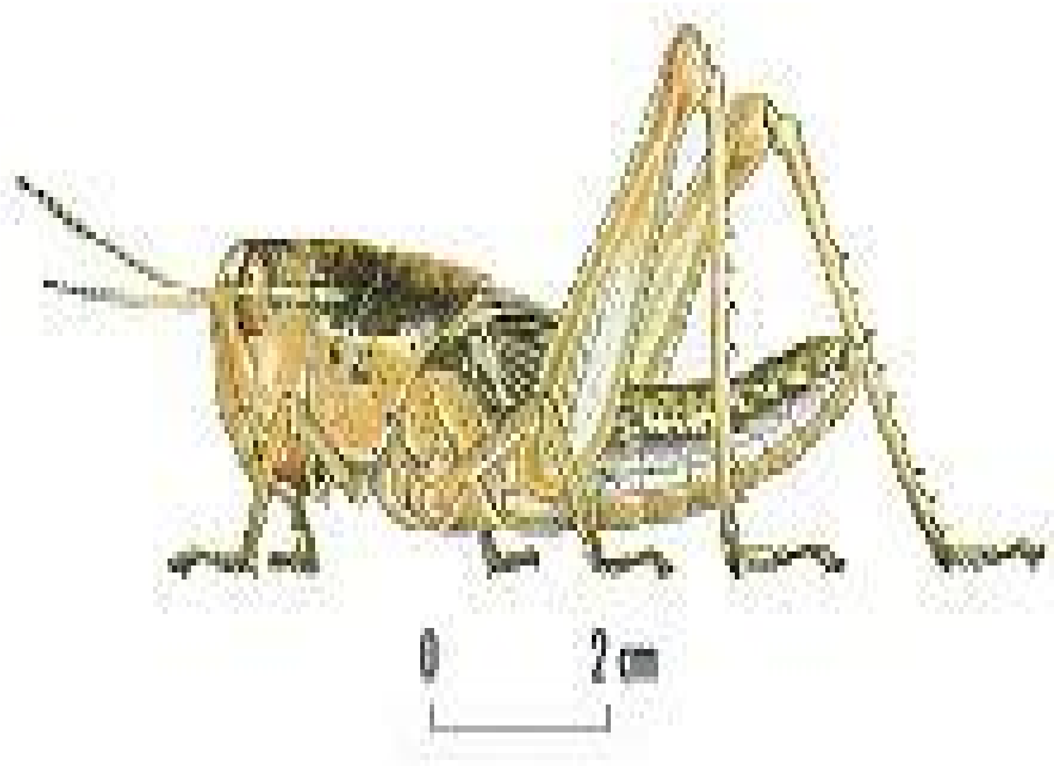

Plate 3: Gregarious hopper of the Migratory locust.

2.6. Biology

The Migratory Locust is univoltine in some areas, but can have up to five generations per year in tropical zones under highly suitable conditions. Oviposition occurs in August-September and the eggs over winter. There are at least 1-3 egg pods per female (up to 5 in southern localities and with warm conditions) with an average of 60-80 eggs (from 40 to 120) per pod. The egg pod is large, slightly bent, 50-85 mm in length, 7-10 mm in diameter.Eggs are 7-8 mm long. Light sandy soils are favorable for egg laying. Hatching takes place between early May and early June; it is quick, completed in 4-5 days in every station. There are 5 hopper instars and the hopper development lasts 35-40 days (i.e. 7-8 days for each instar). Adults appear from June to early July, remaining sometimes as late as November in the warmest parts. The copulation starts 2-4 weeks after fledging, and females start laying eggs 2-3 weeks later usually at the end of July (Meinzingen, 1993).

2.7. Economic importance:

Solitary hoppers and adults can damage various vegetable crops, rice, cotton, as well as plantations of volatile oil bearing plants. During years of mass increases/outbreaks, grain and other crops are severely damaged as well as hayfields and pastures. It is also the case for many tree species. Gregarious hoppers and adults of Migratory Locust can severly damage wheat, rye, barley, oat, maize, rice, *Panicum*, sorghum, millet, alfalfa, clover, peas, legumes, string bean, and other *Fabaceous*crops.They also damage red and sugar-beet, potato, tobacco, cabbage, rutabaga, cucumbers, watermelons, melons, and other cucurbits, sunflower, hop, buckwheat, cotton, flax, castor-oil plant, and other crops. Young plants of many fruit, vines, fruit, forest and bush trees, hay lands and pastures are also affected. Damage on trees stems, fruits and branches broken by the weight of locusts. Meinzingen, (1993).

2.8. The Migratory locust plague dynamics

Plagues begin when well distributed and high rainfall gives favorable conditions for a high multiplication rate in the Sahelian generations, leading to large populations. These populations are concentrated on the scattered hummocks of the flood plains, leading to increased egg pod densities. This in turn leads to hoppers making frequest contact, forming groups and gregarizing. If the adults resulting from these find exceptionally favourable conditions, there may be excessive dry season multiplication so that the first rains generation is given massive impetus. The entire hopper population becomes gregarious and the resulting adults form swarmlets which may leave the outbreak area altogether and initiate a plague. This hypothetical sequence of events, May probably takes place over two or more years. The movements of swarms are associated with the movement of the inter-tropical convergence zone. Oviposition that takes place during these movements and, as there are two or three generation annually, population increase is rapid and a greater invasion area is occupied each year. The plague reaching right across Africa and southward into South Africa. There are numerous authentic records of crop plants of many other families being attacked and sometimes severely damaged. The opinion has often been expressed that damage to these plants occurs only when grasses are not available or are so dry as not to satisfy the water requirements of the Locusts (COPR, 1982 and Meinzingen, 1993).

2.9. Control Measures:

The existence of known major and minor outbreak areas makes it feasible to prevent the development of further plague by controlling the locust in the outbreak areas, so preventing formation of swarms. Field investigations were carried out immediately after the beginning of the last plague in 1928 and this led to the formation in 1948 of an internationally supported control organization, followed, in 1952, by the signing of a convention formally establishing OICMA. This is now supported by 18 Africa countries representing most of those liable to invasion by this Locust in times of plague (COPR, 1982).

