Omkar *Editor*

Polyphagous Pests of Crops

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ISBN 978-981-15-8074-1 ISBN 978-981-15-8075-8 (eBook)
https://doi.org/10.1007/978-981-15-8075-8

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

As human population accelerates and monocultures dominate the agricultural landscape, the reign of insect pests seems to be far from over. Globally, it has been found that the number of insect pests as well as the intensity of their attacks have actually increased post global agricultural revolution. It has been observed that some 137 pathogens and pests cause losses of 10–40% in the staple crops, viz. wheat, maize (corn), soybeans, rice and potatoes, that fulfil about 50% of the calorie intake of humans throughout the world.

While, in general, the losses due to insect pests have increased, monocropping and increased travel of food produce across the globe have especially created a haven for the most dreaded of all insect pests, the polyphagous ones. Polyphagous pests are primarily agricultural pests that feed on economically important agricultural and horticultural crops with wide taxonomic diversity across the globe. They cause massive amount of damage across crop varieties owing to their generalist food habits. The normal cultural practices of crop rotation and plantation of resistant plants find very limited applicability against polyphagous pests.

This book focusses on polyphagous pests not limited to insect pests but also acarine and mammalian (rodent) pests. It covers locusts, termites, aphids, whiteflies, mealybugs, scale insects, gram pod borer, fall armyworm, thrips, mites and rodents. While some of these, such as locusts, termites and rodents, strike a note for both non-specialists and specialists, others have largely vaguer connotations. This book seeks to emphasize how each of these pests is unique in its spread and has the ability to cause extensive damage. Several of these polyphagous pests, in addition to causing direct crop damages, also act as carriers of plant disease-–causing agents. Not only will this book exclusively concentrate on the enormity of losses and the mechanism of losses, but also the means to reduce these losses. In most books dealing with agricultural pests, the emphasis is largely on crop–pest complexes and that too only of insect pests. This book proposes to move beyond specific crops and emphasizes on the pests and view in its entirety and complexity. This unique perspective will provide researchers with better pest management practices that will be more pest specific rather than cross specific and will likely help reduce the cross movement of pests across crops. Not only will this book act as a reference guide to researchers but also to policy planners, academicians and students of entomology.

Right at this moment, globally, polyphagous pests are rising up again. The Middle East countries, the African continent and even the Indian subcontinent are increasingly facing massive locust swarms, which had been under suppression for quite some time. *Helicoverpa* is knocking at the doors of North America, after having extended its range from the traditional old world distribution in southern America. In India, *Helicoverpa* is eating away around 45% of the chickpea crop. The fall armyworm is being feared for its potential spread into new areas. Such resurgences up the ante to study and research more on polyphagous pests; thus, I was motivated to bring together experts on each polyphagous pest and edit a book that would provide the latest information and perspectives on these global pests of crops.

At the very outset, I take this opportunity to express my gratitude to the contributors of different chapters contained in this book for sparing time from their routine to prepare their respective chapters.

I am also thankful to Dr. Geetanjali Mishra, associate professor, Department of Zoology, University of Lucknow, for her intellectual inputs and other final stage support and Ms. Apoorva Shandilya for her assistance throughout this project. I would also like to thank my research students, Dr. Shashwat Singh, Dr. Swati Saxena and M/S Priya Singh, Chandni Verma, Tripti Yadav, Shriza Rai, Lata Verma, Deepali Gupta, and Gauravanvita Singh, for their assistance and support in various ways.

Thanks are also due to my wife, Mrs. Kusum Upadhyay, for her encouragement and support by sparing me from household activities for this work.

I also express my thanks to Ms. Akanksha Tyagi from Springer Nature India, New Delhi, for taking keen interest in this project and for her support to bring out this work on time.

Lucknow, Uttar Pradesh, India Omkar
16 April 2020

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About the Editor

Omkar has been associated with the Department of Zoology, University of Lucknow as a faculty for the past 32 years and a former Head of Department. His specialization is Entomology in which he specifically concentrates on agricultural pests, dealing with the aphids and their natural enemy complex, specifically ladybird beetles. He is author and editor of several books, including Industrial Entomology, Pests and Their Management, and Sucking Pests of Crops, published by Springer Nature. He is an elected Fellow of The National Academy of Sciences, India (FNASc) besides many more.

