In the beginning of this century, many workers became interested in studying the cytology of grasshoppers especially Acrididae because these insects have exceptionally large chromosomes which helped in the better understanding of the cytogenetical mechanisms in this group (Hewitt, 1979).

Pioneer work on the cytology of grasshoppers was done by McClung (1905) who studied the organization and the behaviour of the chromosomes in the germ cells. Since then Orthoptera especially grasshoppers have been considered as a classical material for karyological investigations. Hewitt (1979) reviewed the cytological work done on grasshoppers upto 1974. Many workers (Gallagher et al., 1973; Chatterjee, 1975; Kumaraswamy and Rajasekarsetty, 1976 a,b; Webb, 1976; Webb and Komarowski, 1976 Das et al., 1979) employed banding techniques also to study the structure of chromosomes in this group.

Acrididae, which comprises of about 9,000 species, is the largest orthopteran family. This family is extremely studied cytologically by McClung. In Tryxalis sp., McClung (1914) reported 23 rod-like chromosomes of various sizes arranged radially at the spermatogonial metaphase. Carothers (1917) studied the chromosomes of Trimerotropis sp. and reported the diploid chromosome number to be 23 in the males and 24 in the females. Robertson (1915, 1916, 1917a,b, 1925, 1930, 1931a,b) studied five orthopteran species namely Tettigidea parvipennis, Nomotettix, sp. Acridium sp., Paratettix sp. and Apotettix sp. and all these species were found to have the same chromosome number i.e. 13 in males and 14 in females. Robertson characterised the sex chromosome by its woolly appearance and divided the short-horned grasshoppers into two main groups: one with diploid number of 13 and 14 and the other with 23 and 24. During his studies on short-horned grasshoppers, he further observed that in parthenogenetically produced individuals, homologous chromosomes tend to separate while in bisexually produced individuals they tend to lie together.
Carothers (1931) investigated the multiple chromosomes, polyploidy and heteromorphic homologous chromosomes of family Acrididae. Based on these studies, he concluded that reduction and segregation are two distinct phenomenon. White (1935) studied the chiasma localisation in *Mecostethus grossus* L. and *Metrioptera brachyptera* and reported that chiasmata do not have even distribution with equal frequencies along the entire length of the meiotic chromosomes but they tend to be restricted to certain regions.

Carlson (1936) found an euchromosome which is characterized by its large size and deeply staining capacity in several closely related species of Acrididae i.e. *Chorithippus* sp.; *Curtipennis* sp., *Euchorthippus pulvinatus*, *Omocestus ventralis*, *Stauroderus biguttulus*, *Stenobothrus lineatus*, *Gomphocerus rufus* and *Aeropedellus clavatus*. This large sized, highly stained atypical chromosome was termed as a Megameric chromosome. King and Beams (1938) reported 19 chromosomes in the diploid cells of males and 20 chromosomes in females of *Paratylotropidia brunneri*.


Asana (1931, 1934) investigated the chromosomes of *Colemania* sp., *Chrotogonous* sp. (subfamily Pyrgomorphinae) and *Acrida exaltata* (subfamily Tryxalinae). According to him, the family Acrididae comprises 23 chromosomes
in the diploid cells of males with a single X chromosome. Chromosomes of tettigoniids were investigated by Asana et al. (1938) and later chromosome of more species of tettigoniids were reported by other workers (Dave, 1956; Kacker and Singh, 1978; Kumaraswamy, and Rajaskarsetty, 1979). In Elimaea securigera, Asana et al. (1938) reported that diploid chromosome number is 27 in males (26 AA + X) with all acrocentric autosomes and an X chromosome having a subterminal constriction.

Rao (1932a,b, 1934, 1937) investigated some species of Acrididae cytologically and reported 2n = 23 in subfamilies Tryxalinae, Acridinae and Oediopodinae. However, in the subfamily Pyrgormorphinae, the diploid number was found to vary from 17 in Aularches sp. and Chrotogonus sp. to 19 in Colemania sp. His findings were similar to those reported by Asana (1931) and he made a critical account of the chromosomal aberrations occurring in nature and those induced by X-rays.

Several workers reported the chromosomes of Indian Acrididae. 2n was found to be 23 in the males of Spathosternum prarsiniferum, Oxya sp. and Phloeoba sp. and Gesonia punctifrons (Raychaudhuri and Manna, 1950). Tetraploidy and polyploid nuclei were reported in Atractomorpha sp. (Raychaudhuri et al., 1955). In another species Thisiocetus pulcher, 2n = 22 with neo-X and neo-Y type of sex-mechanism has been reported (Raychaudhuri and Guha, 1952).

