"Studies on the bionomics of Acrida exaltata (Orthoptera: Acrididae) of Kashmir region"

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Introduction

The valley of Kashmir due to its unique geographical position and temperate climate offers an ideal environment for research. It lies in the north temperate region of Asia, in the north-western Himalayas, between 32.17° to 36.58° north latitude and 73.26° to 80.50° east longitude. It has total area of 5,350 sq. kms situated at an average elevation of 1,590 meters above the sea level, surrounded by a high chain of mountains. On this account, it is geographically cut off from Jammu in south and Ladakh in north, which are two provinces of Jammu & Kashmir. Temperature varies from -14°C in winter to 35°C in summer. Thus, weather shows marked seasonality, summers are less rainy than spring and quite warm. By the end of December the valley usually experiences snow which gradually disappears by the end of February and rains replace the snow in spring. The main Kashmir valley is 100 km wide and 15,520.3 km^2 in area. The Himalayas divide the Kashmir valley from Ladakh, while the Pir-Panjal range which encloses the valley from the west and the south, separates it from the Great Plains of northern India. It is divided into ten districts Anantnag, Baramullah, Kupwara, Budgam, Pulwama, Srinagar, Kulgam, Shopian, Ganderbal and Bandipora. Since Kashmir is one of the hotspots for agricultural and horticultural practices, the insect pests affect these industries drastically causing great economic losses. Therefore, an urgent need to study them. Among different insect groups, Orthoptera is one such order / group which attacks our crops.

The name Orthoptera is derived from two Greek words "*Orthos*" meaning straight and "*pteron*" meaning wing, refers to the parallel-sided structure of the front wings (tegmina). There are more than 20,000 species in this order which have a worldwide distribution but are most diverse in the tropics. Body size varies from less than 5 mm to some of the world's largest insects with body lengths up to 11.5 cm and wingspans of over 22 cm. Orthopterans are a common component of terrestrial insect faunas and include some of the most voracious pests (grasshoppers, locusts and certain katydids). The order Orthoptera is divided into two suborders, Ensifera and Caelifera.

The suborder Ensifera includes long-horned grasshoppers, bush crickets, crickets and mole crickets while Caelifera includes short-horned grasshoppers, locusts, grouse-locusts and pigmy mole crickets. Members of both suborders (Ensifera and Caelifera) are generally phytophagous but many species are omnivores as well. Females of most species lay clutches of eggs either in the ground or in vegetation. Some of the best examples of cryptic coloration are seen in this group involving mimicry of leaves and other vegetation or other resemblance to the background (Chopard 1938; Hewitt 1979; Kevan 1982; Rentz 1991). Grasshoppers, katydids and crickets are well known for their abilities to jump and particularly for singing by males (females are typically silent). There are few places in the world where the calls of grasshoppers (usually diurnal), katydids and crickets (usually nocturnal) cannot be heard during warm seasons. Organs of sound production and sound reception involve quite different body parts in the two subgroups (Alexander 1960; Dumortier 1963).

Orthopteroid species have a paurometabolous life cycle or incomplete metamorphosis. The use of sound is generally crucial in courtship and most species have distinct songs. Most grasshoppers lay their eggs in the ground or on vegetation. The eggs hatch and the young nymphs resemble adults but lack wings and at this stage are often called hoppers. They may often also have a radically different coloration from the adults. Through successive moults, the nymphs develop wings until their final moult into a mature adult with fully developed wings. The number of moults varies between species; growth is also very variable and may take a few weeks to some months depending on food availability and weather conditions. Orthoptera is one of the most diverse orders of class Insecta with superfamily Acridoidea being most noted for pests of agriculture and forest areas. The order Orthoptera consists of insects with incomplete metamorphosis, including the grasshoppers, crickets and locusts. Many insects in this order produce sound (known as a stridulation) by rubbing their wings against each other or their legs. They are also well adapted for flight since both direct and indirect muscles work together during flight

movements and thus explains the reason for these insects to cover long distances during swarming conditions that mainly results from overcrowding and scarcity of food. Grasshoppers are beneficial to a healthy, vigorous, grassland ecosystem when they are at low to moderate (non-economic) densities. Grasshoppers developed in the rangeland ecosystem during a long period of co-evolution with other flora and fauna. Grasshoppers ecological role (Van Hook 1971) of providing food for wildlife, stimulating plant growth, creating plant litter for the soil and cycling elements and nutrients was developed as a functional part of the whole ecosystem.

Among Orthopterans, grasshoppers are functionally more important, being the dominant aboveground invertebrates in pastures and natural grasslands when judged by biomass (Scott *et.al*., 1979; Risser *et.al*., 1981). The family Acrididae having members of short horned grasshoppers, first proposed by Latereille (1802) based on Linnaeus genus "*Acrida*" which is a large group with world-wide distribution. It includes economically important migratory and devastating locusts as well as thousands of species of more sedentary habits which contains some of the most phylogenetically advanced grasshoppers. These are recognized at a glance by short-horned antennae and three segmented tarsi. Grasshoppers are characterized by hind femora-tegmen type stridulatory organs, auditory organs on 1st abdominal segment, ovipositor short and curved at tip and abdomen performs function of digging a hole for laying the eggs. Hind femora are typically long and strong fitted for leaping. Those species of grasshoppers that make easily audible noise usually do so by rubbing the hind femora against the forewings or abdomen. Hind wings are membranous while front wings are coriaceous not fit for flight. These are diphasic gregarious and solitary. Grasshoppers which form swarms and fly over great distances are inter-continentally important pests. Most species of grasshopper (Orthoptera: Acrididae) are polyphagous and select host plant species from a number of unrelated plant families (Chapman 1990; Chapman and Sword 1997). However, some grasshopper species do restrict themselves to limited host ranges and a few of them even show

relatively high fidelity to their host species (Sword and Chapman 1994; Sword and Dopman 1999).

Acridoidea is one of the important super families of suborder Caelifera (short-horned grasshoppers with three segmented tarsi and a short ovipositor), rest being Tridactyloidea, Tetrigoidea and Eumastacoidea. Tetrigoidea is easily distinguishable from Acridoidea by the elongate pronotum, usually extending beyond the end of the body, by the absence of an arolium between the claws and the two-segmented tarsi of the fore and middle legs. The other super families of Caelifera are easily recognizable at sight and are not frequently encountered. Superfamily Acridoidea has shown maximum diversity and divided into various families of which family Acrididae, Catantopidae and Pyrgomorphidae are widely distributed in India. Members of superfamily Acridoidea harm chiefly by defoliation, that on the other hand drastically affect the produce by decreasing the overall photosynthetic area or we can say that they are capable enough to affect the green cover (forest and wetlands) negatively.

The name Acrididae is derived from Greek word "*akris*" meaning locust. The Acrididae is the predominant family of grasshoppers comprising some 10,000 of the 11,000 species of the entire suborder Caelifera. The Acrididae are best known because all locusts (swarming grasshoppers) belong to family Acrididae. The subfamily Oedipodinae is sometimes classified as a distinct family Oedipodidae in the superfamily Acridoidea. Acrididae grasshoppers are characterized by relatively short and stout antennae and tympana on the side of the first abdominal segment. Most grasshoppers we find in our gardens, along roadsides and on meadow walks belong to the family Acrididae.

The group is subdivided into several subfamilies and includes slant-faced grasshoppers, stridulating grasshoppers, band-winged grasshoppers and some of the better known locusts. Most species are medium to large in size but members of this huge family vary greatly ranging from about 1–8 cm in length. Many are grey or brown in colour and are camouflaged well among the

plants where they live, the auditory organs are located on the sides of the first abdominal segments and are covered by the wings (when present). Their antennae are quite short typically extending less than half the grasshopper's body length. The pronotum covers just the thorax never extending beyond the base of the wings. The tarsi have three segments.

Grasshoppers feed on plant foliage with a particular fondness for grasses and spurges. When grasshoppers populations increase to the point of crowding, swarms of locusts can completely defoliate grasslands and agricultural crops over large areas. Since earlier days to present time locusts are the main pests in countries bordering deserts as for example Africa, where swarms of locusts have resulted in famine like conditions many a time. A notable taxonomical work on Acrididae was made by Kirby (1914) in the series '*Fauna of British India*' and he divided the family Acrididae into eight subfamilies. Grasshoppers like all members of the order Orthoptera undergo simple or incomplete metamorphosis with three life stages – egg, nymph and adult. In most species the eggs are laid in the soil and this is the overwintering stage. Many male grasshoppers in the family Acrididae use courtship calls to attract mates. Of those that do, most use a form of stridulation in which they rub special pegs on the inside of the hind leg against a thickened edge of the wing. The band-winged grasshoppers snap their wings while in flight making an audible crackle. In some species the male may continue to guard the female after mating. The male guards the female by riding around her back for a day or two to discourage her from copulating with other partners.

Grasshopper species compete with humans for plant resources all over the world (Dempster 1963). In Africa, Australia and Asia, the grasshoppers are generally termed as 'locusts' for their aggressiveness, gregariousness and swarm forming behaviour. They often cause extensive and serious damage with their potential of invading cropping areas in swarms of millions of individuals leaving behind devastated fields and plantations. Luckily, these invasions are infrequent and may be followed by long periods of recession. In contrast grasshoppers form a more chronic problem causing serious yield

losses in most years. DDT and other persistent synthetic chemical pesticides were effective at controlling them but these chemicals had dangerous ecological consequences and were banned in mid 1980's. Modern non-persistent pesticides are not as useful and still far from being environmentally benign. Therefore, the present day focus is on biological methods like green muscle, a myco-pesticide, developed from the spores of the insect pathogenic fungus *Metarhizium anisopliae* var. *acridum*, specific to species of short horned grasshoppers, is widely applied in Africa. Grasshoppers are destructive defoliators like the rice phadka grasshopper, *Hieroglyphus banian* and *Oxya velox*; the surface grasshopper, *Atractomorpha*, sugarcane grasshopper, *Choroedocus illustris*, causing persistent loses to agricultural crops due to their polyphagous mode of feeding. There are few other Orthopterans like mole crickets (Gryllotalpidae), which generally have a subterranean life and cause serious damage to the roots of crops.

Acrida exaltata is commonly known as long headed toothpick grasshopper and is a polyphagous pest feeding on a variety of food crops, grasses, herbs and shrubs, distributed throughout – India, Pakistan, Bangladesh, Tibet, Afghanistan, Sri Lanka, Iran and Nepal. Adults and nymphs are occasionally gregarious and congregate in masses on thick grasses, bushes and treetops up to the height of 25 feet, photosensitive in nature. In Jammu and Kashmir, the species has been reported to feed on paddy, wheat, maize, mustard and other types of grasses. Since, the study carried out on *Acrida exaltata* is primarily on taxonomy and seasonal variations / population dynamics while bionomics has been neglected by most workers, therefore, the comprehensive study of biology, morphometrics, ecology, feeding behaviour and its natural enemies is urgently needed with special reference to Kashmir region. The present study was carried out on bionomics of *Acrida exaltata*, which is derived from two Greek words *bios* – life and *nomos* – law. It is the comprehensive study of an organism and its relation to its environment. Another way of expressing this word is the term currently referred to as "ecology" and therefore, the relation of abiotic and biotic factors was

undertaken with a focus on role of temperature, humidity, light, rainfall, crowding and food on the pest grasshopper and conversely its biocontrol.