2.9.1. Chemical control

The aerial surveys and control measures in the officially designated outbreak areas are now necessary, in the majority of years. In 1951-52 over 17,000 hopper bands were destroyed in north of the equator, in Sudan and Ethiopia. Due to the activities of OICMA, no plague of this Locust has developed since the last plague ended in 1941. Control by individual governments after the escape of swarms would obviously be more difficult and expensive and, in fact, no such improvement of these survey and control operations (COPR, 1982). In recent years sprayable concentrations of this locust have infested many areas in central and southern Africa. It appears that the African Migratory Locust finds favourable breeding conditions in irrigated lands such as those found in sugarcane estates. Heavy and widespread infestations were recorded north of the equator, in Sudan and Ethiopia, in 1974, 1978, 1982and1987 (Meinzingen, 1993).

2.9.2. Natural control

Destruction of the eggs by insect parasites and predators is considerable, and eradicates about 30% of the eggs. The most important parasites and predators are the wasp *Sceliosuda nensis* (Ferriere), Carabid beetle larvae *Chlaenius quadrinotatus* (Dej) and the predator *Homalolachnus sexmaculatus* (Dej). Also the dipteran *Sarcophaga mezzadrii* (Seguy), nematodes worms and ants *Abacetus* *coccobacillus* have been found attacking young hoppers and infecting the adults. Many birds prey on hoppers and adult. The most important may be Storks carmine the bee-eater *Merops nubicus* (Gmel), Abyssinian roller (*Coracias abyssinica* Herm), black kite (*Milvus migrans* boddaert), Little egret Egretta *garzetta*, guinea fowl *Numidia meleagris mirata* pall), turtle doves and francolins. Also the March harrier *Circus aeruginisus* and marabou stork *leptoptilos crumeniferus* (lesson). In one such case a population reduction of 75% was estimated in the Sahel and Sudan. These natural enemies are credited with the destruction of three eggs, hopper bands and adults (COPR, 1982).

CHAPTER THREE

3. MATERIALS AND METHODS

This study was carried out under laboratory conditions an semi-field conditions (cage-experiment)**,** at the unit of Biological Control, quarantine, Insectary laboratory of the Department of Crop Protection, Faculty of Agriculture University of Khartoum, Shambat, during the period from the beginning of May 2014 to the end of December 2014(Temp. 22 ˚C - 39˚C, R.H 17- 19% . and normal day light).

3.1 Rearing of Migratory Locust.

The culture (Plate 6), was started from the initial material (Nymphs and mature adult individuals of the Migratory Locust obtained from eastern part of Sudan, Elgedarif State (Elmaganez district) which lies on Latitude N 14 31 14.4 and Longitude E 035 12 45.0. Two hundred individual nymphs and mature adult locusts of male and female were used to start the mass rearing. The new hatches were reared up to the second generation to ensure the homogeneity of the population. The third and fourth in stars were then used as the experimental insects.

Plate 4: Oviposition unit setup for rearing of Migratory Locust.

3.2 Rearing and egg laying cages.

The rearing cage was made of mosquito wire mesh sides; the bottom was made of plywood. It measured (70 cm ×60 cm ×50cm plate 7). One side of the cage covered by a light cloth in the form of sleave to facilitate the easy handling of insects to perform various activities inside the cage such as feeding and cleaning without the insects being able to escape from the cage. On the bottom surface of the cage, 6 holes were made for fixing plastic cups, filled with moist mixure of sandy clay soil (3:1). These cups were used to provide sites for egg laying. The insects were fed on millet and sorghum fresh leaves, and wheat bran. The rearing-egg laying cage was cleaned daily from insect fecal pellets, with a brush. The insects were monitored and various activities of mature adults including: - soil probing, copulation and egg laying were observed. After the eggs are laid, the cups which contained sufficient egg pods were removed and replaced by new ones, using gloves to protect hands and mask to avoid odours. The cups containing the egg pods were covered with cheese cloth and the soil periodically moistened until egg hatching. The hatched nymphs were reared up to the 3th and 4thinstars, which were used in the experiments.

3.3. Hoppers rearing cage.

The hoppers rearing cage measured (40x30x30 cm, plate.8), is made of wood and mosquito wire net on four sides. The fifth is side made of light cloth fitted with a zip fastener, in the form of a strip. This zipper was made to facilitate carrying out the activities of feeding and cleaning by hand inside the cage, without the insects being able to escape away from the rearing cage.

Plate 5: Migratory locust hoppers rearing cage.

3.4. Food materials.

Five varieties of Millet plants are brought from Darfur states.These five ecotype varieties are :(i) Early Bayouda is dark grey , medium and strong in seeds,it is grown in North Darfur,SarafOmra area in cracked clay soil. (ii) Late Bayouda is slight yellow , long stack , large and strong and has convexed seeds ,grown in cracked clay soil in Jebal Mara.(iii) Wad El lhaw late- maturing is yellowish and spherical seeds , long plant , it's grown in south of Nyala semi cracking clay soil. (iv) Kano is slight grey small seeds, long plant; it's grown in cracking loamy clay soil south west of Nyala and (v) Dembiisrelatively a dwarf short day to maturity, red seeded variety grown in North Darfur Shangil toobaya area. The taller longer season white seeded type has different names in different places (Abuelgasim, 1989; Sabil, 1991 and Abuelgasim 2011).

These five ecotypes were grown in ground basins200×100 cm, Plate 9). Millet seedlings of the 5 varieties are grown in plastic cups to provide daily feed to the nymphs and adults (Plate 9). In addition wheat bran was provided for additional supplementary feeding. The cages were checked daily for cleaning and provision of food. Adult locusts that emerged were transferred to egg laying cage.

Plate 6: Millet seedlings grown in plastic cups and used to feed adults and nymphs.

3.5. Experimental cages.

The cages used in tests were made of wood and wire mesh. Each cage measured (25 × 25 × 30 cm, plate.10) Millet was provided as food for the treated migratory locust. The insects were treated topically and then released into the cages.

Plate 7: Experimental cages.