Dutt (1951) reported a sporadic case of tetraploidy in the spermatogonial stage in an Indian acridid, Oedaleus abruptus. The nuclei of this individual showed 44 chromosomes, two less than what was expected, suggesting either the overlapping of the missing ones or their loss during preparation. No possible explanation for the origin of such nuclei was suggested. Later, Dutt (1955) worked out some more species of grasshoppers of the Indian fauna, belonging to the
subfamilies Acridinae, Oedipodinae, Catantopinae, and Pyrgomorphinae and reported diploid chromosome number to be 23 in Acridinae, Oedipodinae and Catantopinae, while in Pyrgomorphinae the diploid number observed was 19 with subterminal constrictions.

Manna (1954) made a comparative study of the meiosis in 15 species of Indian grasshoppers belonging to different subfamilies viz. Acridinae, Oedipodinae, Catantopinae and Pyrgomorphinae of the family Acrididae. Except the Pyrgomorphinae, where \(2n = 19\), all others possessed \(2n = 23\). The course of the meiosis was stated to be normal. The chromosomal abnormalities in the form of anaphase bridges, fragments and supernumerary chromosomes were also reported.

Sharma et al. (1962, 1963, 1964, 1965 and 1967) investigated the chromosomes of *Chrotogonus trachypterus* and reported that in 75% of these insects, the chromosomal behaviour was normal and in remaining various types of abnormalities such as suppression of pachytene pairing, polyploid cells, anaphase bridges, translocations and unequal bivalents.

Manna and Chatterjee (1963) reported that in *Euprepocnemis* sp, some individuals have \(2n = 23\) including a single acrocentric X chromosome like all the grasshoppers and the others have \(2n = 22\). These workers further stated that the neo-X and neo-Y type of sex-determining mechanisms are very frequent in these grasshoppers. Similar findings have been reported in *Hypochlora alba* (King, 1950), *Mermeria* sp. (Mcclung, 1917; King, 1950), *Machaerocera mexicemia* (Helwig, 1942) and *Thisiocetrus pulcher* (Raychaudhuri and Guha, 1952).

Manna and Mazumdar (1967) investigated the chromosomes of several species of grasshoppers such as *Aidemona asteca* \((2n = 21)\), *Alineatus* sp. \((2n = 21)\) *Miramellia zubowskya* \((2n = 20)\) *Niitakacris* sp. \((2n = 21)\), *Dactylotum bicolor* \((2n = 20)\), *Moraba viatica* \((2n = 21)\) and *Tristria pulvinata* \((2n = 21)\) and
suggested that in all these species, one or two chromosomes lacking were because of two or three centric fusions. Centric fusions between X and an autosome also lead to the reduction of the chromosome number and formation of neo-X and neo-Y system. Further, the chromosomes lacking from the normal karyotype were referred to as degenerated (D) chromosomes.

Chromosomes of grasshoppers from Northern India were studied by several workers. Sharma et al. (1974 a,b) studied the chromosome behaviour of Tryxalis indica Thunb. Mittal and Soni (1977) studied the chromosomes in the male germ cells of Acrida exaltata Walker and Thisiocietus pulcher Bolivar (Acrididae). Handa and Pushpa (1987) reported the chromosomes of twenty one species of grasshoppers from Chandigarh region. Sharma and Dogra (1988) also reported the chromosomes of three acridoid grasshoppers. Yadav et al. (1981) reported the neo-XY system in Tryxalis indica Thunb. Yadav and Yadav (1983) studied the karyotypes of five species of grasshoppers. Later, Yadav and Yadav (1986) reported the chromosome number and sex-determining mechanism in thirty species of grasshoppers. In addition to these, distribution of C-heterochromatin in seventeen species of grasshoppers was also reported by these workers (Yadav and Yadav, 1993).

All natural populations of grasshoppers are endowed with some kind of variations at the chromosomal level and these are either structural or numerical. Role of chromosomal change in evolution is still controversial, despite the fact the karyotype of well over 6,000 species have been studied (White, 1973). The spontaneous fusion of two acrocentric chromosomes in the region of their centromeres to form one metacentric chromosome is called `Robertsonian' change and this has been reported in several cases. Similarly centromeric fissions also account for many of the changes in chromosome number in the evolution of the
orthopteran karyotype, particularly in Acridoidea (White, 1969). The phenomenon of centric fusion is discussed in relation to the process of 'Karyotypic Orthoselection' according to which there is a tendency for similar structural changes to establish themselves in one member of the karyotype (White, 1975) and this has been observed in a number of organisms particularly in the grasshoppers. The phenomenon of orthoselection in Orthoptera could be due to prevalence of polarised exchanges (Westerman, 1968; Yadav and Yadav, 1982).