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Locusts

1

N. P. Singh and Vinod Kumari

Contents

Abstract

The term 'locust' is given to those species of grasshoppers, which are capable of forming large swarms under certain conditions. They belong to family Acrididae, suborder Caelifera, order Orthoptera and class Insecta. The locust swarms move over wide and distant areas and cause severe damage to cultivated and natural vegetation, where the swarms settle. There are many species of locusts, amongst which desert locust, *Schistocerca gregaria*, is the most damaging pest. The locust problem is not new. Since the beginning of civilisation, they have been a serious threat to agriculture. A substantial increase in locust population, which may cause serious devastation of crops, is known as outbreak. Each locust can exist in two main forms, i.e. solitary phase (phasis solitaria) and gregarious phase (phasis gregaria), which are quite distinct morphologically as well as behaviourally. An

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Omkar (ed.), *Polyphagous Pests of Crops*,
https://doi.org/10.1007/978-981-15-8075-8_1

intermediate phase (phasis transiens) also occurs in between two extreme phases. Each locust is a grasshopper, but every grasshopper is not a locust.

Locust breeding and seasonal migration patterns follow no international boundaries; hence, international intervention and cooperation is essential for their control. A locust plague begins, when sufficient rains are there in potential outbreak areas, simultaneously leading to tremendous breeding and increase in locust populations, resulting into upsurge of locust population. Like other pest management, locust control also aims at protecting agricultural productions.

Current information on locust breeding, density and phase is the starting point of all control operations. Chemical control has superseded various other traditional methods for killing, viz. digging trenches, burning, beating and smoking the hopper bands and swarms.

The first international locust conference took place in Rome in 1920. The International Locust Information Network and Anti-locust Research Centre were established in London in 1930. After 1993, the latest swarms of desert locust invaded India on 21 May 2019, which is still continued in major parts of northwest India. The Locust Warning Organization (LWO) and Field Station for Investigation on Locusts (FSIL), established by the Government of India, are active to control the locust swarms and outbreaks. Using certain improved technology for spraying operations, Global Positioning Systems (GPS) leading to new navigational technology, other modern gadgets and mathematical models under integrated pest management (IPM) programme, we will be able to combat the locust problem with international cooperation.

Keywords

Locust · *Schistocerca gregaria* · Upsurge · Outbreak · Plague · Locust control strategies

1.1 Introduction

The term locust is correctly given to a few species of Acrididae family of the suborder Caelifera belonging to the order Orthoptera and class Insecta (Richards and Davies 2013), having antennae less than 30 segments and tympanum located on the lateral side of the first abdominal segment. They are capable of forming large swarms under certain environmental conditions. Thus, the locust is a migratory grasshopper that swarms at regular intervals. The periodicity of locust swarms is mainly governed by complex environmental factors. The locusts are polymorphic species, which exist in three unstable phases, viz. phasis solitaria, phasis gregaria and phasis transiens, differing in the structure, habit and behaviour. The gregarious and solitary phases differ so much from each other that for a long time they were considered as distinct species. The phasis transiens or transitory phase is a series of transitional forms between the solitary and gregarious phases. The transitory phase includes phasis congregans in between solitary and gregarious phase, and in between gregarious and solitary phase is the phasis dissocians. Pradhan (1969) proposed a

theory, explaining probable cause of phase transformation and swarm outbreaks in periodic and cyclic manner. According to this theory, drastic climatic conditions of breeding areas of the locusts are solely responsible for the periodic locust outbreaks.

Swarming takes place in gregarious phase, and diapause occurs in eggs of individuals of this phase. The adult individuals of gregarious phase migrate, and migration occurs on sexual maturation. The solitary phase is characterised by the presence of isolated individuals, which exhibit no sign of migration. The eggs of individuals of solitary phase develop without diapause, and sexual maturity is not followed by colour change and migration. In locusts, the actual stimuli, which promote migration, are internal and are associated with the maturation of gonads.