3.6. Food preference experiments (Feeding tests)

Five varieties or ecotypes of Millet plant were sown in five different ground basins. Then after emerging and during shooting period, before application experiments 2o grams of fresh plant shoot were weight and dried for later parameters calculation. The plant shoots were weighted using a sensitive balance and then placed inside the cages which contained twenty nymphs which are considered as an experimental replica unit. The experiment was arranged in a completely randomized design (CRD) and factorial experiment (FE) with three replications. The feeding rate on the five millet plant ecotypes, and survival of the tested insects were used as parameters to evaluate preference.

The weight of Food consumption (Food intake) of each ecotype fed by hoppers (3^{rd} and 4^{th} instars) was recorded after 24hrs, 48hrs and 72hrs for each experiment. The weights of fecal pellets in all cages for three days werealso recorded. The parameters (ingested food, assimilated food, fecal pellets and their percentages were calculated using the following equations:

Ingested food (D) = A-B.

Assimilated food (E) = A-(B+C).

Ingested food % = D×100/A.

Assimilated food % = (B+C) ×100/A.

Where:

A = Wet weight of shoot amount.

B = Spill

C = Feces.

3.7. Statistical analysis.

Factorial experiment in a Completely Randomized Design (CRD) was used for setup of analysis of the experiments. The obtained data were analyzed according to SAS programme version3, SAS, 1997. The accepted level of significance was ≤ 0.05 and means were separated using the least significant difference (LSD) according to Gomez and Gomez (1984).

CHAPTER FOUR

4.RESULTS

4.1. Food preference (Feeding tests)

The results of all treatments indicated significant difference in the susceptibility of ecotypes.

The result presented in table 1, and fig 1 showed the significant difference in the susceptibility of pearl millet's five ecotypes. The preference of ecotypes by nymphs was increased according to with time.

The highly susceptibility variety was Bayouda-cold resistant (V5) compared to four other ecotypes of treatments. The others were Kano-late maturing (V3), Wad elahow-late maturing (V4), Bayouda-early maturing (V2) and Dembi-short maturing (V1) respectively.

Table 1: Amount of food -intake in gram by the migratory locust nymphs.

Ecotype	24hrs	48hrs	72hrs	Mean	SE±
V1	16.90±0.44	17.93±0.79	18.15±1.52	17.66	0.92
V2	16.69±0.24	17.49±0.49	18.42±0.88	17.54	0.64
V3	17.29±1.18	18.20±0.36	18.27±0.28	17.92	0.61
V4	16.48±0.67	18.29±0.84	18.54±0.65	17.77	0.72
V5	17.82±0.78	18.19±1.26	18.46±0.40	18.15	0.81
Mean	17.04	18.02	18.37	17.81	0.74

V1 = Dembi-short maturing, V2 = Bayouda-early maturing, V3 = Kano-late maturing, V4 = Wad elahow-late maturing and V5= Bayouda-cold resistant.

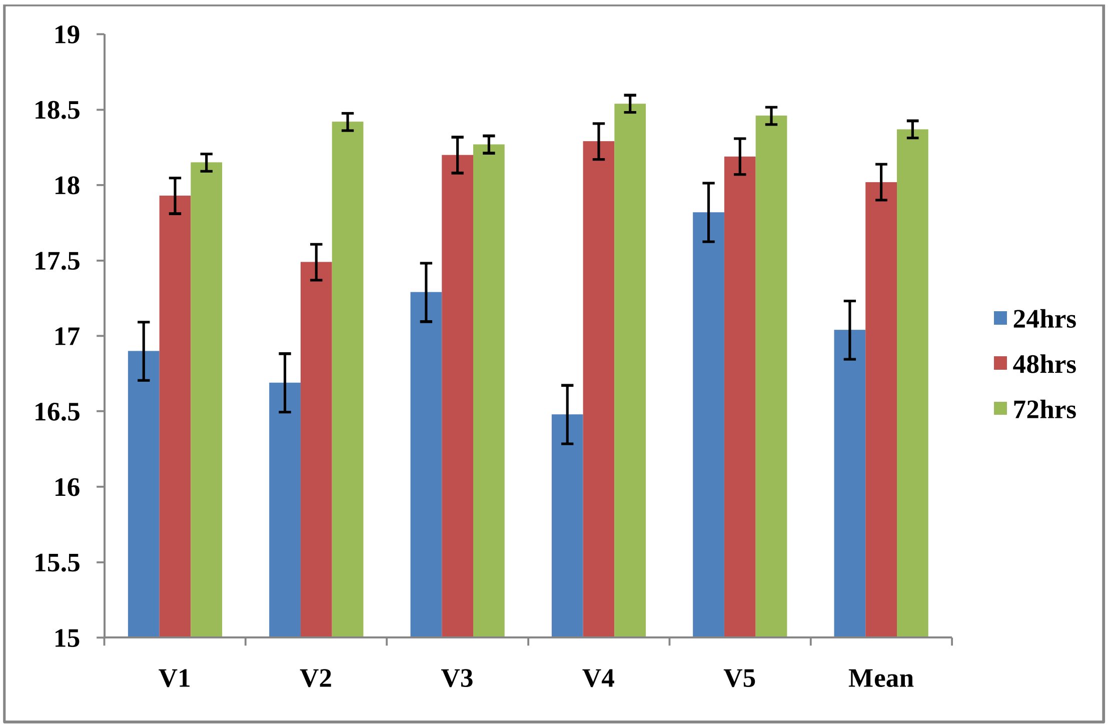

Figure 1. Food-intake in gram of the 5 test varieties by the 3rd. and 4th. migratory locust nymphs.

V1 = Dembi, V2 = Bayouda-early, V3 = Kano-late,

V4 = Wad elahowV5= Bayouda-late.

4.2. Percentage of food -intake by Migratory locust hoppers on the fife millet ecotypes.

The percentages of five Pearl millet ecotypes intake by hoppers of migratory locust are presented in table (4-2) and (Fig 4-2). There was clear significant difference among the five ecotypes. The highest percentage was recorded in Bayouda –cold resistant V5 ecotype (90.4%), next is Wad elahow-late maturing V4 ecotype (89.4%),followed by Kano-late maturingV3 ecotype (89.3%),then Dembi-short maturingV1 ecotype (89.3%) and Dembi-short maturingV2 ecotype (87.8%). During the experiments it was noticed that the preference of ecotypes V1 and V5 after the second day the percentage of food-intaken was similar. However the percentage of intaken of ecotype V5 was highest in the first and third day of experiments.