In natural populations of Orthoptera, a large number of cases have been reported to show the chromosomal variations within and between the species. Inversions, translocations, centric fusions and fissions, sex chromosome rearrangements, supernumerary chromosomes are the categories of the chromosome variations reported. The factors which determine the course of evolution of a chromosome mutation may be genetical, chromosomal, populational, ecological and geographical in nature (Hewitt, 1979).

Acridoid grasshoppers exhibit most of the chromosomal anomalies (White, 1973). Due to environmental changes, the karyotypic variability within a species with regard to chromosomal morphology and number, is likely to occur resulting in the production of chromosomal rearrangements. In nature, the genic balance is maintained by elimination of harmful mutations and selection of useful ones which are retained and incorporated into the genetic system (Yadav and Yadav, 1989).

Various chromosomal anomalies such as suppression of pachytene pairing, anaphase laggards and anaphase bridges, unequal bivalents, supernumerary chromosomes, polyploidy, chromosome breakage and understained regions have been reported in *Chrotogonus trachypterus* Blach. by Sharma *et al.* (1962, 1965). Many other chromosomal anomalies have also been reported in many natural populations of grasshoppers from India (Manna, 1954; Rajassekarsettty, 1969; Sharma *et al.*, 1974; Yadav and Yadav, 1982).
McClung (1928) observed the 'ditactic bivalents' in *Stethophyma* sp., which are due to the stickiness between heterochromatic blocks. Both these homologues lie parallel to each other on the spindle equator and are closely associated near their centromeres. Their association has been interpreted differently by several workers. McClung (1928) reported a chiasma in the short arm of one of the small bivalent in *S. gracile* and similar finding were reported by White (1973). However, the ditactic M₆ bivalent in *Stethophyma* sp. (Shaw 1970, 1971) are clearly not associated in the short arm but in the long arm proximal to centromere where there is large block of heterochromatin. This association does not appear at all chiasmata.

John and Hewitt (1968) reported the centromeric chiasmata in *Chorthippus parallelus*. Ditactic bivalents have also been reported in *Trimerotropis pallipedipennis, Chloroplus cactocaetes* (White, 1973), *Oedalenonotos orientis* (Hewitt and Schroeter, 1968). Fontana and Vickery (1974) also reported the ditactic associations in the M₄, M₆ and M₇ bivalents of *Stethophyma gracile* and *Stethophyma lineatum*, which were proximal to or in the centromere.

White (1940a) recorded nonhomologous heterochromatin association in a long-horned grasshopper, *Metrioptera brachyptera*. Such an association is not a unique feature of this grasshopper, as the process has been discussed in a number of plants and animals (Slack, 1938; Schroder, 1941; Verma, 1954; Li and Jackson, 1961; Koul, 1964).

A trisomic aneuploid individual in *Mecostethus grossus* was reported by Callan (1941). In this species, the third largest autosome was represented three times instead of twice. There were 23 autosomes and a single X chromosome instead of normal 22 autosomes and a single X chromosome and was, therefore, referred to as trisomic aneuploid.
Power (1942) reported that in the chromosomes of Acrididae, the long chromosomes have been the recipient of chromatin from other elements, so that a portion of genetic material was duplicated. He concluded that the short chromosomes were not the results of deletions which had supplied the genetic material to the larger components but they represented short primitive chromosomes of the original stock. No significant variation in karyotypes of individuals collected from different colonies was observed by him. The mechanism held responsible for the production of such rearrangements involves the deletion of a minute portion from one chromosome and its subsequent incorporation into the other element.

Ris (1945) gave an account of the lampbrush type of processes in Chrotophaga viridifasciata. Ris (1949) further reported two independent factors i.e. shortening of the spindle fibre on one hand and the elongation of the spindle fibres on the other were responsible for the anaphase movement of chromosomes in different species of grasshoppers such as Chrotophaga viridifasciata, Dissosteira carolina, Melanoplus femur-rubrum, Arphia xanthoptera, and Hippiscus sp.

In different populations of Trimerotropis sp., White (1948, 1949) observed normal rod-shaped elements as well as those having centric fusions resulting in the formation of Vs. Such chromosomal variations were also reported in Trimerotropis maritine and Trimerotropis citrina. In one individual of Trimerotropis latifasciata, he recorded a V-shaped supernumerary chromosome which was reported to be responsible for the formation of unequal bivalents.

According to Coleman (1948), in Trimerotropis gracilis sordida and Trimerotropis suffusa, the zygotene-pachytene stages were heterozygous for centromeric shifts and showed normal synapsis with no sign of reverse pairing loops. He further concluded that these shifts were caused not by pericentric
inversions but either by an intrachromosomal translocation of the centromeric region or by the organisation of a centromere in a different position. White and Nickerson (1951) gave an account of the presence of certain heterochromatic segments in three small pairs of autosomes in two species of the genus *Pedioscirtes* i.e. *P. navadensis* and *P. maculipennis*.