Locusts and grasshoppers are polyphagous in nature, feeding on a variety of vegetation in the form of various crops, grasses, vegetables, etc. They are distributed throughout the world but abundantly occur in tropical and subtropical regions. The locust problem is not new; since the beginning of human civilisation, grasshoppers and locusts have been among the most devastating threats to agriculture. Locusts and grasshoppers are quite different from other pests. In comparison to others, their population can grow to catastrophic levels and can cause a great damage in a very short time. Locusts have been in competition with human beings, since the agricultural practices started by them have been mentioned in holy books, like Bible and Quran. Uvarov (1944) reported death of thousands of people in the Roman colonies of Cyrenaica and territories of Libya, Algeria and Tunisia from famine due to locust plague. The invasion of locusts destroyed 1,67,000 tonnes of grains in Ethiopia in 1958, which could be sufficient for one million people for a year (Steedman 1988).

Locusts and grasshoppers are distributed all over the world, except Antarctica. Their number is found more near the equator, flourishing in subtropical and tropical countries. Their devastating nature has been of much concern to the economic entomologists. Locust outbreaks have been reported in every continent, except Antarctica, which may affect the livelihood of about 10% of the world population (Latchininsky 2010). Though the damage caused by locusts may be nonsignificant for the entire national economy of a country, it may result into 100% loss of the whole season's work for the farmers, adversely affecting the entire family. Amongst the various locust species, desert locust, *Schistocerca gregaria*, is most known for its wide distribution (Fig. 1.1). The desert locust plague occurred in West Africa in 2004 due to unusual heavy rains with favourable environmental conditions for swarming. To handle this outbreak, millions of USD were spent.

The recent desert locust swarms invaded northwest India on 21 May 2019. These desert locust swarms continued to form during December 2019 in west Rajasthan (Phalodi, 2706 N/7222E, and Bikaner, 2543 N/7125E) and in west Gujarat (Palanpur, 2410 N/7226E). A few more late instar hoppers remained active in Bikaner and Pakistan border. Another generation of locusts had breeding in Rann of Kutch, northwest of Bhuj in Gujarat (2312 N/6954E). In some areas, hoppers and solitary adults were also observed in active state (Fig. 1.2).

According to sources received from the Directorate of Agriculture, Government of Rajasthan, previously the desert locusts invaded in 1993 in an approximate area of 310,482 hectares, while in 2005 an area of 16,440 hectares was infested by these

Fig. 1.1 Distribution of *Schistocerca gregaria* (Forskal 1775), desert locust. (Source: CABI datasheet)

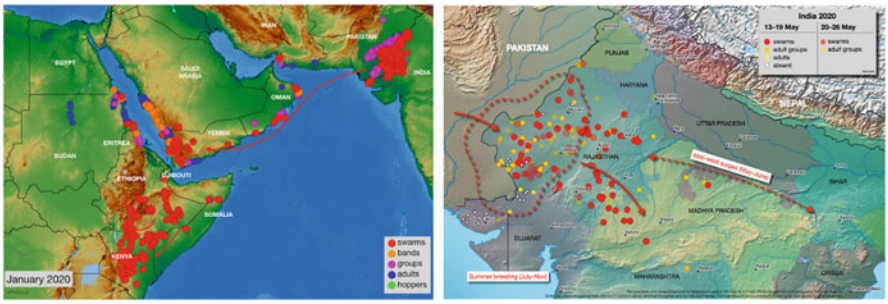

Fig. 1.2 Situation of desert locust. (**a**) Worldwide as on 3 February 2020, (**b**) India as on 27 May 2020. (Source: FAO)

locusts. According to reports of the Food and Agriculture Organization (FAO) of the United Nations, a swarm of locusts comprising of about 40 million individuals can consume the amount of food in a day sufficient for 35,000 people or 20 camels or six elephants. Thus, the destruction to crop yield can be enormous (Fig. 1.3).