COLLECTION SITES : Different breeding / feeding sites of *Acrida exaltata* verified were –

CENTRAL KASHMIR

SRINAGAR : It is the situated in the centre of Kashmir valley, most of the green meadows and agricultural fields are confined to Alastang, Batpura, Tialbal, Harwan and the areas adjoining Nishat and Shalimar. The grasshopper infestation was highly observed in the paddy, mustard and grass fields of these areas mostly in the months of June to September.

BUDGAM : It is also centrally located in the Kashmir valley. Although the district has several high mountains but most of the land is devoted to rice, wheat, maize, mustard etc. The grasshoppers were abundantly found in the agricultural fields and orchards in Nagam, Badipora, Hayatpora, Chadoora, Panzan etc feeding on different types of crops and grasses.

GANDERBAL : This district belongs to central kashmir and most of the land is under agriculture. Grasshoppers were collected abundantly from rice, maize, mustard and other grasses. Photographic plates **1** and **2** depict collection sites in central Kashmir.

SOUTH KASHMIR

PULWAMA : Located in south eastern part of valley, although most of the land is involved in cultivation of saffron but paddy, maize, mustard culture are also the main occupation. Grasshoppers were collected from the agricultural fields.

ANANTNAG : It is the southernmost district of the valley. Rice, maize, mustard, wheat are mostly grown in this district, which makes it one of the important site for collection of the Grasshopper species. Photographic plate **3** depicts collection sites in south Kashmir.

NORTH KASHMIR

BARAMULLAH : It is the northern district of the valley and agricultural fields are devoted to cultivation of rice, maize, mustard etc. grass hoppers were abundantly found in the agricultural fields.

BANDIPORA : It is situated on northern side of the valley. It is bounded by district Kupwara, Ganderbal, Kargil and Baramullah. Agriculture is the main activity of the people which also involves paddy and maize culture. Grasshoppers were found in good numbers in agricultural lands. Photographic plate **4** depicts collection sites in north Kashmir.

Red dots indicate the collection sites

Chapter-2

Review of Literature

The studies on the locusts and grasshoppers have been carried out since the early 20's. Notable contributions in the field of Acridology have been made by many Acridologists in India and abroad (Norris 1954; Katiyar 1955; Parihar and Pal 1978; Chapman and Page 1979; Ali 1982; Riede 1987). Studies on the effect of different degrees of temperatures and level of humidity on different stages of acridids have been worked out by many workers like Grewal & Atwal 1968; Khan & Aziz (1973a, 1974c) and Majeed & Aziz (1980a, 1980b) attributing the temperature and humidity as an ecological factor responsible for the rate of development and hopper duration periods.

The first account of acridid fauna in India was given by Kirby (1914). He described 329 species under 124 genera in the *Fauna of British India* including Burma and Ceylon. He recognised 8 subfamilies under the family Acrididae viz. Arcydiinae (with 6 groups: Tripetalocerini, Cladonotini, Scelimenini, Metroderini, Acrydiini, Batrachidiini), Eumasticinae (with 4 groups: Xiphicerini, Erianthini, Gomphomastacini, Eruciini), Tryxalinae, Oedipodinae, Batrochotriginae, Pyromorphinae, Pamphaginae and Cantantopinae. In his pioneer work Kirby has given a generalised account of the morphology and also furnished identification keys. Uvarov (1921) gave description of some of Indian Acrididae. In the same year, he described a new species of alpine grasshopper, *Conophyma mitchelli* from Kashmir, India. Agarwala (1952) made a comparative study of the ovipositors in the family Acrididae and mentioned that anatomically the ovipositors are correlated with the soil conditions where the eggs are to be deposited. On these basis, he established 6 groups and 37 species of the Acrididae and supported it with the structural differences in the sub-genital plates and the paired valves. Suhail

et.al., (1994) carried out the taxonomic studies of the Acridoidea from Pakistan. Sharma & Gupta (1996) studied biology and taxonomic parameters of some short horned grasshoppers from sub-shivalik plains of Jammu region. Mahmood *et.al*., (2004) carried out a preliminary study of grasshoppers (Orthoptera: Acrididae) of Baltistan, Azad Jammu & Kashmir, Pakistan. Azim & Reshi (2010) gave taxonomic notes on the tribe *Acridini* of Kashmir, India. Usmani & Nayeem (2012) conducted studies on taxonomy and distribution of Acridoidea of Bihar, India. Nayeem & Usmani (2012) carried out study of the taxonomy and field observations of grasshopper and locust fauna of Jharkhand, India.

Ahmad *et.al*., (1992) studied insects associated with tea at Mansera, Pakistan. The study revealed that *Acrida exaltata* acts as a pest of tea in Pakistan. Chitra *et.al*., (2000) studied the Orthoptera in rice fields of Coimbatore. Ingrisch (2001) studied the Orthoptera from Bhutan, Nepal and North India in the Natural History Museum Basel. Shishodia *et.al*., (2003) studied Orthoptera from Pong Dam wetland, district Kangra, Himachal Pradesh, India. Kandibane *et.al*., (2004) studied diversity and abundance of Orthoptera in an irrigated rice ecosystem in Madurai, India. Kandibane *et.al.,* (2004) studied Orthopteran diversity in irrigated rice ecosystem in Madurai, Tamil Nadu. Study revealed the presence of *Acrida exaltata* in the irrigated rice ecosystem. Mayya *et.al*., (2005) conducted a survey of short-horned grasshoppers from Dakshina, Kannada district, Karnataka. Paulraj *et.al*., (2009) studied distribution of grasshoppers among different host plants and habitats in two districts of Tamil Nadu. Tak & Bhat (2009) carried out an assessment of epigeal invertebrate community in cement polluted and non polluted areas. Mukhtar *et.al.,* (2010) studied biodiversity and occurrence of grasshoppers of Quetta division of Balochistan. Senthilkumar (2010) studied Orthopteroids in Kaziranga National Park, Assam, India. *Acrida exaltata* was also in the park on the grasses. Koli *et.al.,* (2010) gave Orthopteran fauna of Chandoli National Park, Maharashtra. Azim *et. al*., (2010) carried out the observations on the seasonal variations in population of three species of

grasshoppers (Orthoptera: Acrididae) of Kashmir Himalaya. During their field observations it was found that the population of hoppers and adults of three species of grasshoppers *viz.*, *Sphingonotus longipennis*, *Oedaleus abruptus* and *Acrida exaltata* was abundant during the months of April, August and September, October, respectively in the Kashmir valley. The mating was found to occur during the months of September and October. Soon after mating eggs were laid, which remained under diapause during winter months and hatched on the onset of spring season. The hoppers of *Acrida exaltata* were found to appear first after the winter months followed by *Sphingonotus longipennis* and *Oedaleus abruptus* respectively. Saha *et.al*., (2011) studied the effects of anthropogenic disturbances on the diversity and composition of the Acridid fauna of different Sites in the dry deciduous forest of West Bengal, India. Tamkeen *et.al.,* (2011) carried out study on the grasshopper species composition in Mirpur division of Azad Jammu and Kashmir, Pakistan. Thakur & Thakur (2011) studied Orthopteran crop-pest relationship in Roper Wetland and its environment Punjab, India. Bahaar & Bhat (2012) studied the community structure and distribution of epigeal-cum-herb layer fauna in the rice fields of Jammu and Kashmir, India. Their study revealed that the epigeal-cum-herb fauna included 50 genera belonging to 2 classes viz., Insecta and Arachnida. *Acrida exaltata* was also found besides 7 other Orthopteran taxa. Wani and Ahmad (2012) carried out preliminary studies on the food preferences and polymorphism in natural population of *Acrida exaltata* (Orthoptera: Acrididae) of Kashmir region. Akhtar *et.al*., (2012) surveyed the species diversity and abundance of grasshopper fauna in rice ecosystem from Uttar Pradesh state of India. During their study maximum diversity was shown by family Acrididae (85%) followed by pyrgomorphidae (15%). The species of genera *Oxya*, *Hieroglyphus* and *Acrida* collected from the fields were found feeding on rice foliage with severe damage shown in the later stage of the crop growth and hence were considered as major pests of rice. Usmani *et.al*., (2012) carried out the field observations on the incidence of grasshopper fauna (Orthoptera) as a pest of paddy and pulses.

Life history and life cycle were studied in the laboratory as well as field conditions for different species by various workers (Roffey 1979; Sharma & Gupta 1996). Significant contribution to grasshopper fauna of Kashmir was made by Bei-Bienko & Mishchenko (1951). Pant & Agrawal (1964) worked out the free amino acid composition of the haemolymph of the hemimetabolous *Acrida exaltata* and *Poekilocerous pictus*. Verma *et.al*., (1978) reported *Aiolopus thalassinus tamulus* and *Acrida exaltata* as pests on *Calotropis procera* in India. *Aiolopus thalassinus tamulus* was found throughout the rainy season except during the fourth week when temperature was maximal and humidity was minimum. On the contrary, high temperature and low relative humidity favoured the abundance of *Acrida exaltata*. The sex ratio of *Aiolopus thalassinus tumulus* was 119 males: 207 females and it was suggested that this might account for its major pest status. It was thought that *Calotropis procera* could be used as a trap-crop for insects infesting cotton and other economically important crops. Roffey (1979) studied life history and life cycle of some acridids in the laboratory as well as field conditions. Ali (1982) studied the effect of temperature and humidity on the development and fertility-fecundity of *Acrida exaltata*. The effect of temperature and humidity on *Acrida exaltata* has been studied to have two aspects in relation to (1) its effect on hopper development and (2) its effects on the fertility-fecundity. He observed that the rate of development was affected by the moisture present in the environment with no development at 0%, 10% and 20% RH and most desirable range of humidity was found to be between 50-70% RH. He further concluded that percentage of hoppers reaching the adult stage, longevity of adults, average number of copulation and average number of egg pods per female was also influenced by the temperature. Bhat and Qadri (1999) studied the micro-distribution and fidelitic status of Orthopteran populations in grasslands of Dachigam National Park of Kashmir region. Reports of role of food plants in grasshoppers and their selection has been extensively studied by Gangwere (1995, 1998). Ganguly *et.al.,* (2008) carried out scanning electron microscopy of two common Indian short horned grasshoppers (Orthoptera: Acrididae). Their study concluded that

the surfaces of the eggs of acridids show chronic sculpturing - distinct features that can be used to identify these species. With the help of electron microscope they documented dimensions and surface details of eggs of two Indian acridids: *Hieroglyphus banian* and *Acrida exaltata*. Their eggs were characterized by distinct features: *Acrida exaltata* by many small tubercles scattered almost uniformly. *Hieroglyphus banian* by thick ridged hexagonal polygons. The similarities and dissimilarities of their egg surfaces to those of other acridid species were not consistent with sub-famial classification. Studies have been also made on the seasonal variations in the population of *Acrida exaltata* of Kashmir (Nayer *et.al*., 2010). Recently, some studies were carried-out on incubation period, hatching of eggs, duration of hoppers, food preferences, applications of Dyar's law and cannibalistic behaviour of some acridid species (Ahmad *et.al*., 2007; Ahmad 2008; Ahmad & Nabi 2009, 2010, 2012) in North India.