In *Circotettix undulatus*, presence of two chromosomal races were reported (Evans, 1954), one with $2n=21(0)$ and the other with $23(0)$ having the interspecific hybrid with $2n=22(0)$. Occurrence of supernumeries (1 to 3) and polyploid cells was also reported in this species.

White (1954) reported presence of procentric chiasmata in *Bryodema* sp., which is an unusual feature of grasshoppers. White (1956) reported chromosomal polymorphism in *Moraba scurra*, which was observed to have two chromosomal races: one with $2n = 15$ and the other with $2n = 17$ in the males. The difference in the chromosome number was suggested to be due to the dissociation of a large metacentric chromosome.

Lewis and John (1959) reported the occurrence of non staining gaps in Acridid meiosis. These gaps indicate the genetic imbalance rather than the structural heterozygosity. Henderson (1961) reviewed the chromosomes of British *Tetrigidea*, namely *Tetrigidea undulata*, *Tetrigidea ceproi* and *Tetrigidea subulata* and reported $2n = 13$ in males. Sex chromosomes appeared distinct despite the small size of leptotene-zygotene nuclei. The diplotene stages were extremely diffused and in addition to these, polyploidy, occurrence of supernumerary chromosomes and the failure of pairing were also observed. White (1963, 1966) studied the cytogenetical mechanisms in grasshoppers *Moraba scurra* and *M. virgo* of Australian population.

Henderson (1962) studied the effect of increased temperature and reported that this resulted in the induction of univalence in *Schistocerca gregaria* which has
According to him, the higher temperature also affected the spiralization of chromatin and the centromeric orientation as well.

John and Hewitt (1963) observed an extensive chiasma formation in an interstitial chromosomal segment in *Chorithippus brunneus* as a result of which there was a spontaneous interchange in the chromosomes. Carothers (1963) suggested that in *Trimerotropis sparsa*, chromosomes other than the regular centromere might take up spindle fibre activity to produce an apparent centromeric shift. John and Lewis (1965) reported unequal chromatids in *Euprepocnemis plorans* as a consequence of dicentric bridge formation. Fox (1966) studied the chromosomal aberrations and further reported that stickiness is a pathological condition which has no evolutionary significance.

Lewis and John (1967) studied the meiotic consequences of spontaneous chromosome breakage. Anomalies like asymmetrical bivalents, dicentric bridges, acentric fragments, bivalents with half chiasma and side arm bridges were supposed to be constituting a common meiotic syndrome which can be explained in terms of spontaneous breakage and translocations. Associations of the syndrome with meiosis suggested the possibility of the breakage-exchange patterns reflecting errors in chiasma formation.

White (1974) reported that in morabine grasshoppers, 22 evolutionary changes of chromosomes occurred due to dissociation and 39 changes occurred due to fusions. In the natural population of these grasshoppers, the peculiarities observed are instability of chromosome number and behaviour during mitosis and meiosis, one or more supernumerary chromosomes, tetraploidy, octaploidy, aneuploidy (monosomic and trisomic), non-disjunction of homologues, synapsis, formation of separate micronuclei by the sex chromosome and the spermatogonial telophase.
John and Hewitt (1968), while discussing the pathways of chromosomal evolution in Orthoptera, stated that the chromosomal rearrangements which played a great role in chromosome evolution were principally exchanges in which parts of chromosomes or chromosomes themselves establish a spatial relationship. Further, these workers presumed that such arrangements were secondary events which followed from the primary production of chromosomal breakage, a process leading to the formation of unstable fracture sites which were available for exchanges. They strongly supported the existence of telocentric chromosomes. Earlier Lima–De–Faria (1956) demonstrated the presence of telocentric chromosomes in *Stethophyma grossus*.

White (1970) analysed the karyotypes and meiotic mechanisms of chromosomes in Eumastacid grasshoppers from East Africa, Madagascar, India and South America. Earlier, White (1965) while working out subfamilies Thericleinae and Pseudochinidiinae reported that karyotypic variation or deviation in these two subfamilies were much less than those in Morabine grasshoppers. However, findings in case of Thericleinae were very interesting as in these there was cryptochiasmate type of synapsis of the homologous chromosomes.

A relationship between the presence of heterochromatin and chiasma location has been reported according to which the variation in the chiasma location can appear as a result of polymorphism for C-heterochromatin (Fox et al., 1973; Klasterska et al., 1974; Morgan, 1978).