Table 2: Food-intake by Migratory locust hoppers of the fife millet ecotypes.

Ecotype	24hrs	48hrs	72hrs	Mean
V1	88.5%	90.5%	89.1%	89.3%
V2	88.1%	86.6%	88.7%	87.8%
V3	89.2%	90.2%	88.6%	89.3%
V4	90.4%	88.2%	89.5%	89.4%
V5	90.8%	90.4%	90 %	90.4%
Mean	89.4%	89.1%	89.2%	89.2%

V1 = Dembi-short maturing, V2 = Bayouda-early maturing, V3 = Kano-late maturing, V4 = Wad elahow-late maturing and V5= Bayouda-cold resistant.

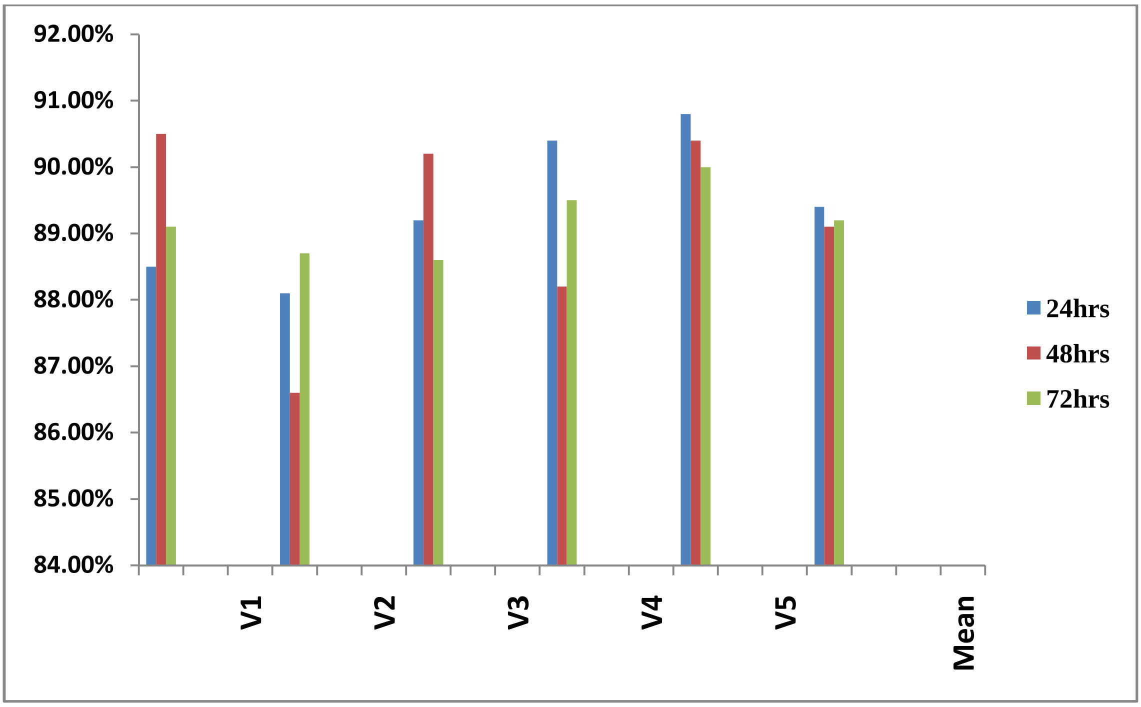

Figure 2: Percentage of Ecotypes preference or food-intake by Migratory locust hoppers.

V1 = Dembi, V2 = Bayouda-early, V3 = Kano-late,

V4 = Wad elahowV5= Bayouda-late.

4.3. Weight of ingested food .

The table (4-3) and (fig 4-3) show clear variation in amount of food consumption of five ecotypes with 3rd and 4th instars of migratory locust. The variations were (17.5 g) in Kano ecotype, (17.48g) in wad elahow ecotype, (17.24g) in Bayouda-early ecotype, (17.12g) in Bayouda-late ecotype and (17.04g) in Dembi ecotype. The lowest amount of food ingested in the experiment was (17.04 g) in Dembi ecotype variety and the highest amount ingested of food taken by hoppers, comparing with other four ecotype varieties of pearl millet was (17.5 g) in Kano ecotype.

Table 3: Weight of ingested food in grams.

Ecotype	24hrs	48hrs	72hrs	Mean	SE±
V1	16.89±2.60	17.41±1.21	16.83±1.05	17.04g	1.62
V2	17.40±1.69	17.1±1.05	17.23±1.29	17.24 g	1.34
V3	16.72±0.95	17.65±2.66	18.12±0.34	17.5 g	1.32
V4	17.07±1.89	17.61±3.47	17.75±0.46	17.48 g	0.86
V5	16.71±0.68	16.9±1.14	17.76±0.79	17.12 g	0.87
Mean	16.96	17.33	17.54	17.28 g	1.2

V1 = Dembi-short maturing, V2 = Bayouda-early maturing, V3 = Kano-late maturing, V4 = Wad elahow-late maturing and V5= Bayouda-cold resistant