Bhide (1968) described the morphological resistance to grasshoppers attacking sugar cane varieties and concluded that significant differences were found in the incidence of attack by *Acrida exaltata* among 40 varieties of sugar beet. Nine varieties were significantly more susceptible to attack. There was no correlation between differences in leaf colour and incidence of attack but there was an apparent association between the type of serration of the leaf margin and insect attack. Feeding occurred usually from the leaf margin, varieties with leaves with sharply serrated margins had a lower incidence of attack than those with relatively smooth leaf margins. Irshad (1977) studied grasshoppers on rice in Pakistan and concluded that *Hieroglyphus banian* and *Oxya multidentata* are the major pest species. *Hieroglyphus banian* was predominant in hilly regions and related it to the destruction of oviposition sites under the intensive cultivation of the plains. *Oxya multidentata* was also more frequent in the hills. *Oxya velox, Acrida exaltata, Acrotylus humbertianus, Atractomorpha acutipennis, Calliptamus* species *Catantopspinguis, Chroedicus illustris, Eyprepocnemis plorans, Shirakiacris shirakii, Oedaleus abruptus* and *Truxalis grandis* were listed as minor rice

pests in Pakistan. Most damage was caused by young larvae in nurseries, destruction of egg pods by digging or ploughing in winter was recommended for control. Gangwere (1995) studied in detail role of food plants in grasshoppers and their selection. Haldar *et.al.*, (1995) conducted a laboratory study of food preferences of common Indian grasshopper, *Acrida exaltata* of the laterite zone of West Bengal, India, which involved offering as food a total of 51 plant species belonging to 23 families. Of the 51 species, 31 were always rejected, with the remaining 46 either sampled briefly or eaten as food. Only 15 were regularly accepted as food. Plants of the family Poaceae were most preferred by *Acrida exaltata*. The role food plants and application of Dyar's rule to different hopper instars of *Acrida exaltata* and *Choroedocus illustris* has been significantly carried out by Ahmad (2012); Ahmad & Nabi (2012). Their study was aimed at comparing the influence of diet, effect of crowding and temperature on the growth of larval stages in the pest grasshopper.

Singh (1977) gave the colour variation in the natural population of *Acrida exaltata* in the Kumaon Himalayas and came up with the conclusion that *Acrida exaltata* exists in three colour morphs: green, straw-coloured monochrome forms and banded forms. The latter either have a single brown band or two pinkish bands on the elytra. Intermediate forms between all three morphs were common. He further showed that green morphs comprised 60%, straw-coloured morphs 15%, and banded morphs 25% of the population with male: female ratio 2:1 in green and of 2:5 in straw-coloured morphs and concluded that age, sex, season and habitat are not directly responsible for colour variation in this species. Roonwal (1977) carried out studies in intra specific colour variation with field observations on green-brown polymorphism in grasshoppers and their biological significance.

Anand *et.al*., (2008) gave potential value of Acridids as high protein supplement for poultry feed. Four acridid species were used in experiments namely *Oxya fuscovittata*, *Acrida exaltata*, *Spathosternum prasiniferum* and *Hieroglyphus banian*. The nutritional evaluation of four acridid species was

carried out and the results revealed that the acridids have a higher amount of protein content as compared to the conventional soybean and fish meals. Das *et.al*., (2010) studied nutrient analysis of grasshopper manure for soil fertility enhancement. Their study was based on reliable estimation of nutrients in grasshopper excreta which was required to formulate alternative low cost organic acridid manure for sustaining crop production. Their study showed that different N, P, K valued manure can be prepared by mixing different amount of excreta of different species depending on soil quality and crop type. Das *et.al*., (2012) studied the effect of food plants on nutritional ecology of two acridids viz., *Oxya hyla hyla* and *Spathosternum prasiniferum prasiniferum*, to provide alternative protein supplement for poultry. Their study concluded that a large annual acridid biomass should be produced on acridid farms to manufacture high-quality, low-cost feed for the poultry industry.

Some potential uses for the insect repellent properties of neem (*Azadirachta indica*) were reviewed by Radwanski (1977). Neem seed cake had been shown to have a specific gustatory repellent action against *Locusta migratoria* and application of a paste made from crushed neem seed to leaves had inhibited feeding in *Schistocerca gregaria*. The active ingredient of neem was a triterpenoid named azadirachtin. Other Orthopteran species controlled by neem were *Chortoicetes terminifera* and *Acrida exaltata*. Sharma & Khan (2004) studied the effect of certain neem extracts against *Acrida exaltata* as a production enhancement measure. Their results showed that *Acrida exaltata* adults indicated highest mortality 82.00% at 1.0% concentration of *Azadirachta indica* leaves while least mortality response around zero was observed at 0.005% concentration.

Looking at the available literature a lot of work has been carried out at national and international level notwithstanding, the valley of Kashmir has been neglected in particular by entomologists. This is proven by the fact that no work has been carried out on bionomics except few scattered reports by few workers that too on biology, seasonal variations and taxonomy (Balderson

& Yin 1991; Sharma & Gupta 1996; Bhat & Qadri 1999; Mehmood *et.al*., 1999, 2002, Reshi 2007, 2010). Therefore, the present study was undertaken keeping in view the economic importance of rice grasshopper, *Acrida exaltata* and to fill the gap between this region and rest of the world.

Chapter-3

Material and Methods

COLLECTION OF SPECIMEN

Grasshoppers are among the best insects to collect as they are commonly large, at least by insect standards, which makes them relatively easy to handle and identify. They vary in difficulty of collection, some species are easy to obtain whereas others require considerable searching or travel to a specific location in the state. The appropriate time for grasshopper collection was from the first week of May until third week of December from the various collection sites such as Srinagar, Ganderbal, Kokernag, Pulwama, Budgam, Baramullah and Bandipora that are predominantly vested to paddy, mustard, wheat and maize culture. Grasshoppers were also abundantly collected from different grass species by sweeping net, made of heavy white muslin cloth and was used with a sweeping motion to capture insects in crops, grasses or any other type of vegetation. *As they show saltatory type of locomotion,* sweeping the net through vegetation of paddy, mustard, wheat, maize and grasses catch many grasshoppers. Sweeping net is more durable and was thus recommended for such rough usage. After prolonged net sweeping, the insects collected from different sites were removed and desired specimens were placed separately in small jars measuring (20×10cms). The specimens thus collected in a jar were transferred to rearing cages (51×51×61cms) for the rearing purposes. Since *Acrida exaltata* is a large grasshopper, body size reaching up to 51.48 mm, the adult individuals were also be collected by hand picking method. However, the best method used for the collection of *Acrida exaltata* was sweeping net method. The collection of *Acrida exaltata* was started from first week of March but due to persistent rains till the end of April, no grasshopper could be located. It was the first week of May, 2012 when nymphs were collected from the grasses present in the mustard fields. Photographic plate **5** depicts the collection / sweeping net and collection jars. Single specimens were transferred more easily by lightly holding them in a fold of the net with one hand while inserting the open jar into the net with the other. The jars were covered with muslin cloth.

IDENTIFICATION

Identification of collected specimen were done by considering morphological characters. *Identification ranges from quite simple to requiring close, detailed examination, so there were various levels of challenge.* Based on the external morphological characters, the taxonomic classification of the collected specimen of grasshoppers can be given as;

Class : Insecta

Order : Acridoidea

Family : Acrididae (Macleay, 1821)

Subfamily : Acridinae

Genus : *Acrida* (Linnaeus, 1758)

Species : *exaltata* (Walker, 1859)

Tribe Acridini Latreille

DIAGNOSIS

Body usually slender; pronotum usually with median and lateral carinae; tegmina and wings fully developed; spurious median vein of tegmina usually absent; prosternal process usually absent; femoro tegminal stridulatory mechanism absent; hind femur without row of modified peg like structures at lower edge of inner surface; male with epiphallus bridge shaped having ancorae and lophi, aedeagus with basal apical valves connected by flexure.

Members falling under two sub tribes of Acridini are found in Kashmir.

Key to sub-tribes of Acridini found in Kashmir

1. Head strongly oblique; antennae ensiform; hind legs long and slender; epiphallus with bilobate lophi . . . . . *Acridina*.

1’Head slightly oblique; antennae usually filiform, rarely slightly ensiform; hind legs never very long and slender; epiphallus usually

with unilobate lophi . . . . . *Phlaeobina*.

In Kashmir, the sub-tribe *Acridina* is represented by *Acrida*, while *Phlaeobina* is represented by *Phlaeoba*.

Genus *Acrida* Linnaeus

Gryllus (*Acrida*) Linnaeus, 1758. *Syst. Nat*. (10th ed.), 1: 427.

Type-species: *Gryllus (Acrida) turritus* Linnaeus.

The identification at the genus level is based on following distinguishable characters

Large sized insects; body elongated, almost stick-like; head elongated, conical antennae ensiform, gradually tapering to the apex; fastigium of vertex projecting strongly in front of eyes; fastigial foveolae absent; frontal ridge narrow, shallowly sulcate; pronotum elongate, dorsum crossed by posterior transverse sulcus only, median and lateral carinae low, but distinct; tegmina and wings fully developed with acute or obtuse apex; lobes of hind knee with acute to obtuse apices, upper inner lobe slightly longer than external; arolium moderately large, shorter than claw; male with supra-anal plate triangular, cercus short, conical, sub genital plate conical, epiphallus with ancorae large, lophi bilobate; female with sub genital plate obtuse angular, weakly trilobite or almost truncate, ovipositor short, robust with robust and slightly curved valves.

The genus can easily be distinguished in having elongated stick-like body and conical head. The genus is represented by three species in Kashmir.

Key to species of *Acrida* found in Kashmir

1. Body greenish, lateral carinae of pronotum not clear with a black line . . . . . 2.

1’ Body yellowish, lateral carinae of pronotum clear with a black line . . . . . *Acrida gigantea* Herbst.

2. Tegmina without distinct coloured margin . . . . . *Acrida exaltata* Walker.

2’Tegmina with edges pinkish brown . . . . . *Acrida lugubris* Burr.

Acrida exaltata Walker

Various workers based on their study have named *Acrida exaltata* differently viz.