Besides being a serious pest of various cultivated and noncultivated crops, locusts (the species is *Locustana pardalina*) have been a delicious food in Africa, Thailand, etc. The tribal people of Uganda and North Central Africa eat *Ruspolia nitidula,* a cone-headed grasshopper. In Kampala (capital of Uganda), the locusts are collected from the street lights. These insects are attracted towards light in huge numbers; when the tribal people collect them, sometimes even the problem of traffic jam is caused.

Fig. 1.3 Hopper bands of desert locust in anonymous field (Rajasthan, India)

Throughout the world, the grasslands and even some forests are permanent home of locusts, and their density varies depending on the season, location and year. The term "outbreak" is used to describe substantial increase in the number of locusts. Outbreak can occur following the arrival of migratory adult locusts. These locusts gather at the site and start breeding (laying eggs) producing enormous individuals. This spectacular congregation results in the formation of hopper bands, subsequently huge swarm of adults, which are capable of migration. Certain advanced agricultural and industrial practices may favour locust outbreaks, such as overgrazing, deforestation, irrigation and introduction of new varieties of crops.

It is estimated that 500 adults of *S. gregaria* per hectare are enough to initiate an outbreak (Fig. 1.4), as they become gregarious. Their colour, morphology, behaviour, biology and ecology are changed. The most significant result of these changes is the formation of hopper bands and swarming adults. Their swarms can migrate hundreds of kilometres per day and invade areas covering millions of square kilometres. The consequences of the swarm invasions can be disastrous for the food production and livelihood of poor rural workers and farmers.

The cost of control practices and strategies is tremendous. The large amount of chemical pesticides affects the environment adversely. This has been a practice for the last so many decades. However, during the past half-century, locust and grasshopper control has made progress through better knowledge of their biology and ecology and increasing the use of high-level technology, such as satellites, high-tech computers and new mathematical models, at our disposal. Previously, due to lack of resources, the information could not be sent well in time by the field workers. Nowadays, special gadgets and wireless sets are provided to the field squads for this purpose, and if needed immediate appropriate action can be taken.

Fig. 1.4 Swarm outbreak in Rajasthan, India (Dec, 2019)

1.2 Major Locust Species

There are around 12,000 locust and grasshopper species throughout the world, of which around 500 species cause damage to crops. The following are particularly important ferocious species of locusts.

1.2.1 The Migratory Locust, *Locusta migratoria* (Linnaeus, 1758) (Fig. 1.5)

The migratory locust (*Locusta migratoria*, Linnaeus, 1758) can go unnoticed for long periods but reproduces continuously, with four or five generations per year. It is distributed in Europe, Africa, Pakistan, Eastern Asia and Australia. Its swarms occurred in Chennai in 1878. This is normally confined to the Central Highlands of Queensland, though low numbers are common as far south as northern New South Wales. There was heavy and concentrated breeding and swarm formation of this locust during February–March 1954 in the Ramanathapuram district of Tamil Nadu, and this was attributed to the swarm observed over Bengaluru (then Bangalore) in June 1954. In general, the locust breeds in Balochistan (Pakistan) during the spring, and the resultant adults migrate to the desert areas of India and breed there during summer. Hoppers pass through five to six instars. In sub-Saharan Africa and Madagascar, four fifths of the islands were affected between 1997 and 2000. The