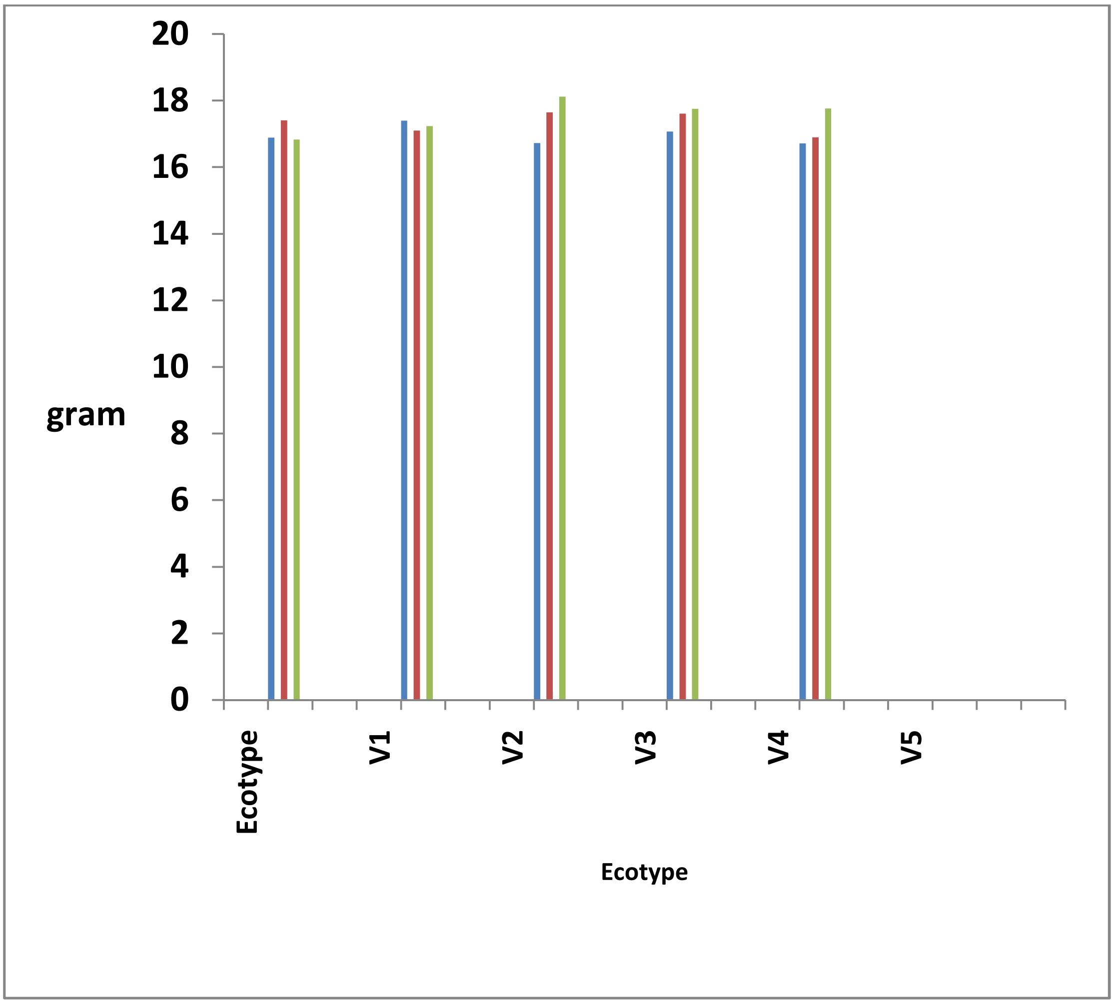

Figure 3: Weight of food ingested.

24 hrs **48hrs** **72 hrs**

V1 = Dembi-short maturing, V2 = Bayouda-early maturing,

V3 = Kano-late maturing, V4 = Wad elahow-late maturing and V5= Bayouda-cold resistant

4-4: Percentage of ingested food.

The table (4-4) and (fig 4-4) show the different percentages of amount of ingested food of five ecotypes of pear millet *Pennisetum glaucum variety*, by 3rd and 4th instars of migratory locust. The difference percentage was (98.2%) in wad elahow ecotype (V4), (97.3%) in Bayouda-late ecotype (V5), (96.7%) in Kano ecotype (V3), (96.5%) in Dembi ecotype (V1) and (96.1%) in Bayouda-early ecotype (V2) respectively.

Table 4: Percentage of ingested-food.

Ecotype	24hrs	48hrs	72hrs	Mean
V1	95.4%	97.2%	97.1%	96.5%
V2	97.2%	95.1%	96.1%	96.1%
V3	96.3%	95.3%	98.5%	96.7%
V4	96.9%	99.5%	98.2%	98.2%
V5	98.1%	94.9%	98.8%	97.3%
Mean	96.8%	96.4%	97.8%	97%

V1 = Dembi-short maturing, V2 = Bayouda-early maturing, V3 = Kano-late maturing, V4 = Wad elahow-late maturing and V5= Bayouda-cold resistant