Truxalis exaltata Walker, 1859. *Ann. mag. nat. Hist*., 4(3):222.

Truxalis brevicollis Bolivar, 1893. *Feuille Jeunes nat*., 27(8): 162.

Acrida lugubris Burr.,1902. *Trans. R. ent. Soc. Lond*.,2:170.

Acrida curta Uvarov, 1936. *Linn. Journ. Zool*., 39:536.

The characters are same as described by Kirby (1914). The genitalic characters are as follows: Male sub genital plate long and pointed; female sub genital plate with posterior margin setose, dorsal valve of ovipositor shorter than lateral apodeme, spermatheca with apical diverticulum well developed, pre-apical diverticulum sac like.

Acrida lugubris Burr. (Junior synonymy of *Acrida exaltata* (Walker, 1859)

Acrida ligubris Burr., 1902. *Trans. ent. soc. Lond*., 157, 170.

It is a junior synonymy of *Acrida exaltata* Walker. However Kirby (1914) and Sharma & Gupta (1997) did not treat this as a synonymy of *Acrida exaltata*. The species was recorded from Kashmir by Kirby (1914) and Sharma and Gupta (1997) recently recorded it from Jammu region of the state.

REARING OF SPECIMEN

The grasshoppers collected by different methods were reared in laboratory. The rearing cages used during the study were made of wood with a wire mesh above the bottom of cage on which food for the grasshoppers was kept. Everyday new food was put in the rearing cages for the feeding purpose. Grasshoppers were fed with different plants. Sometimes only leaves were given and most of the times the whole plant was given as food. Food used to

feed the grasshoppers was thoroughly washed to remove any pesticides, shaked to remove water and then put vertically in the cage well away from the electric lamp. No excess water was put in the rearing cages as the grasshoppers got their water from the food. The size of the cages was 51×51×61 cms fitted with electric bulb. The cages were specially designed, fitted with temperature instrument and drawers for maintaining constant temperature and proper cleaning of faecal matter respectively. Removing of any uneaten food and waste was done regularly. A petridish of water covered with perforated wire gauge was kept in each cage and refilled as often as necessary to keep the humidity at desired level. Each of the cage used during the study could hold about 200 nymphs or 150 adults but the number was reduced to about 150 nymphs or 100 imagos in order to reduce mortality during moulting. The temperature of the cages was maintained between 25-30^0 C with 35-65% RH as the grasshoppers were less active at higher temperatures and high humidity respectively. The cages were placed near the light source, light was available for about 14 hours a day because grasshoppers needed to stay warm. Releasing of collected grasshopper specimens into the rearing cages was done with utmost care so that no specimen could be lost. These cages were having six inbuilt removable egg laying tubes. For the purpose of laying eggs, these tubes were filled with sand. The humidity in the egg laying tubes was kept more (70-80%) compared to cages, for optimum oviposition. The ratio of sand to water was kept 100:15 by volume to achieve a humidity of 70-80% for optimum oviposition. Sand was always kept moist but not soggy. The egg laying tubes after oviposition were removed and replaced by new ones. These egg laying tubes with egg pods were placed close to a heat source until the eggs in egg pods hatched. The grasshoppers were kept warm and dry in order to keep them healthy and encourage them to breed. These tubes were observed on daily basis for hatching. The grasshopper rearing room was made available from the insectary building of the department of Zoology, University of Kashmir equipped with proper rearing space, ventilation and natural light. Photographic plate **6** depicts the rearing cages and rearing of grasshoppers in rearing cages.

PREPARATIONS FOR MORPHOMETRICAL STUDIES

For the study of morphometrics Vernier's Digital calliper was used. A number of adult specimens of the *Acrida exaltata* (both males and females) were examined and morphometrical parameters viz. total body length (TBL), antennal length (AL), tegmen length (TL), tegmen width (TW), head length (HL), pronotum length (PL), pronotum width (PW), hind femur length (HFL) and hind tibial length (HTL) were taken and recorded. Also egg pod length, egg pod width, egg length, egg width, total number of eggs per pod were studied in detail. Photographic plate **7** depicts the Vernier's caliper and measuring some morphometric parameters.

PREPARATIONS FOR MORPHOLOGICAL STUDIES

Dry mounts were also prepared for better understanding of certain characters like size, colour, texture etc. For this purpose, the specimens were first relaxed, stretched and later they were pinned and labeled properly. Permanent collections of pinned specimens were kept in store boxes and cabinets for further studies on their morphological structures.

PREPARATION OF STUDIES ON EFFECT OF TEMPERATURE

To study the effect of temperature on development, grasshoppers were reared in cages under laboratory conditions. Cages with dimensions 51×51×61 cms having aluminium bottom and screen sides and top were stocked with 10 I^{st} instars, hatched within the last 24 hours. Newly hatched hoppers were kept in cages for observations on hopper development at 25^{o} C and 30^{o} C. Nymphs were provided with fresh food twice daily. Grasshoppers were monitored daily for moulting. Each day grasshoppers were counted and the number surviving and the number at each stage were recorded. The stage of any dead grasshopper was also recorded. Males and females were reared in separate cages.

EXPERIMENTAL SET UP FOR STUDIES ON FOOD PREFERENCES

Acrida exaltata, a polyphagous pest feeds on a variety of food plants. A laboratory study of food preferences of this grasshopper species of Kashmir region was carried out under laboratory conditions. Grasshoppers collected from different places had only morphological or taxonomical variations etc. Adults used in the experiments were collected from fields in Kashmir (Batpura, Nagam, Danwethpora, Plan Bandipora and other sites) and acclimatized in cages for laboratory studies. The insects were confined in wooden cages (51×51×61 cms). Halder's technique (1995) was adopted with some modifications. Vegetation was procured either from campus garden or from nearby fields. Green shoots were clipped and placed immediately into 50 ml conical flask filled with water. Each species of food plant was kept in a separate flask. *Cynodon dactylon* was used as a standard (control) against which the other five plants were compared. The grass was selected primarily because of its easy availability in the habitat of *Acrida exaltata.* For each set of experiments, the cage was supplied with six species of plants at a time, one sample each of the control plant and five others. A total of 50 adult grasshoppers which had been deprived of food for 24 hours were used for each set of experiments. After a few exploratory bites, the grasshoppers started to feed on selected plants within each choice test. Counts of grasshoppers feeding on plants were taken after three consecutive 5-minute intervals. After that, the positions of the plant samples were changed and counts were taken again.

SEASONAL VARIATION

Observations on the seasonal variations in population of *Acrida exaltata* were studied. Field observations were recorded on population dynamics of *Acrida exaltata* from January to December at fortnightly interval during the year 2012. The samples of hoppers and adults were obtained by net sweeping method. The collections were made in the afternoon for an hour from specific areas selected in the districts of Budgam and Srinagar. Meteorological records were obtained from the Metrological Department of India (Metrological

Centre, Rambagh complex, Srinagar) for Budgam and Srinagar stations. The number of individuals collected fortnightly in each month (January to December) were recorded.

PRESERVATION OF COLLECTED SPECIMEN

Grasshoppers normally are preserved by killing with chemicals. They can also be killed by exposing them to a small amount of toxic fumigant such as ethyl acetate or toxicants placed in conjunction with a specially prepared killing jar, best placed in alcohol to prevent excessive distortion (Lewis & Taylor 1965; Seber 1973; Barrowclough 1992). In the present study, the collected specimens of grasshoppers were preserved in 70% alcohol.

STATISTICAL ANALYSIS

Data obtained from experimental groups were subjected to one-way analysis of variance (ANOVA), (MS Exel 2007, PRIMER software) with repeated measures and significant means were determined using Tukey's Multiple Comparison Test (TMCT). Separate histograms for different temperature treatments, morphometrical parameters and polymorphism were produced using MS Exel. Line graphs of seasonal variations were also produced by same software. Food preferences were shown by both pie and radar charts using MS Exel.

PHOTOGRAPHY

Photographs during the study were taken using two types of cameras Nikon Coolpix L 23 and Sony cyber shot DSC-W620.

Collection sites in Srinagar

Collection sites in Budgam

Photographic plate 2

Collection sites in Ganderbal

Photographic plate 3

Collection sites in Pulwama

Collection sites in Anantnag

Photographic plate 4

Collection sites in

Collection sites in Bandipora

Photographic plate 5

Collection net / sweeping net

Collection jars

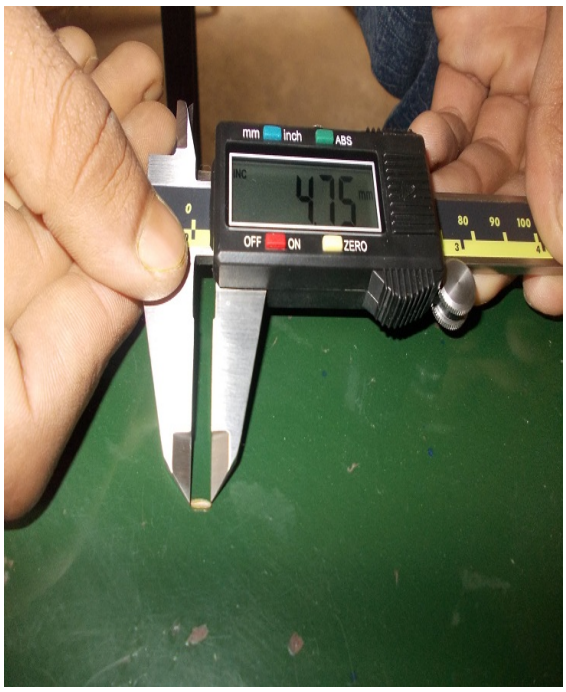
Photographic plate 6

Rearing cages for grasshoppers

Grasshopper rearing in cages

Photographic plate 7

Digital caliper used for morphometrical studies



Egg morphometrics.