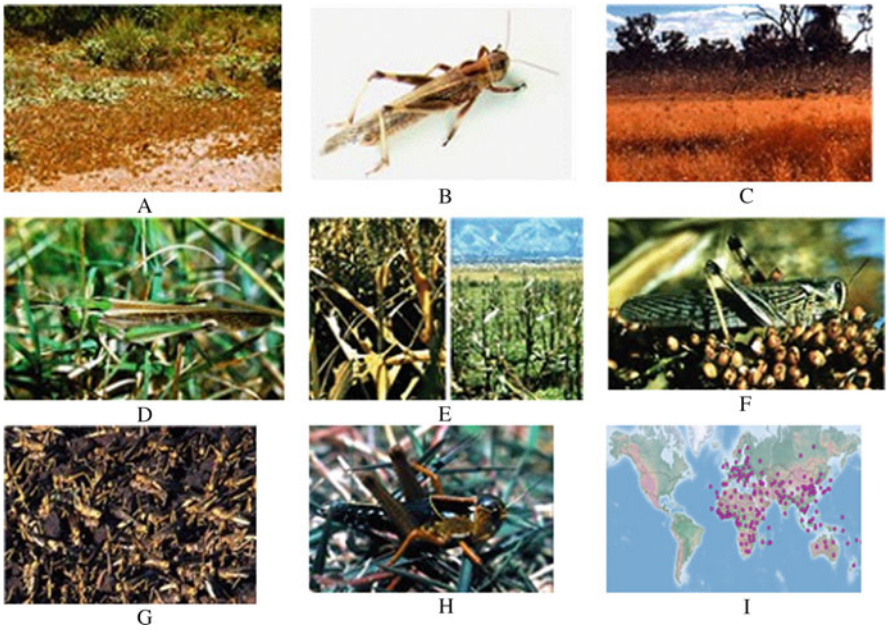

Fig. 1.5 Different stages and distribution of *Locusta migratoria* (Linnaeus, 1758): (**a**) Hopper band, (**b**) adult, (**c**) swarm, (**d**) adult female solitary, (**e**) Left: loose swarm causing damage to maize, Markham Valley, Papua New Guinea. Right: feeding damage on sorghum, Australia, (**f**) adult Female gregarious feeding on sorghum. Females 50–75 mm in length, (**g**) gregarious adults of on egg bed, (**h**) gregarious, fourth instar, length 25–35 mm, (**i**) distribution. (Source: CABI datasheet)

main migratory locust gregarisation area in Africa (where the insect switches from a solitary to a gregarious phase and the first swarms form) is in Mali, on the Niger River floodplain. The last major invasion in this area was in 1928. Within 5 or 6 years, it had spread to a large part of Africa, south of Sahara. It lasted until 1940. In Madagascar, the gregarisation area is in the southwest, the driest part of the island. Invasions starting from there have been known to cover up to 500,000 square kilometres. A large-scale invasion began in Madagascar in 1997. There were also severe outbreaks in the Lake Chad basin in 1997 and on numerous Indonesian islands, particularly Sumatra in 1998.

The hopper bands and swarms are known to attack millet, maize, rice, sugarcane, wheat, banana, pineapple, oil, date or coconut palm, cotton, groundnut, pasture and kitchen garden and even ornamental crops.

Migratory locusts have four generations per year, but egg mortality is reported in dry periods. At high population densities, hopper band and adults form swarm. The solitary form is green or brown, but gregarious (swarming) is straw coloured. Hindwings are greenish yellow without markings. The mandibles are dark purple to black. Hopper bands are generally black and tan coloured. There are many subspecies of migratory locusts with variation in their morphometrics and distributions. Vijay Veer et al. (2013) reported that locust outbreak which occurred

in Ladakh during 2006 belonged to subspecies *L. migratoria migratoria*, revealed through molecular characterisation. The following subspecies are described by Mani (1973):

I. *L. migratoria migratoria*—found in southeast Russia
II. *L. migratoria rossia*—found in central Russia and western Europe
III. *L. migratoria capito*—found in Madagascar
IV. *L. migratoria migratorioides*—found in Africa, western Asia
V. *L. migratoria manilensis*—found in Malaysia, East Indies, Philippines and China

1.2.2 The Italian Locust *Calliptamus italicus* (Linnaeus, 1758) (Fig. 1.6)

It is dark brown, yellowish brown or greyish in colour. At the base, the hindwings are rose coloured posteriorly. Forewings project beyond the tip of hind femora with two or three rudimentary brown spots. This species is found in whole of central, meridional and eastern Europe, Caucasia and west Siberia. Breeding takes place in sagebrush steppes and in loose dry soil, with sparse vegetation.