According to Bender et al. (1974), the target for all chromosome aberration production is the DNA, suggesting that the chromosome aberrations are the result of lack of repair, partial repair or mispair of damage to DNA. Extra segments leading to unequal bivalents and chromatids may be as a result of translocation of autosomal material such as in *Tristria pulvinata* (Yadav and Yadav, 1982). This exhibits a loss of chromatin material to account for the additional segment or due
to translocation of some part of supernumerary chromosome. Origin of unequal chromatids through reciprocal translocations has been reported in *Acrida lata* (Sannomiya, 1968).

Various cases of polymorphism, involving the occurrence of additional heterochromatic segments, which are accompanied by a radial distribution of chiasmata within the bivalents have been reported in *Atractomorpha similis* (Micklos and Nankivell, 1976; John, 1981) and *Gomphocerus sibiricus* (Gosalvez and Lopez- Ferrandez, 1981). These heterochromatic segments are distally located in *Atrctomorpha sibiricus* and proximally located supernumerary segments are observed in *Heteropternis obscurella* (John and King, 1982). Fixed distal heterochromatic blocks are observed in *Cryptobothrus crysophorus* (John and King, 1980).

Brogger (1979, 1982) hypothesised that chromosomal breaks and fragments have their origin in misrepair or unfinished repair of DNA. He further classified the chromosomal gaps into 'clastogenic' and turbagenic' types. The former appear due to an alteration in the first stage of chromatin condensation involving DNA damage and the latter is caused by disturbance in a later stage of chromosome fibre folding. Ramussen and Holm (1980) stated that the breakage and reunion of trapped non-homologues during zygotene causes decline in the number of interlocking bivalents.

Camacho *et al.* (1981) studied the chromosomal rearrangements and karyotypic evolution in Decticinae and discussed that the variation is principally caused by chromosomal rearrangements such as centric fusions and pericentric inversions. Yadav and Yadav (1982) reported the spontaneous chromosome mutations viz. non-staining gaps, unequal bivalents, unequal chromatids, bridges, supernumerary chromosomes, stickiness and clumping, despiralization,
multivalent associations and polyploid nuclei in a wild population of *Tristria pulvinata* Uvarov.

Single pair mating studies of the grasshopper *Atractomorpha similis* (2n = 19, 20) showed that in the progeny, three families out of eleven showed a tendency towards chromosome fusions. This fusion syndrome has a transmissible tendency towards centric fusion (Peters, 1982). Gosalvez et al. (1982) observed a spontaneous interchange which breaks in the centromeric regions of the L₂ and L₃ submetacentric chromosome pair, using the C-banding technique in a male of the mountain grasshopper *Gomphocerus sibiricus* (2n = 17). The interchange was present as a ring of four and concordant separations during anaphase I in the cells of hundred follicles of the mutant. However, a single follicle was found where a chromosome had split resulting in two telocentric chromosomes. The appearance and properties of meiotic configurations produced by a heterozygous interchange depend on the morphology of the chromosomes (Brunham, 1956; John and Lewis, 1965, 1968; Sun and Rees, 1967; Vosselman, 1981). They further added that frequency of chiasmata in multivalent and the orientation and segregation of the chromosomes are affected by the size of the interstitial segment and the position of the point of interchange.

Vilardi (1984) analysed the karyotype and meiotic behaviour of the chromosomes in two Argentine populations of *Staurorhectus longicornis*. Basic karyotype in this species is found to have 23 telocentric chromosomes in males (22 autosomes + X). Chromosomal variations in the form of centric fusion, pericentric inversion, elastic constriction and supernumerary segments have also been observed.

Yadav and Yadav (1984) reported the reduction in the diploid chromosome number in the karyotype of a North Indian grasshopper *Paraconophymak kashmiricum* Uvarov. The reduction from 2n = 24 (XX) to 22 (XX) in *P.*
**kashmiricum** is supposed to be due to two centric fusions between the two original acrocentric autosomes.

Bhunya and Das (1985) studied the somatic chromosomes of two Indian Gryllids namely *Plebeiogryllus gultiventris* (Walker) and *Medicogryllus confirmatus* and reported the chromosomal aberration in only one male of *Plebeiogryllus gultiventris* (walker). In this species, chromatid break in X chromosome, isochromatid break and chromatid gap in autosomes were observed.

John and King (1985) studied the distribution of chiasmata and the effect of the presence of the polymorphic heterochromatic blocks or segments in seven grasshopper species. In six of these species, (*Cryptobothrus crysophorus, Trimerotropis bilobata, Calliptamus wattenwylianus, Arcyptera fusca, Pezotettix glorni and Acrotylus insubricus*), the polymorphic heterochromatic segments were terminally located and their presence made the radial redistribution of chiasmata and in only one species *Oxya japonica*, both polymorphic and fixed blocks were present. The polymorphic blocks made the chiasma redistribution radial while fixed blocks were found incapable in producing such effect.