Photographic plate 8

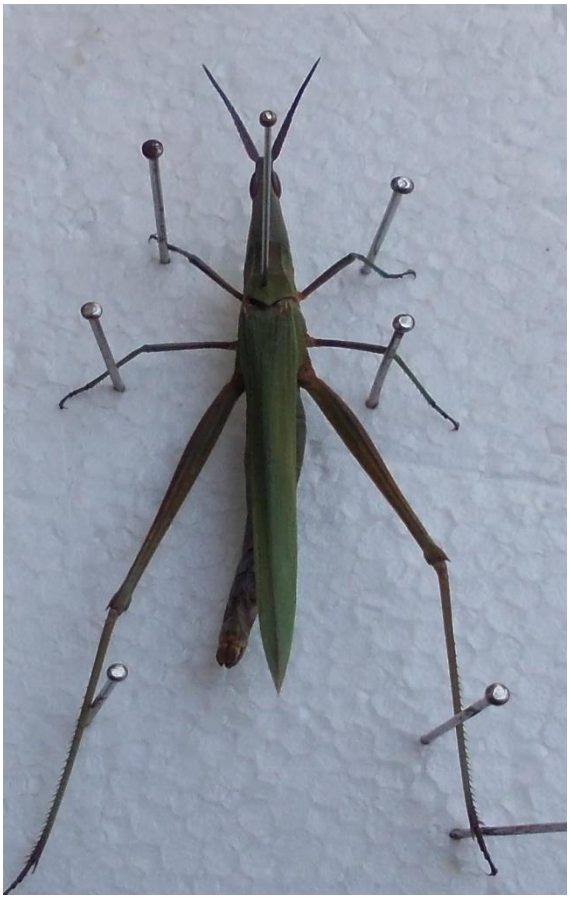
Egg pods

Egg pod opened to view eggs

Egg of *Acrida exaltata*

Photographic plate 9

Male **Female**



Male **Female**

Photographic plate 10

Green morph

Brown morph

Straw coloured morph

Photographic plate 11

Moulting

Feeding

Mating

Egg laying

Chapter-4

Results

ADULT

The adult of *Acrida exaltata* is generally green in colour, head and pronotum of equal length, tegmina obtusely pointed, scarcely longer than hind femora, wings yellowish hyaline, the cells in the posterior part cloudly in the middle, head conically ascending, fastigium broad, laminate and truncate at apex. Transverse sulcus of pronotum present about the middle of pronotal disc. Male sub genital plate comparatively long. Tegmina a little produced beyond the hind knee and hind wings slightly shorter than tegmina. The main distinguished feature of the *Acrida exaltata* found in Kashmir valley is that the tegmina is without distinct coloured margin. In Kashmir, the species was abundantly found in different fields having crops of importance like rice, maize, mustard, wheat and other grasses. The study was carried out for one and a half years (2011-2013) which revealed its abundance from June to October with least population in the months of November and December. No specimen of the species was collected during the months of January, February, March and April. Food and feeding observations showed its preference on succulent saplings and occasionally on stems.

LIFE CYCLE

Grasshoppers go through simple metamorphosis (i.e., egg, nymph, adult) and have chewing type of mouthparts. The species under study showed only one generation per year in Kashmir. Eggs were laid in the soil in autumn and these typically hatch the following spring. The eggs were laid in groups held together in a pod formed from a sticky secretion to which loose soil becomes bound. Eggs hatched in the spring depending on temperature. Immature grasshoppers called nymphs go through five larval instars before becoming adults. The nymphs are flightless but gradually develop small wing pads. Most adults are capable of flying great distances. This species has its own unique life history including habitat and food preferences. Grasshoppers are often depicted

as indiscriminate feeders; however, individual species like *Acrida exaltata* show marked preferences for certain kinds of food plants. The life cycle of *Acrida exaltata* was studied under both field as well as laboratory conditions, there was no marked difference in life cycle under natural and laboratory conditions, however, the laboratory reared specimens reached adulthood a few days earlier than field individuals. The individuals were reared at 25^0C to study their life cycle. The life cycle of *Acrida exaltata* started from first week of May i.e., eggs hatched during first week of May and upto end of the May almost all eggs hatched from overwintering eggs laid in the soil upto 2-3cms deep under natural conditions and in the sand filled egg laying tubes under laboratory conditions. The eggs were laid in egg pods which were light brown in colour measuring 11.96±1.83 mm in length and 4.29±0.34 mm in breadth. Each egg pod had a clutch of 13.1±2.02eggs. The eggs were yellowish brown in colour, each egg measuring about 4.65±0.24 mm in length and 1.052±0.28 mm in width. Photographic plate **8** depicts egg pods and eggs of *Acrida exaltata*.

There were five larval instars and emergence of nymphs from overwintering eggs depended upon a number of physical factors such as temperature, moisture and light. Adults mated during the months of September-October. Soon after mating, egg laying occurred. Due to the low temperature during winter months, eggs underwent diapause, so there was no movement of grasshoppers during these months. With the gradual increase in the temperature, hatching took place during spring season. Thus it was concluded that *Acrida exaltata* in Kashmir valley is univoltine i.e., only one generation of *Acrida exaltata* occurs throughout the year.

SEXUAL DIMORPHISM

Males and females of *Acrida exaltata* were conspicuously distinct. The females were larger in size measuring 51.48±2.49 mm in length while males were comparatively smaller measuring 32.05±0.88 mm in length. Morphometrical analysis of the various body parameters viz. total body length, antennal length, tegmen length, tegmen width, head length, pronotum length, pronotum width, hind femur length and hind tibial length of male and female

specimens of *Acrida exaltata* showed prominent differences viz. antennal length in case of females was measured to be 13.45±0.84 mm while in males it was 11.64±0.77 mm. Similarly tegmen length, tegmen width, head length, pronotum length, pronotum width, hind femur length and hind tibial length of female specimens were measured to be 41.20±2.23 mm, 4.27±0.38 mm, 13.39±0.55 mm, 9.33±0.47 mm, 4.87±0.14 mm, 28.54±0.85mm and 28.51±1.10 mm respectively while in males these were measured to be 25.92±2.29 mm, 3.26±0.17 mm, 8.94±0.42 mm, 5.25±0.29 mm, 2.69±0.24 mm, 19.96±0.98 mm and19.22±1.85 mm respectively (**Fig.1**). The 9 morphometric parameters of both males and females are discussed in the table **I**. The photographic plate **9** depicts sexual dimorphism in *Acrida exaltata*.

Table I: Morphometrical studies of adult males and females of *Acrida exaltata* walker, reared at 25^{0}C with 70±5% RH (10 replicates)

Morphometric parameters	Male	Female
Total body length (TBL)	**31.11-34.04** (32.05±0.883)^a	**48.34-54.80** (51.48±2.495)^b
Antennal length (AL)	**11.01-13.21** (11.64±0.771)^a	**12.50-14.98** (13.45±0.844)^b
Tegmen length (TL)	**23.18-30.01** (25.92±2.293)^a	**38.72-44.45** (41.20±2.238)^b
Tegmen width (TW)	**3.09-3.56** (3.26±0.177)^a	**3.36-4.80** (4.27±0.381)^b
Head length (HL)	**8.22-9.62** (8.94±0.424)^a	**12.80-14.44** (13.39±0.552)^b
Pronotum length (PL)	**4.80-5.82** (5.25±0.291)^a	**8.26-8.80** (9.33±0.471)^b
Pronotum width (PW)	**2.31-3.10** (2.69±0.245)^a	**4.58-5.10** (4.87±0.147)^b
Hind femur length (HFL)	**18.59-21.10** (19.96±0.984)^a	**27.28-30.15** (28.54±0.857)^b
Hind Tibial length (HTL)	**17.01-21.23** (19.22±1.859)^a	**26.75-30.18** (28.51±1.106)^b

Values within each row that do not share the same superscript are significantly different ($^{a\text{-}b}P<0.05$). The data was evaluated by one-way ANOVA followed by Tukey test to detect effect of temperature on development. Differences were considered to be statistically significant if $p < 0.05$.

POLYMORPHISM

The adults of *Acrida exaltata* exist in three colour morphs in Kashmir valley, the green morph, the brown morph and the straw coloured morph. The percentage of these morphs was estimated at different collection sites in different districts of Kashmir valley. The data revealed green morph was found in highest percentage at Nagam, Budgam (71%) while lowest in Bandipora (60%). The brown morph was found in highest percentage at Larr, Ganderbal (25%) and lowest at Danwethpora, Kokernag (13%). Straw coloured morph occurred in highest percentage at Bandipora (21%) while lowest at Nagam, Budgam (9%) as shown in table **II**. Moreover, during the study, green morph was found in abundance at all the sites in relation to the brown and straw coloured morphs.

Green morph : This morph had the general colour green all over. A pair of fairy wide pale brown streaks were running horizontally from tip of snout across pronotum and two thirds of elytra fading posteriorly into green. Legs greenish. Abdomen purple green both above and below; side green. Eyes with 3-10 olive to pale brown stripes. During the present study this morph composed 65% of total population of the species.

Brown morph : This morph had the same colour pattern as in the green morph but the green was replaced entirely by dark smoky brown, the brown of the green morph here was much darker. Eyes stripes greyish chocolate. The purple on lower abdomen almost absent replaced by pale brown. This morph composed 20% of the total population of the species in the valley.

Straw coloured morph : This morph had straw colour in general and a single brown band or two pinkish bands on the elytra. This morph composed of 15% of the total population of the species during the present study.

Fig. 2. Shows the relative percentage of three colour morphs of *Acrida exaltata*

at different study sites while photographic plate **10** shows its polymorphism

Table II: Polymorphism in natural population of *Acrida exaltata*

Sites	**Proportions in hoppers**			**Proportions in adults**		
	Green	**Brown**	**Straw coloured**	**Green**	**Brown**	**Straw coloured**
Batpora (Srinagar)				64	23	13
Nagam (Budgam)				71	20	9
Danwethpora (Kokernag)	No Polymorphism seen			67	13	20
Bandipora				60	19	21
Larr (Ganderbal)				63	25	12
Mean Percentage				**65**	**20**	**15**

EFFECT OF TEMPERATURE

Temperature played an important role in the development of *Acrida exaltata*. In general increase in temperature decreased the developmental period of hoppers and vice-versa. Newly hatched hoppers were kept individually in rearing cages (51×51×61 cms) for observations on hopper development (both males and females) at 25^{o}C and 30^{o}C, respectively. The mean development period for Ist instar larva (male) was 12.4±1.07 at 25^{0}C and 9.2±0.63 at 30^{0}C ($p < 0.05$). The mean development period for IInd instar larva (male) was 14.2±0.788 at 25^{0}C and 13.2±1.22 at 30^{0}C ($p < 0.05$). The mean development period for IIIrd instar larva (male) was 18.2±1.135 at 25^{0}C and 16.6±1.34 at 30^{0}C ($p < 0.05$). The mean development period for IVth instar larva (male) was

22.77±0.97 at 25^0C and 19.66±1 at 30^0C ($p < 0.05$). The mean development for V^{th} instar larva (male) was 16.22±1.20 at 25^0C and 12±0.86 at 30^0C ($p < 0.05$). The total development period in case of males was 96.01 days at 25^0C and 82.77 days at 30^0C. The mean development period for I^{st} instar larva (female) was 13.6±0.96 at 25^0C and 11.4±1.07 at 30^0C ($p < 0.05$). The mean development period for II^{nd} instar larva (female) was 17.6±1.34 at 25^0C and 12.2±1.22 at 30^0C ($p < 0.05$). The mean development period for III^{rd} instar larva (female) was 20.4±1.17 at 25^0C and 16.4±1.42 at 30^0C ($p < 0.05$). The mean development period for IV^{th} instar larva (female) was 25.33±1.32 at 25^0C and 21.66±1.22 at 30^0C ($p < 0.05$). The mean development period for V^{th} instar larva (female) was 19.11±0.92 at 25^0C and 17.33±1.22 at 30^0C ($p < 0.05$). Total development time in this study was 96.01 days and 111.15 days at 25^0C for males and females, respectively. At 30^0C, the total development time for males and females was respectively, 82.77 and 93.59 days. Minimum development time of 12.22±0.83 days were taken by V^{th} instar male to transform into the adult at 25^0C while at 30^0C in case males it was I^{st} instar which showed fast development. In other words, it took significantly 9.2±0.63 days to transform into II^{nd} instar. In case of females at 25^0C, I^{st} instar took the least time of 13.6±0.96 days to form II^{nd} instar while at 30^0C least development time 11.4±1.07 days was again taken by I^{st} instar. Among males and females subjected to two different temperatures, least development time was taken by I^{st} instar male (9.2±0.63 days) at 30^0C while the highest time taken during development was taken by IV^{th} instar female (25.33±1.32 days) at 25^0C (**Fig.3** and **Fig.4**). Both males and females were affected by the temperature significantly although to the different extent. Study revealed that temperature affected development process of males, females as well as hopper development period significantly. The results are summarised in tables **III** and **IV**.