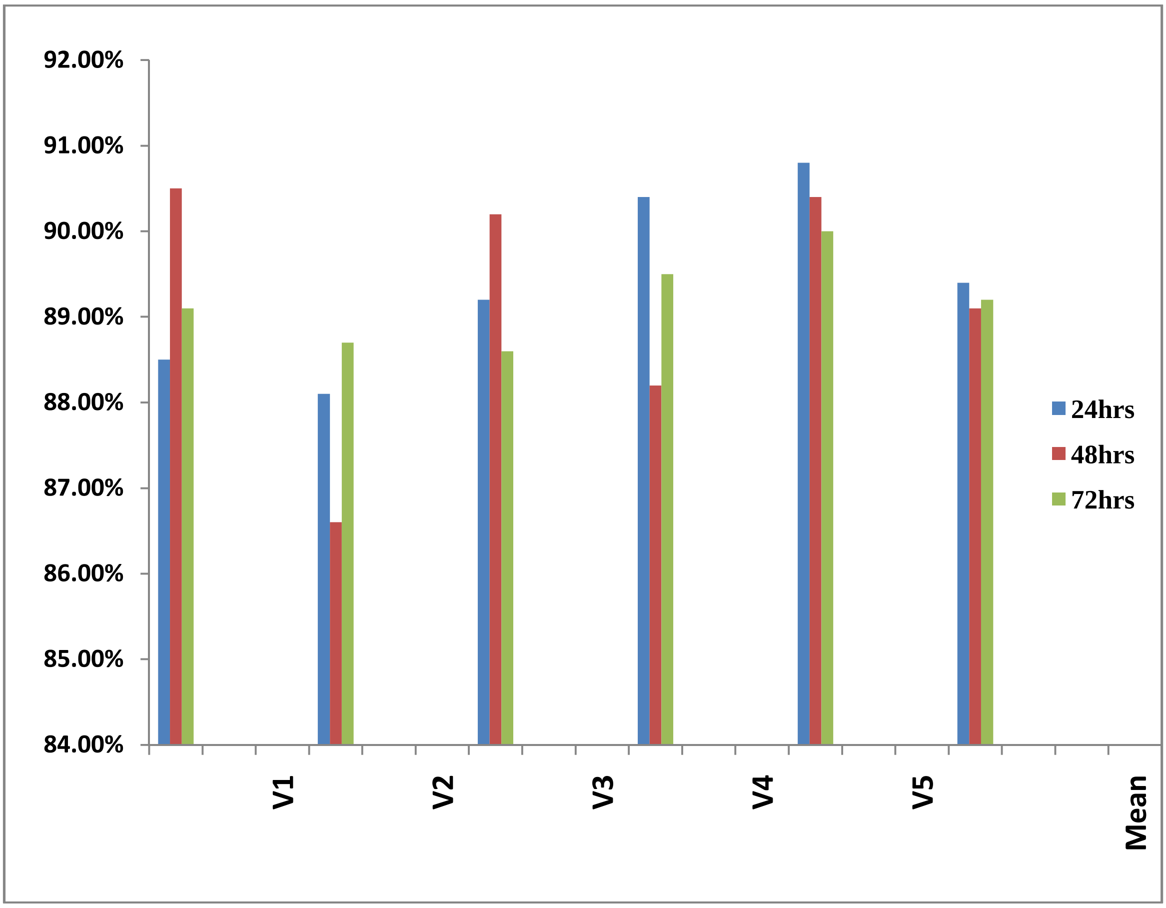

Figure 4: Percentage of ingested-food.

V1 = Dembi-short maturing, V2 = Bayouda-early maturing, V3 = Kano-late maturing, V4 = Wad elahow-late maturing and V5= Bayouda-cold resistant

4-5: Weight of Feces in grams.

Table (4-5) and (fig 4-5) show the susceptibility of five ecotypes of pearl millet, according to remains of fece in any ecotype variety. The least amount of fece was (0.28g) in ecotype (V5) Bayouda late, This means that a large part of the food-intaken was ingested, digested and assimilated in comparison with the others four ecotypes. The different percentages of ingested food consumption of the five ecotype, by 3rd and 4th instars of migratory locust, execrated feces ranked 0.47g in Bayouda-early ecotype (V2), 0.66g in Dembi ecotype (V1), 0.67g in wad elahow ecotype (V4) and 0.68g in Kano ecotype (V3) respectively.

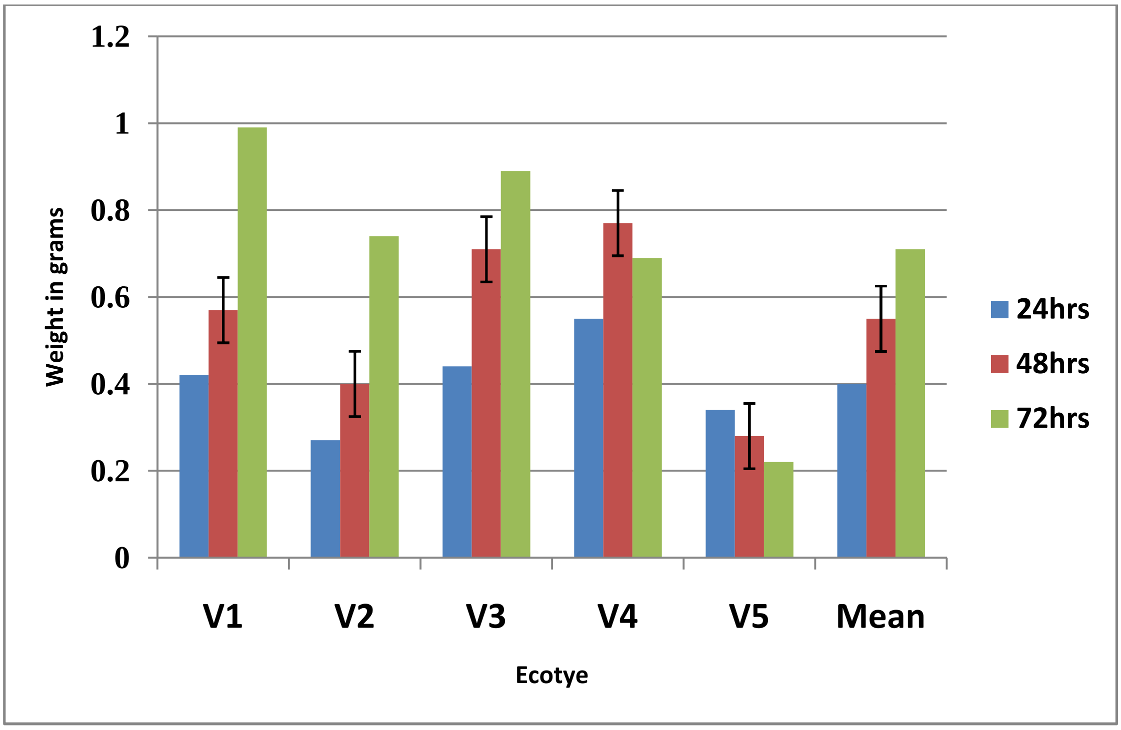

Figure 5: Weigh of feces in gram

V1 = Dembi-short maturing, V2 = Bayouda-early maturing, V3 = Kano-late maturing, V4 = Wad elahow-late maturing and V5= Bayouda-cold resistant.

CHAPTER FIVE

5.DISCUSSION

Sudan is one of the countries whose national income depends largely on agricultural commodities and natural resources. Pearl millet, *Pennisetum glaucum* is an agricultural commodity that represents the staple cereal of many millions of the world's poorest people in the semi-arid regions of tropical and subtropical developing countries in Asia and Africa.

In the Sudan pearl millet (Dukhun) is mainly grown in the western parts of Sudan (Darfur and Kordofan states) also, it's grown in eastern the region, red sea, Kassala and Gedaref states.

Pearl millet in these areas is frequently attacked by locusts. Among these, it's found that the African migratory locust *Locusta migratoria migratorioides* is considered a devastating pest on pearl millet through its ability to form dense aggregations of nymphs (hoppers) and highly mobile aggregations of adults (swarms) that feed on various graminaceous crops (Sorghum and Millet).

Since the migratory locust is a main threat to these crops and resources, its outbreaks are seriously followed and a prompt of control measures. So the possibility of manging the African migratory locust on pearl millet by sowing resistance cultivar prevailed.