Yadav and Yadav (1985) reported that the frequent clumping and stickiness of the chromosomes occur after the treatment with mutagens. Yadav and Yadav (1989) reported chromosomal aberrations in the natural populations of six species of grasshoppers viz. *Hieroglyphus nigrorepletus* Bol., *Oxya hyla hyla* Serv, *Spathosternum prasiniferum* Walk., *Gelastorrhinus filatus* Walk., *Ceracris deflorata* Walk., and *Chrotogonus trachypterus* Blanch. Various chromosomal anomalies recorded were polyploidy, interlocking of bivalents, multivalent associations, translocations, chromatid gaps and breaks, unequal bivalents and chromatids, precocious coiling, anaphase bridges, stickiness and fragmentation. Yadav and Yadav (1993) further reported the distribution of C-heterochromatin in
seventeen species of grasshoppers. These studies showed that the number and the location of C-bands in Acridoidea exhibit both intra and interspecific variations.

Yadav and Yadav (1996) reported the karyotypic diversity in catantopine grasshopper *Tristria pulvinata* Uvarov. There were five different karyotypes having diploid numbers as 23, 22, 21, 20 and 19 in male. The variation in chromosome number was observed in both germ cells as well as in somatic cells. The nature, behaviour and origin of degenerated (D) Chromosome during cell division has also been investigated by these workers. They further added that the karyotypic diversity observed in this species is due to the gradual elimination of D chromosomes, tandem fusions, polysomy producing a type of supernumerary variation and occurrence of simultaneous rearrangements.

Populations of many species of Orthoptera have individuals with chromosomes that are additional to the regular diploid complement and can be differentiated (Hewitt, 1979). These chromosomes have been given various names such as 'heterochromosomes' (Stevens, 1908), B-chromosomes (Randolph, 1928) and accessory chromosomes (Melander, 1950). Battalgia (1964) recorded as many as 15 names from literature for such chromosomes. These chromosomes do not pair with standard chromosomes and have no phenotypic effect on the individual as previously believed but in recent years a variety of effects of supernumerary chromosomes on quantitative characters have been recorded in plants and animals including chiasma formation, rate of development, morphology and fertility. Chiasma formation is affected by supernumerary chromosomes in a number of species, whilst in others no change can be detected (Schroeter and Hewitt, 1974). Such modifications may be due to change in chromosome replication and condensation of the supernumerary chromosomes.
According to white (1973) there are four categories of supernumerary chromosomes, which are reviewed by Hewitt (1979). According to first type, there are large heterochromatic chromosomes found in a number of grasshopper species. In the second type, the B-chromosomes are small and are similar in size and shape to the smaller members of the complement. These are frequently but not invariably heterochromatic and unstable. Third category is of dot-like supernumerary chromosomes. These, being so small, must be deletion products of the regular members of the complement or larger existing supernumerary chromosomes, containing a minimum functioning centromeric region. The fourth category of supernumerary chromosomes is a heterogenous collection, but it is distinguished by isochromosome chromocentre. The centromere is median or near median and the two arms pairing to form a ring in some cases has been shown to be chiasmate.

Evans (1954) reported the occurrence of the supernumerary chromosomes in Orcottettix which has two chromosomal races with 2n=21 and 2n=23 and an interspecific hybrid having 2n=22. Nur (1963) carried out detailed studies on supernumerary chromosomes and observed that the variation in their number was due to non-disjunction in early meiotic germ line. John and Hewitt (1965) reported the variation in the structure of supernumerary chromosomes within the species in Myrmeleotettix maculatus.

Jackson and Cheung (1967) reported distortional meiotic segregation of the supernumerary chromosomes in Phalacridium cirtatum. According to these workers, there is no morphological variation with the carriers of supernumerary chromosomes. They recognised the presence of supernumerary chromosomes at diplotene due to the strong heteropycnosis. Nur (1969) reexamined Camnula pellucida and Locusta migratoria cytologically and observed mitotically unstable supernumerary chromosomes in both species confirming the findings of Itoh.
(1934) and observed that supernumerary chromosomes in *Calliptamus palaestinensis* were mitotically unstable and underwent non-disjunction in early mitosis of the germ-line, thus increasing their frequency. This preferential segregation was termed as an accumulation mechanism.

Fox *et al.* (1974) found that supernumerary chromosomes are usually heterochromatic in meiotic prophase of *Myrmeleotettix* sp. and this is generally coupled with late replication of DNA in the premeiotic S phase and reduced RNA transcription.