Table III: **Effect of temperature on the development of male instars at 25^0C and 30^0C.**

Hopper instars	**AT 25^OC Males**	**AT 30^OC Males**
1^{st} Instar	**11-14** (12.4±1.07)^a	**8-10** (9.2±0.63)^b
2^{nd} Instar	**13-15** (14.2±0.788)^a	**11-15** (13.2±1.22)^b
3^{rd} Instar	**17-20** (18.2±1.135)^a	**14-18** (16.6±1.34)^b
4^{th} Instar	**21-24** (22.77±0.97)^a	**18-21** (19.66±1)^b
5^{th} Instar	**14-18** (16.22±1.20)^a	**11-13** (12±0.86)^b
5^{th} Instar-Adult	**11-13** (12.22±0.83)	**11-14** (12.11±1.05)

Values within each row that do not share the same superscript are significantly different ($^{a\text{-}b}P<0.05$). The data was evaluated by one-way ANOVA followed by Tukey test to detect effect of temperature on development. Differences were considered to be statistically significant if $p < 0.05$.

Table IV: Effect of temperature on the development of female instars at 25^0C and 30^0C.

Hopper instars	At 25^0C Females	At 30^0C Females
1st Instar	**12-15** (13.6±0.96)[a]	**10-13** (11.4±1.07)[b]
2nd Instar	**15-19** (17.6±1.34)[a]	**11-14** (12.2±1.22)[b]
3rd Instar	**19-22** (20.4±1.17)[a]	**14-18** (16.4±1.42)[b]
4th Instar	**23-27** (25.33±1.32)[a]	**20-24** (21.66±1.22)[b]
5th Instar	**18-20** (19.11±0.92)[a]	**16-19** (17.33±1.22)[b]
5th Instar-Adult	**14-16** (15.11±0.927)	**12-15** (14.6±0.86)

Values within each row that do not share the same superscript are significantly different ($^{a\text{-}b}P<0.05$). The data was evaluated by one-way ANOVA followed by Tukey test to detect effect of temperature on development. Differences were considered to be statistically significant if $p < 0.05$.

FOOD PREFERENCES

Most of grasshoppers started to feed within 10 minutes and most had stopped after an additional 30 minutes. Each choice test was repeated three times with fresh samples of grasshoppers and plants. The ranking of the preferred plants was determined by the numbers of grasshoppers feeding on each plant species and expressed as a value of the number of individuals feeding on a plant species compared with the number feeding on the control (*Cynodon dactylon*). Table **V** indicates that Rice *(Oryza sativa*) was most preferred, with mean acceptance value of 155.6% followed by Wheat (*Triticum aestivum*) with mean acceptance value of 113.3%. The leaves of Cauliflower (*Brassica oleracea var. botrytis*) were least preferred with mean acceptance value of 27%. The leaves of *Solanum melongena* were rejected with mean acceptance of only 2.66%. **Fig 5a** and **5b** elaborates the food preference of *Acrida exaltata* on different food plants.

Table V: Plants preferred as food by the Grasshopper, *Acrida exaltata*, in a laboratory study.

Food plants	Common name	Acceptability percentage		
		Exp. 1	Exp. 2	Exp. 3
Cynodon dactylon	Durba grass	100	100	100
Oryza sativa	Paddy	180	125	162
Zea mays	Maize	80	66	87
Triticum aestivum	Wheat	120	83	137
Brassica oleracea var. botrytis	Cauliflower	20	24	37
Solanum melongena	Brinjal	0	8	0

SEASONAL VARIATION

The number of individuals collected fortnightly in each month (January to December) are shown in the table **VI**. During field observations, it was found that the hoppers and adults were almost abundant during summer and autumn seasons. Hoppers were usually found in abundance during mid summer and adults during late summer and early autumn. Their abundance is due to availability of optimum ecological conditions particularly temperature, relative humidity and food for their development and other biological activities. Results from the table reveal that the population of *Acrida exaltata* was recorded almost zero during the months of January, February, March and April. This was due to non availability of favourable climatic conditions like temperature and due to lack of food. Besides, there were prolonged rains upto April which might have altered their biology. Copulation was observed in September and October. Soon after copulation, eggs were laid and due to low temperature during winter season, eggs underwent diapause and as such there was no movement of grasshoppers during winter months. With the increase in temperature, eggs hatched during the spring season. The first instar hoppers of *Acrida exaltata*

were collected during the first fortnight of May. **Fig. 6** shows seasonal variations in population of *Acrida exaltata*.

Table VI: Population count of *Acrida exaltata*

Year 2012	Temperature (^{0} C)			Collected Fortnightly			
	Max.	Mini.	Mean	Hoppers	Total	Adults	Total
January	9.4	-4.1	2.65	-		-	
	11.6	-4.5	3.55	-	-	-	-
February	10.5	-3.4	3.55	-		-	
	11.2	-2.5	4.35	-	-	-	-
March	20.8	1.2	11.0	-		-	
	20.6	1.5	11.05	-	-	-	-
April	23.1	1.7	12.24	-		-	
	24.10	4.5	14.30	-	-	-	-
May	26.7	6.5	16.60	**16**		-	
	25.0	7.0	16.0	**21**	**37**	-	-
June	29.20	8.9	19.05	**28**		-	-
	34.9	12.0	23.45	**31**	**59**	-	-
July	34.2	13.5	23.85	**49**		-	-
	34.0	15.5	24.75	**58**	**107**	-	-
August	34.7	14.5	24.6	**65**		**17**	
	33.5	13.1	23.3	**33**	**98**	**43**	**60**
September	32.4	11.2	21.8	**6**		**68**	
	31.8	9.8	20.8	**3**	**9**	**63**	**131**
October	29.50	6.4	17.95	-		**48**	
	23.5	-0.2	11.65	-	-	**26**	**74**
November	20.4	-1.5	9.45	-		**15**	
	17.8	-2.4	7.7	-	-	**11**	**26**
December	11.6	-5.5	3.05	-		**07**	
	10.6	-5.7	2.45	-	-	**05**	**12**

PEST STATUS

Acrida exaltata in Kashmir valley although, not a serious pest but can be a potential pest as at many study sites viz. Nagam and Kokernag damage was recorded more than usual. The main affected crops were rice, maize and wheat. So far no control measures have been applied for *Acrida exaltata* in Kashmir valley as its population was found to be regulated by its natural enemies (birds). Also damage done by *Acrida* was not found upto the economic threshold. As mentioned above it can become a potential pest if not regulated.