The present work was conducted to investigate the susceptibility of five pearl millet varieties (ecotypes) to infestation by the 3^{rd} and 4^{th}nymphal instars of the species (Reiche& Fairmaire 1850).

According to the results of the study, it was evident that all five ecotype varieties of pearl millet were palatable to the migratory locust 3^{rd} and 4^{th}nymphal instars. These results in general were similar to the results pearl millet pests inventoried by Kamal *et al*., (2013) they showed that pear millet was infested by many pests, such as the larvae of *Spodoptera* sp, locusts (*Schistocerca gregaria* and *Locusta migratoria migratorioides*). The results showed that there was variation in infestation rate in the five ecotypes. This finding was in agreement with Siddig *et al*., (2013) who stated that different varieties of pearl millet reflect different levels of susceptible and resistance to pests.

From the results it was noticed that the nymphs and adults of African migratory locust prefer the vegetation shoots of pearl millet than bran and grains. This result is in agreement with Sharma *et al*., (1996) who mentioned that nymphs and adults of the African migratory locust occasionally attack all stages of the pearl millet causing heavy damage during outbreaks but, Prefer to feed on leaves, flowers, and developing grain.

According to the result in Table (1) and figure (1) of this study, the susceptibility and food preference on the five varieties by the 3rd and 4thnymphal instars of the African migratory locust, was high on Bayouda- Late maturing, Kano-late maturing, Wad elahow-late maturing, Bayouda-early maturing and Dembi-early maturing successively rand in decending order . Also these results are confermed the amount of food intaken in gram in Table (2) and Figure (2).

According to Tables 3, 4, Figuer 3 and Figure 4 of weight amount and percentage of food ingested by 3rd and 4th hoppers of African migratory locust.

The results on the amount of feces that excreted by the hoppers in Table (5) and histogram in Figure (5) the result. Indicated that there was significant difference at 1% level, among remain of fece of any ecotype variety and application period.

It is found that the percentage of intaken and ingested food was 86.4 %. Of the assimilated food from total ingested was 97 % and only 3 % was excreted as feces. These results were in line with Sharma and Davies,(1988) who showed that the locust hoppers and bands are particularly devastating and invade millet in Sudan. It is also in agreement with result that stated by Niassy *et al.,(*2011) who mentioned that the Late instars and adults cause economic damage directly to pasture and crops such as millet. Moreover Latchininsky:,(2013)confirmed that the African migratory locusthas the largest distribution among all grasshoppers and locusts but, the ecological requirements of the migratory locust are quite narrow and the devastating damage caused by hopper bands and swarms are primarily restricted to grasses, milletand others.

From the results on (Tables 1,2,3 and figuers 1,2,3) it is noticed that the most susceptible ecotype was Bayouda –early, Bayouda-late, Wad Ellhaw , Kano and the least susceptible was Dembi-early. In theory mentioned by Abuelgasim,(1989); Sabil,(1991) and Abuelgasim,(2011) mentioned that early Bayouda grown in cracked clay soil in Jebal Mara, late Bayouda grown in cracked clay soil in Kabkabia, Wad Ellhaw grown in south of Nyala semi cracking clay soil, Kano grown in cracking loamy clay soil south west of Nyala and Dembi grown in mixed sandy clay soil. This was confirmed by Guichard (1955), SEA, (1990), who mentioned that the locust prefers to live in black cracking clay land and boundary lands of savannah, which means that its feed behavioral preferring plants grow in similar environmental lands.

Although there is differences in the condition. Where the varieties are cultivated of the location where the study is made there is no difference regarding susceptibility of the 5 varieties to the pest.

CONCLUSIONS.

The results showed significant difference in the susceptibility of five varieties ecotype of pearl millet.

The preference and susceptibility of ecotypes by nymphs was increased with the increase of application time.

The highest percentages of ingested food in the five ecotypes of pear millet *Pennisetum glaucum variety*, with 3rd and 4th instars of African migratory locust was in Bayouda-late maturing.

RECOMMENDATIONS.

Further testing of different graminaceous species on different nymphs of African migratory Locust is needed.

Further research works on evaluation of food preference and susceptibility of infestations of pearl millet varieties with other pest, is recommended.

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Appendices.

Appendix (1): all food amounts of five varieties ingested by hoppers

1-v1	16.72	17.38	16.53	50.63
1-v2	17.38	17.18	17.65	52.21
1-v3	15.36	17.51	17.29	50.16
1-v4	16.32	17.29	17.61	51.22
1-v5	15.81	17.21	17.12	50.14
2-v1	17.13	16.79	18.3	52.22
2-v2	16.53	17.34	17.42	51.29
2-v3	17.26	17.69	17.99	52.94
2-v4	16.76	18.44	17.62	52.82
2-v5	15.5	17.23	17.96	50.69
3-v1	15.07	17.72	17.71	50.5
3-v2	16.22	17.6	17.88	51.7
3-v3	17.88	18.43	18.05	54.36
3-v4	17.17	17.61	18.46	53.24
3-v5	17.39	17.69	18.19	53.27
				777.39
	n	45		3
	r	3		5
	t	15		1
	cf	604335.2	13429.67	
	Total of ss	13457.25	27.57532	
	Treatment of ss	40312.82	13437.61	7.935053
	Error of ss			19.64027

Appendix (2): accumulated of food amount of five varieties ingested by Hoppers for three days

	1st	2nd	3rd	Total	
v1	50.63	52.22	50.5	153.35	
v2	52.21	51.29	51.7	155.2	
v3	50.16	52.94	54.36	157.46	
v4	51.22	52.82	53.24	157.28	
v5	50.14	50.69	53.27	154.1	
total	254.36	259.96	263.07	777.39	
15	Days of ss	201484	13432.27	2.597693	
9	Variety of ss	120880.7	13431.19	1.520009	
	D x v of ss			3.817351	
			ANOVA		
	source	df	ss	Ms	F value
	Period	2	2.597693	1.298847	1.983955
	Variety	4	1.520009	0.380002	0.580444
	PxV	8	3.817351	0.477169	0.728863
	Error	30	19.64027	0.654676	
	Total	44	27.57532		
		MEANS			
		1d	2d	3d	mean
	v1	16.87667	17.40667	16.83333	17.03889
	v2	17.40333	17.09667	17.23333	17.24444
	v3	16.72	17.64667	18.12	17.49556
	v4	17.07333	17.60667	17.74667	17.47556
	v5	16.71333	16.89667	17.75667	17.12222
	mean	16.95733	17.33067	17.538	17.27533
		t	2.042		
5%LSD:					
period	0.603307	2	1.309351		
variety	0.778866		0.08729	0.145483	0.43645
PxV	1.349035		0.295449	0.381423	0.660644