Variation in the structure of supernumerary chromosomes in *Chortoicetes terminifera* was reported by Webb (1976) and Webb and Neuhaus (1979) which appear as a result of differences in the meiotic behaviour of the supernumeraries. Cabero *et al.* (1986) studied the effect of eight different supernumerary chromosomes in grasshopper *Chorthippus binotalus* on nucleolar organiser regions and reported that the presence of extra chromosomes in their vicinity affects the normal functioning of NORs, resulting in an increased transcription of ribosomal DNA presented in NORs.

Umadevi and Aswathanarayana (1987) reported a supernumerary chromosome system in a wingless grasshopper *Orthocris* sp. In this species, diploid chromosome number in males is 19 (18+XO) and all the chromosomes are acrocentric. The X chromosome is the largest of the complement and the supernumerary chromosome is the smallest of the complement. Yadav and Yadav (1990) reported the presence of supernumerary chromosomes in eight acridoid species and found that their number varied from 1 to 4 in different species and these appear as dot shaped or small, medium and large in size. Supernumerary system in *Eyprepocnemis plorans* is studied in details by many workers (Camacho *et al.*, 1980, 1984; Henriques *et al.*, 1983 and Henriques and Arana, 1990).
Santos et al. (1993) studied the meiotic behaviour of supernumerary chromosomes in *Omocestus burri* and reported that supernumerary chromosomes do not accumulate in male germ line but their accumulation occur in female germ line. Pardo et al. (1994) studied the transmission of mitotically unstable supernumerary chromosomes of *L. migratoria*. These workers showed that supernumerary chromosomes are significantly eliminated during sexual transmission in case of males. On the other hand they are significantly accumulated in females presumedly by their preferential migration to the secondary oocyte during the first meiotic division.

Nucleolar organizer regions (NORs) are the areas of chromosomes that carry clusters of DNA coding for ribosomal RNA and the chromosomes that have these NORs are referred to as nucleolar chromosomes (Busch, 1974). NORs have been reported in a number of species of grasshoppers (Czaker, 1978; Garcia de la Vega et al.; 1982; Rufas and Gosalvez, 1982; Rufas et al., 1985; Cabrero et al., 1986). From India, Yadav and Yadav (1985) reported the location of NORs in seven species of grasshopper viz. *Aloolopus thatassinus* Fabr. (Tryxalinae); *Oedaleus abruptus* Thunb., *Gastrimargus transversus* Thunb, *Heteropternis respondens* Walk. (Oedipodinae), *Praahieroglyphus biliniatus* Bol., *Spathosternum prasiniferum* Walk. (Catantopinae) and *Atractomorpha crenulata* Fabr. (Pyrgomorphinae).

The sex determination mechanism in grasshoppers is generally of XX-XO type. However, McClung (1917) reported both XO and neo-XY mechanism in *Hesperotettix viridis*. At present, numerous instances of transformation of XX:XO to XX:XY system of sex determination during the course of evolution have been reported which probably occurred due to centric fusions of acrocentric X of an
Koller (1940) reported an unusual behaviour of the sex-chromosome in *Hexacentrus mundus* (2n=31 ♂), being strongly heteropychnotic during early meiotic prophase stages. During pachytene, this sex chromosome divided, but the two daughter sex-chromosome remained associated till anaphase II. In tetraploid spermatocytes, two Xs were seen but they never synapsed suggesting that heteropycnosity prevents pairing.

White (1940 b, 1941 a and b) stated that Orthopteran species generally have an XX-XO type of sex-determining mechanisms. There are exceptions where few species have secondarily acquired XX-XY mechanism of sex-determination. XX-XY mechanism was the consequence of a fusion of the sex-chromosome with one of the autosomes, the partner of the latter becoming a neo-Y. The sex chromosome-autosome complex became neo-X and this was confirmed by King (1950).

Helwig (1941, 1942) stated that neo-XY mechanisms were known to occur in 14 genera of grasshoppers at that time. Since then, many additional instances have been reported in North and South American grasshoppers (King, 1950; White, 1953; Saez and Diaz, 1958; Saez, 1963 and Mesa 1956 and 1964), in an Indian grasshopper species (Raychaudhuri and Guha, 1952), in an African and in an European grasshopper species (White, 1956; John and Hewitt, 1970). King and Beam (1950) also stated the XX:XY mechanism has arisen from an ordinary pair of autosomes and this XX:XO mechanism is of a primitive type from which neo-X : neo-Y mechanism has arisen.

Raychaudhuri and Guha (1952) reported a neo-X : neo-Y type of sex-mechanism in a short horned grasshopper, *Thisiocetrus pulcher* (Catantopinae). White (1953) reported a fusion of X chromosome with one of the autosomes in the
males of *Paratypotropidia* genus converting primitive XX:OXO mechanism of sex determination into neo-X and neo-Y type. In *P. morsei* and *P. brunneri*, an additional fusion had given rise to \( X_1 X_2 Y \) system of sex determination.