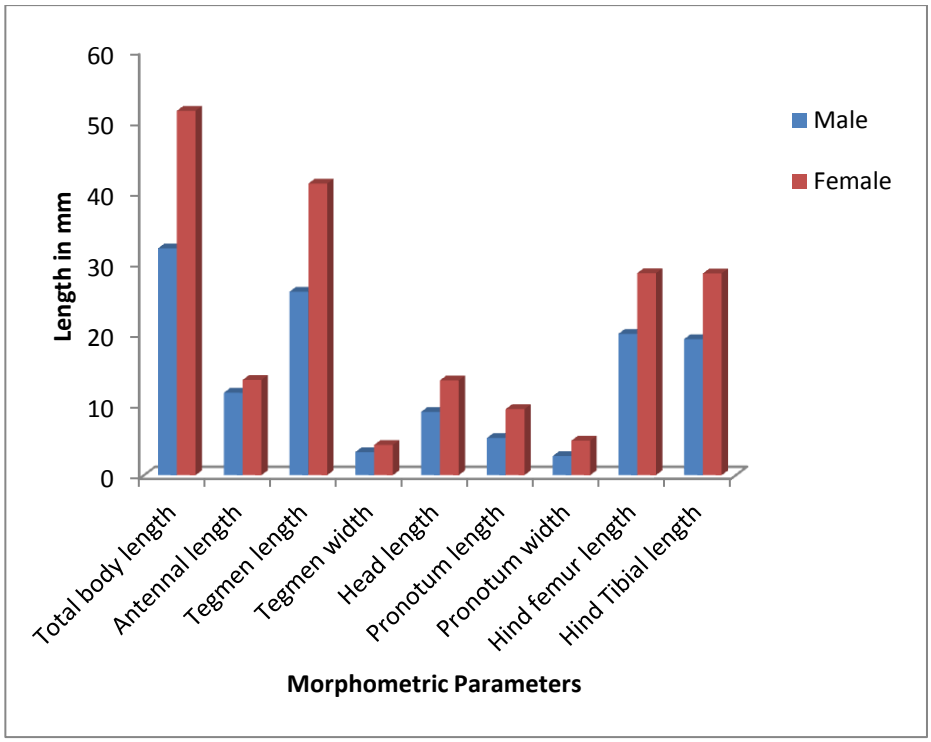


Fig 1: Morphometrical studies of different parts of *Acrida exaltata*

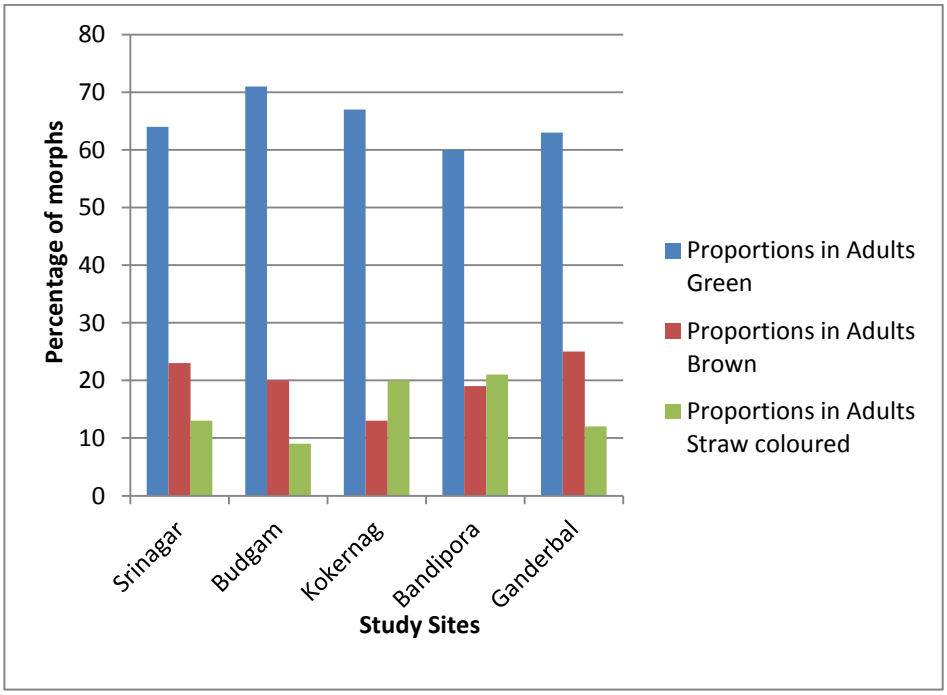


Fig. 2: Polymorphism in *Acrida exaltata*

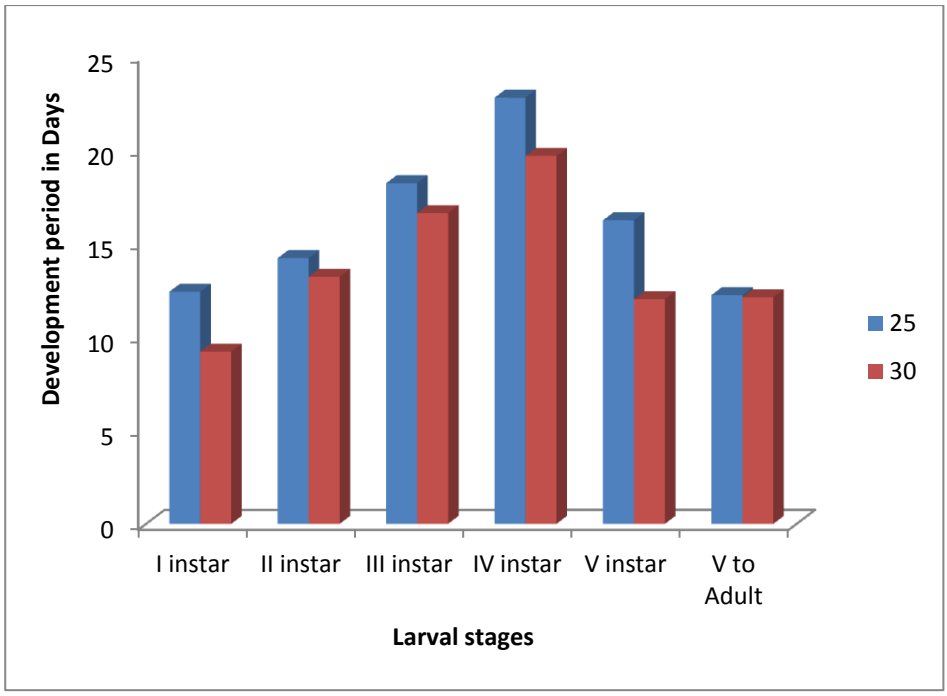


Figure 3: Effect of Temperature on development of Male instars

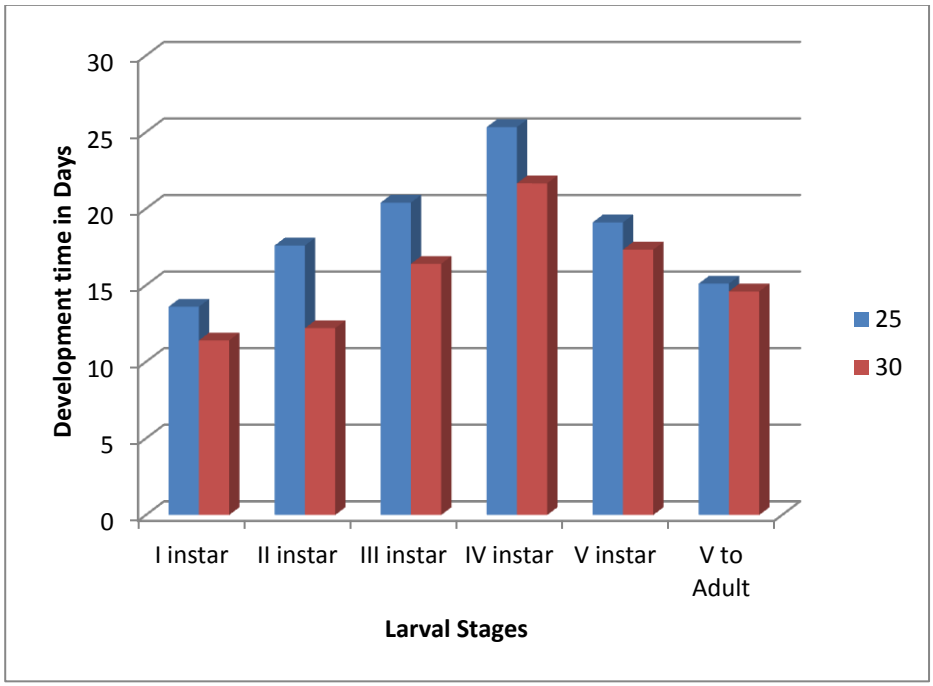


Figure 4: Effect of Temperature on development of Female instars

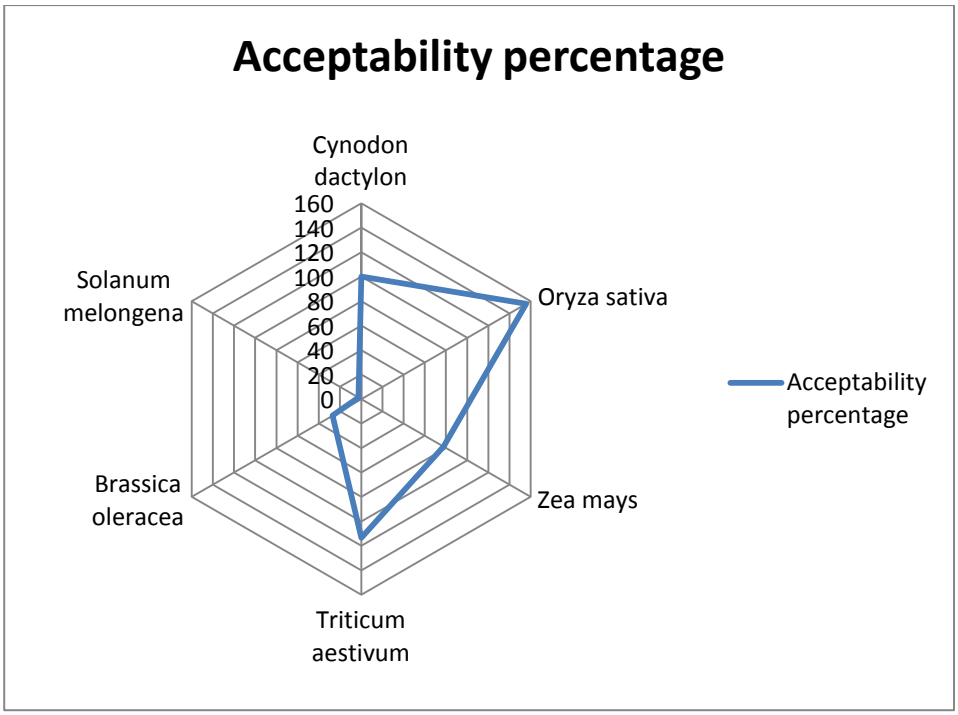


Fig 5a: Food preference of *Acrida exaltata* under laboratory conditions

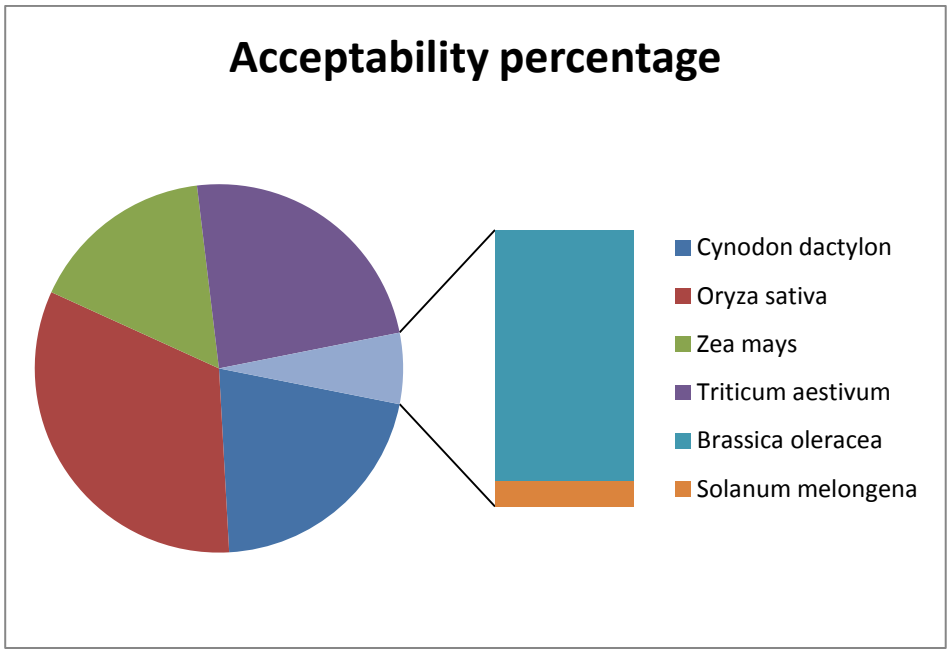


Fig 5b: Food preference of *Acrida exaltata* under laboratory conditions

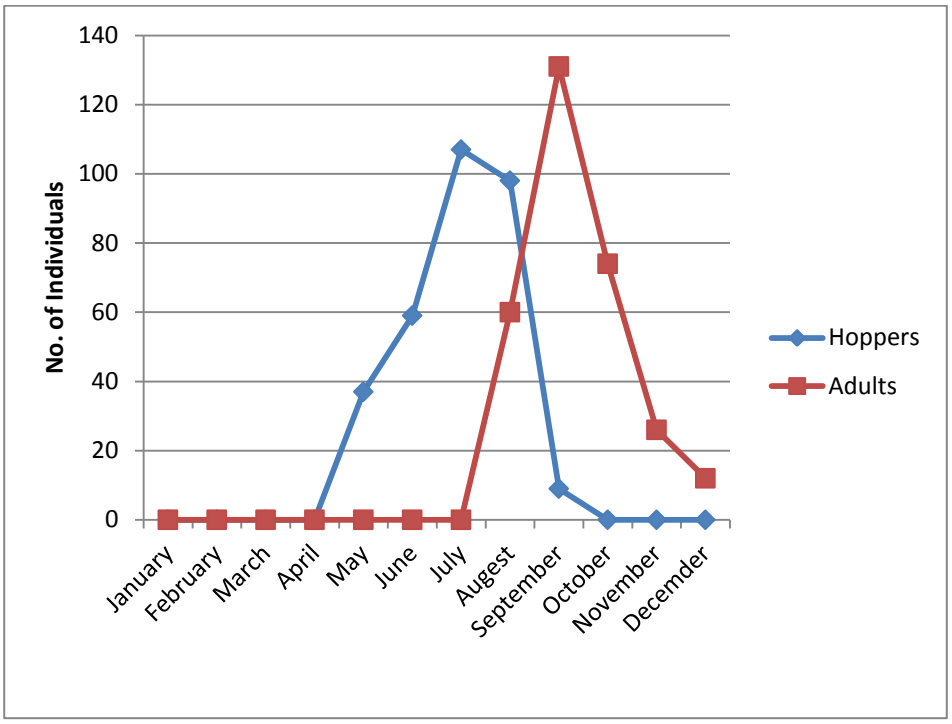


Fig. 6: Seasonal variations in population of *Acrida exaltata*

Chapter-5

Discussion

In Kashmir, the *Acrida exaltata* was abundantly found in different fields having crops of importance like rice, maize, mustard, wheat and other grasses. The study was carried out for one and a half years (2011-2013) which revealed its abundance from June to October with least population in the months of November and December. No specimen of the species was collected during the months of January, February, March and April. The results were in contrary to the results of Azim and Reshi (2010) who reported to have collected first instar hoppers of *Acrida exaltata* during first fortnight of April but during present study the first instar hoppers of *Acrida exaltata* were collected during the first week of May, the reason for the late emergence of *Acrida exaltata* could be attributed to long rainy season during the year 2012. The results were also contrary to Khan and Aziz (1973) and Susanta and Halder (1998) who recorded the occurrence of hoppers throughout the year. Food and feeding observations showed its preference on succulent saplings and occasionally on stems. The species under study showed only one generation per year (univoltine) in Kashmir. Eggs were laid in the soil in autumn and these typically hatch the following spring. The eggs were laid in groups held together in a pod formed from a sticky secretion to which loose soil becomes bound. Hatching of eggs in the spring depended on various factors especially food, temperature and moisture. Immature grasshoppers called nymphs go through five larval instars before becoming adults. The results were in contrary to the results of Ali (1982) who reported seven larval instars of *Acrida exaltata*. Nevertheless, the results in the present study were in conformity with the results of Ahmad and Nabi (2009) and Ahmad (2012) who also reported five larval instars of *Acrida exaltata*. The rearing of the species was carried out in laboratory in rearing cages. There was need to rear

grasshoppers because laboratory reared specimens are free of disease, whereas specimens from the field are often contaminated with different pathogens. A good supply of specimens was maintained all round the year without being dependent on field populations and thus, rearing was of utmost importance. Photographic plate **11** depicts different behaviours of *Acrida exaltata*.

Sexual dimorphism was shown by the species. Males and females varied in size, the males were smaller than females. Different morphometrical parameters were measured which revealed that males differ significantly from females. The results were in conformity with the results of Suhail *et.al.,* (1994), Ahmad *et.al*., (2007, 2008) and Usmani *et.al.,* (2012).

The adults of *Acrida exaltata* exist in three colour morphs in Kashmir valley, the green morph, the brown morph and the straw coloured morph. The percentage of these morphs was estimated at different collection sites in different districts of Kashmir valley. It was found that the green morph was abundant than other two morphs. Green morph constituted about 65% of the total population of the species followed by brown morph with 20% and least population was that of straw coloured morph with 15% of the total population. Our results were in conformity with the results of Singh (1977) and Roonwal (1977) who also reported the polymorphism in *Acrida exaltata*.

Temperature played an important role in the development of *Acrida exaltata*. In general increase in temperature decreased the developmental period of hoppers and vice-versa. Total development time in the study was 96.01 days and 111.15 days at 25^0C for males and females respectively. At 30^0C the total development time for males and females was respectively 82.77 and 93.59 days. Minimum development time i.e.,12.22±0.83 days were taken by V^{th} instar male to transform into the adult at 25^0C while at 30^0C in case males it was I^{st} instar which showed faster developmental period of 9.2±0.63 days to transform into II^{nd} instar. In case of females at 25^0C I^{st} instar took the least time 13.6±0.96 days to form II^{nd} instar while at 30^0C least development time was also taken by I^{st} instar with 11.4±1.07 days. Among males and females at both the temperature least development time was taken by I^{st} instar

male (9.2±0.63 days) at 30^0C while the highest time taken during development was taken by IVth instar female (25.33±1.32 days) at 25^0C. Both males and females were affected by the temperature significantly although to the different extent. Study revealed that temperature affects development process significantly. The results were in conformity with the results of Ali (1982) who also reported that increase in temperature decreases the developmental period. Abou-Elela and Hilmy (1977) also reported the same.

Acrida exaltata was recorded as a polyphagous pest feeding on a variety of food plants. A laboratory study of food preferences of this grasshopper species of Kashmir region was carried out. Laboratory conditions involved offering as food a total of five plant species viz paddy (*Oryza sativa*), maize (*Zea mays*), wheat (*Triticum aestivum*), Brinjal (*Salonum melongena*), cauliflower (*Brassica oleracea var. botrytis*) and a control Durba grass (*Cynodon dactylon*). It was observed that *Oryza sativa* was most preferred followed by *Triticum aestivum* while *Brassica oleraceae* var. *botrytis* was least preferred. The ranking of the preferred plants was determined by the numbers of grasshoppers feeding on each plant species and expressed as a value of the number of individuals feeding on a plant species compared with the number feeding on the control (*Cynodon dactylon*). Table **V** indicates that Rice *(Oryza sativa*) was most preferred, with mean acceptance value of 155.6% followed by Wheat (*Triticum aestivum*) with 113.3%. The leaves of Cauliflower (*Brassica oleracea var. botrytis*) were least preferred. The leaves of *Solanum melongena* were totally rejected. The results were in conformity with the results of Ahmad (2009, 2010, 2012) and Halder *et.al.*, (1995).