Appendix (3): accumulated of food amount of five varieties

Intaken by hoppers for three days

intake	grams	ANOVA			
source	df	ss	ms	F value	
Period	2	14.30248	7.151242	25.91238	**
Variety	4	2.066702	0.516676	1.872164	ns
PxV	8	2.853138	0.356642	1.292286	ns
Error	30	8.279333	0.275978		
Total	44	27.50166			
	MEANS				
	1d	2d	3d	mean	
v1	16.90333	17.93	18.15	17.66111	
v2	16.69333	17.49333	18.42	17.53556	
v3	17.29333	18.20333	18.27	17.92222	
v4	16.47667	18.28667	18.54333	17.76889	
v5	17.81667	18.18667	18.45667	18.15333	
mean	17.03667	18.02	18.368	17.80822	
5%LSD:					
period	0.391708				
variety	0.505693				
PxV	0.875885				

Appendix 4: percentages of intaken and digested food by hoppers.

	intake%				digested%		
treat	1st	2nd	3rd		1st	2nd	3rd
1-v1	16.72	17.38	16.53		97.37	96.34	92.44
1-v2	17.38	17.18	17.65		97.8	98.45	95.25
1-v3	15.36	17.51	17.29		97.4	95.68	95.84
1-v4	16.32	17.29	17.61		98.31	97.57	94.72
1-v5	15.81	17.21	17.12		98.38	98.51	97.27
2-v1	17.13	16.79	18.3		98.39	97.1	95.96
2-v2	16.53	17.34	17.42		96.32	94.54	94.46
2-v3	17.26	17.69	17.99		97.51	95.98	92.33
2-v4	16.76	18.44	17.62		98.47	103.36	96.65
2-v5	15.5	17.23	17.96		95.32	93.64	95.83
3-v1	15.07	17.72	17.71		98.3	96.56	96.4
3-v2	16.22	17.6	17.88		94.68	97.18	96.54
3-v3	17.88	18.43	18.05		98.13	98.76	98.68
3-v4	17.17	17.61	18.46		98.39	97.72	98.61
3-v5	17.39	17.69	18.19		97.8	99.54	99.07

intake%		ANOVA			
source	df	ss	ms	F value	
Period	2	0.541818	0.270909	0.017998	ns
Variety	4	30.81979	7.704948	0.511883	ns
PxV	8	25.06872	3.133589	0.208182	ns
Error	30	451.5649	15.05216		
Total	44	507.9953			
MEANS	1d	2d	3d	Mean	
v1	88.48333	90.48333	89.06667	89.34444	
v2	88.08333	86.63333	88.7	87.80556	
v3	89.23333	90.22333	88.58333	89.34667	
v4	90.41667	88.18333	89.45	89.35	
v5	90.8	90.35	90.03333	90.39444	
mean	89.40333	89.17467	89.16667	89.24822	
5%LSD:					
period	2.892841				
variety	3.734642				
PxV	6.468589				

Appendix 5: percentages of digested food by hoppers.

digested%		ANOVA				
source	df	ss	ms	F value		
Period	2	15.02382	7.511909	2.712226	Ns	
Variety	4	22.96591	5.741478	2.073	Ns	
PxV	8	49.58865	6.198581	2.23804	Ns	
Error	30	83.0894	2.769647			
Total	44	170.6678				
	MEANS					
	1d	2d	3d	mean		
v1	95.38333	97.15	97.08667	96.54		
v2	97.16667	95.10667	96.13333	96.13556		
v3	96.30667	95.27333	98.52333	96.70111		
v4	96.86667	99.49333	98.24	98.2		
v5	98.05333	94.93	98.80333	97.26222		
mean	96.75533	96.39067	97.75733	96.96778		
5%LSD:						
period	1.240901					
variety	1.601997					
PxV	2.77474					
digested	grams	ANOVA				
source	df	ss	ms	F value		
Period	2	2.597693	1.298847	1.983955	Ns	
Variety	4	1.520009	0.380002	0.580444	Ns	
PxV	8	3.817351	0.477169	0.728863	Ns	
Error	30	19.64027	0.654676			
Total	44	27.57532				
	MEANS					
	1d	2d	3d	mean		
v1	16.87667	17.40667	16.83333	17.03889		
v2	17.40333	17.09667	17.23333	17.24444		
v3	16.72	17.64667	18.12	17.49556		
v4	17.07333	17.60667	17.74667	17.47556		
v5	16.71333	16.89667	17.75667	17.12222		
mean	16.95733	17.33067	17.538	17.27533		
5%LSD:						
period	0.603307		F tab	period	variety	PxV
variety	0.778866	*	5%	3.32	2.69	2.27
PxV	1.349035	**	1%	5.39	4.02	3.17

Appendix 6: Amount of feces excreted by hoppers

feaces	grams	ANOVA			
source	df	ss	ms	F value	
Period	2	0.703338	0.351669	8.087234	**
Variety	4	1.117858	0.279464	6.426768	**
PxV	8	0.590796	0.073849	1.698296	ns
Error	30	1.304533	0.043484		
Total	44	3.716524			
	MEANS				
	1d	2d	3d	mean	
v1	0.416667	0.573333	0.993333	0.661111	
v2	0.273333	0.396667	0.743333	0.471111	
v3	0.443333	0.713333	0.893333	0.683333	
v4	0.546667	0.77	0.693333	0.67	
v5	0.336667	0.276667	0.223333	0.278889	
mean	0.403333	0.546	0.709333	0.552889	
5%LSD:					
period	0.155486				
variety	0.200732				
PxV	0.347678				
	F tab	period	variety	PxV	
*	5%	3.32	2.69	2.27	
**	1%	5.39	4.02	3.17	