The \( X_1 X_2 Y: X_1 X_2 X_2 X_2 \) system that have been described in a few Acridoidea (White 1953; Mesa, 1963; White and Cheney 1966; Mesa and Mesa, 1967), has arisen by an additional Y-autosome fusion. Nicklas (1961) observed an extremely peculiar behaviour of sex chromosome in *Melanoplus differentialis* which has \( 2n=23(0) \). During prometaphase I, it performed recurrent pole to pole movements while the autosomes started congressing on the equater of the spindle.

Manna and Chatterjee (1963) reported two types of male individuals in *Euprepocnemis* sp. with \( 2n = 23 \) and 22. The latter with 22 chromosomes had a sex-mechanism of neo-X : neo-Y type. Previously this mechanism was reported in *Hypochlora alba* (King, 1950), *Mermeria* sp. (McClung, 1917; King, 1950), *Machaerocera mexicana* (Helwig, 1942) and *Thisiocetris pulcher* (Raychaudhuri and Guha, 1952).

Mesa (1964) reported that in South American grasshoppers, *Leiotettix sanguineus*, there are two chromosomal races, one with \( 2n = 23 \) having XO type of sex mechanism and the other with \( 2n = 22 \) having XY type of sex-mechanism. Similarly *L. politus* had also two chromosomal races with \( 2n=14 \) having XY mechanism and \( 2n=13 \) with \( X_1 X_2 Y \) type of sex-mechanism. Dave (1965) studied the chromosome of *Isopsera* sp. and *Lentana atomifera* belonging to the family Locustidae, a group of long-horned grasshoppers, and reported unusual sex-chromosome constitutions namely neo-X + neo-Y and \( X_1 X_2 + \text{neo-Y} \) respectively, in the male individuals. Mesa and Mesa (1967) studied the chromosomes of two chromosomal races in South American acridid, *Leiotettix sanguineus*, one with 11
pairs of autosomes plus one sex-chromosome and the other with a diploid complement of 11 pairs with neo-X type of sex-mechanism.

White et al. (1967) reported that two species of Tettigonoidea i.e. *Theudoria melanocnemis* (Phaneropterinae) from South America and *Yorkiella picta* Carl. (Listroscelinae) from Australia possess neo-XY mechanisms. Hewitt and Schroeter (1968) studied the karyotype and chromosome behaviour of *Oedaleonotus enigma*, which had a sex-mechanism of neo-X : neo-Y type. Hewitt (1979) reported more than 100 cases of neo-XY and X₁X₂Y and sex chromosome systems in saltatoria with 40XA fusions. Yadav et al. (1981) reported XA fusions in *Tryxalis indica* Thunb.

The structure of the metaphase I bivalents of the neo-XY race of *Pycnogaster cucullata* was revealed by Sentis et al. (1984) using silver impregnation after 2 x SSC pretreatment. Ault (1984) studied the orientation stability of the sex univalent in the grasshopper *Melanoplus sanguinipes* and concluded that this stable unipolar orientation was an intrinsic characteristic of the X chromosome.

Yadav and Yadav (1986) reported the chromosome number and sex-determining mechanisms in thirty species of Indian Orthoptera. Out of these, *Euprepocnemis alacris* Serv. showed both XX-XO and neo-XY mechanism of sex determination. The neo-XY type of sex mechanism was also recorded in *Choroedocus capensis* Thunb. and *Thisiocetrus nobilis* Uvarov. The remaining species showed XX-XO type of sex-mechanism.

Ault (1986) studied the stable versus unstable orientation of sex-chromosomes in two species of *Melanoplus*. In *Melanoplus sanguinipes*, X chromosome showed stable unipolar orientation while in *Melanoplus differentialis*, unstable unipolar orientation of univalent X chromosome was reported.
chromosome reorients after making complete pole to pole trips during prometaphase to metaphase I (Nicklas, 1961).

Yadav and Yadav (1990) studied the cytology of Catantopine grasshoppers (Euprepocnemis alacris serv., Choroedocus capensis Thunb., and Thisiocetrus nobilis Uvarov) and found that morphologically similar individuals exhibited dimorphism with regard to the male sex chromosome mechanism in E. alacris and C. capensis and two cytotypes were evident in the same population of these species, viz. 2n=23 (XO) with all chromosomes acrocentric, and 2n=22 (neo-XY) with all autosomes and the Y Chromosome acrocentric and a submetacentric X chromosome. Other species Thisiocetrus nobilis showed only 2n=22 with neo-XY. chromosomes.