Observations on the seasonal variations in the population of *Acrida exaltata* were carried out. During field observations, it was found that the hoppers and adults were almost abundant during summer and autumn seasons. Hoppers were found in abundance during mid summer and adults during late summer and early autumn. Their abundance was due to availability of optimum ecological conditions particularly temperature, relative humidity and food for their development and other biological activities. Results showed that

the population of *Acrida exaltata* was recorded almost negligible during the months of January, February, March and April. This was due to non-availability of favourable climatic conditions like temperature and due to lack of food. Copulation was observed in September and October. Soon after copulation, eggs were laid. Due to low temperature during winter months eggs underwent diapause, so there was no movement of grasshoppers during winter months. With the increase of temperature eggs hatched during the spring season. The first hoppers of *Acrida exaltata* were collected during the first week of May. The results were contrary to the results of Azim and Reshi (2010) who reported that *Acrida exaltata* first hopper was collected during the first fortnight of April but during our study first hoppers of *Acrida exaltata* were collected during the first week of May. This could be attributed to prolonged rainy season in the months of March and April in the year, 2012.

Acrida exaltata in Kashmir valley is not a serious pest but it can be a potential pest, as at many study sites damage was recorded more than usual. The main affected crops were rice, maize and wheat. So far no control measures have been applied for *Acrida exaltata* in Kashmir valley as its population was found to be regulated by its natural enemies viz. birds (Myna). Usmani and Nayeem (2012) reported that *Eutrombidium trigonum* (grasshopper mite) parasitizes this grasshopper, however, this was not reported during the present study as the natural enemy of *Acrida exaltata*. Also damage done by *Acrida* was not found upto the economic threshold. However, as mentioned above, if not regulated in future it can become a potential pest, keeping the continuous biodiversity changes in concern like deforestation, rapid urbanization, pollution and other factors (decrease in population of its natural enemies) which actually can trigger its exponential growth and tremendous increase in its population, leading to voracious feeding on our cash crops like rice, maize, wheat etc and in turn economic losses.

Therefore, the present study was an attempt to observe the potentiality of short horned grasshopper, *Acrida exaltata* in three important cash crops viz.

rice, maize, wheat and conversely, their control measures. Further, no study in this direction (short horned grasshoppers) has been carried out in Kashmir and therefore, the present study can form a basis for controlling this pest species in future, when there are likely chances of outbreaks.

Chapter-6

Summary and Recommendations

The present study, "Studies on the bionomics of *Acrida exaltata* (Orthoptera: Acrididae) of Kashmir region" was carried out both under natural as well as under laboratory conditions. General parameters were studied in field while some of the parameters for in-depth study were taken in laboratory. The observations on seasonal variations in population of *Acrida exaltata* and studies on polymorphism were carried out in natural conditions. Parameters like effect of temperature on development of hoppers / nymphal instars and observations on food preferences were studied under laboratory conditions. Life cycle was studied both in laboratory as well as field conditions. Morphometrics was done with the help of Vernier's calliper.

Acrida exaltata is univoltine in Kashmir valley as it has only one generation. Life cycle starts when eggs hatch in the month of May. There are five larval instars. Adults appear in the months of August-September and start mating. Eggs are laid in October which undergo diapause till next spring. There are three colour morphs of *Acrida exaltata* in Kashmir valley viz. Green, Brown and Straw coloured. Sexual dimorphism is conspicuous. Temperature plays an important role in the development of *Acrida exaltata*. In general increase in temperature decreases the developmental period of hoppers and vice-versa. Albeit, *Acrida exaltata* is a polyphagous pest but it prefers certain food plants over others, significantly. Studies on seasonal variation

showed that hoppers were abundant during the month of July. No grasshopper specimens were seen during winter months. The present study revealed *Acrida exaltata* is not a key pest of our cash crops but has the tendency to become a potential pest in near future.

Recommendations:

- Extensive study of feeding, oviposition and mating behaviour is to be carried out in order to design different control strategies.
- There should be emphasis on the biological control by using natural enemies of *Acrida exaltata* to get efficient results and also restore the ecological balance. In case of severe infestation the chemical control can also be recommended to prevent heavy losses.
- Plant pest interaction has to be studied in detail to devise different methods so that the pest does not cause losses to the level of economic threshold.
- Mass rearing of *Acrida exaltata* can be done which in turn can be used as the feed for the poultry because this grasshopper species is rich in proteins and can prove a better feed than traditional soya bean feed.

Chapter-7

Conferences

1. 8th J&K Science Congress, 2012.
2. National seminar on science for shaping the future of India, Faunal Diversity- challenges and opportunities, 2012.
3. International conference on recent trends in climate change researches vis-à-vis Biodiversity, 2012.

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