1.2.3 Moroccan Locust, *Dociostaurus maroccanus* (Thunberg, 1815) (Fig. 1.7)

It is testaceous brown, with black spots. Pronotum is with two straight diverging black bands; hind femora is black apically with three black transverse bands, and distal half of hind tibial spines are black. Tegmina are variegated brown; hindwings are transparent. Cerci are short, and lamina is triangular; female is 20–33 mm long, and male 1is 7–28 mm long. This species occurs in the whole of central Europe,

Fig. 1.6 The Italian locust *Calliptamus italicus* (Linnaeus, 1758): (**a**) Male; (**b**) female

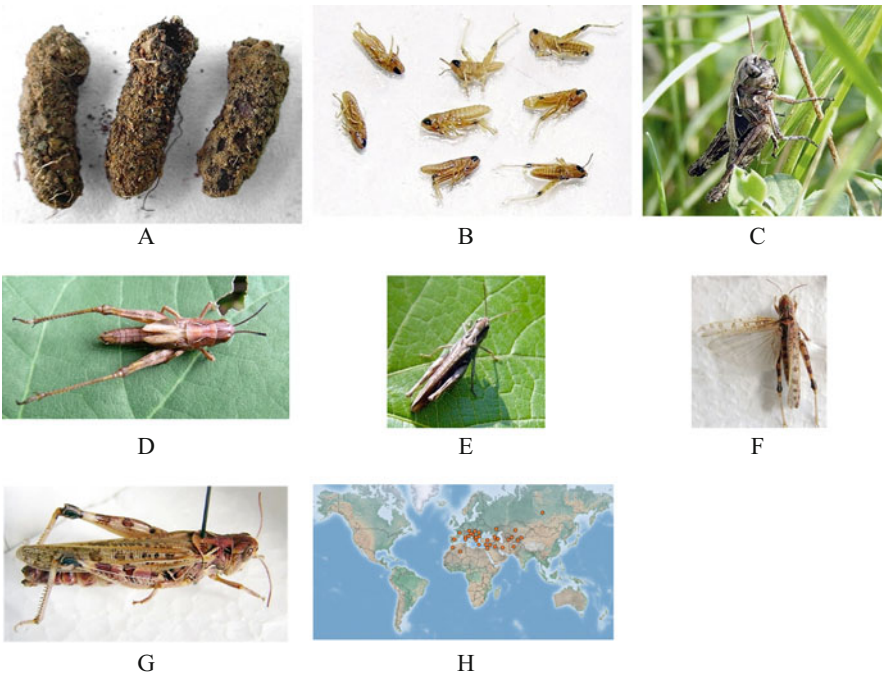

Fig. 1.7 Different stages and distribution of *Dociostaurus maroccanus* (Thunberg, 1815). (**a**) Egg pods. The eggs are whitish to pale yellow, elongated, stick-shaped and arranged in three to four rows in egg pods (oothecae), (**b**) newly hatched nymph, (**c**) third instar nymph on wild grasses. The third instar nymphs have visible wing buds. They are olive red with black spots on the head and body, (**d**) fourth instar nymph on a leaf (note developing wing pads), (**e**) male on vine leaf, (**f**) male with stretched wings; set specimen, (**g**) female set specimen, (**h**) distribution. (Source: CABI datasheet)

Africa from north of Morocco to Tunisia, Asia Minor, Iraq and Transcaucasia. It is specially abundant in Spain. It breeds in hilly or mountainous regions.

1.2.4 Australian Plague Locust, *Chortoicetes terminifera* (Walker, 1870) (Fig. 1.8)

The adults show variation in length ranging from 20 to 45 mm, and colour is grey, brown or occasionally green—often with a pale stripe down the middle of the back. The head is higher than the thorax. The thorax possesses 'X'-shaped marking. Wings are clear with a dark spot at the end. This is the most economically important Australian locust because of the extent of damage and frequency of outbreaks. It occurs throughout Australia, except moist and cooler regions in the southeast and most of Tasmania.

Adults make short flights just above the grass, often landing side onto the observer. This flight is also typical of several grasshopper species, including the eastern plague grasshopper. This insect looks very similar to *Chortoicetes*

Fig. 1.8 Adult ([A] side view and [B] stretched wings) of *Chortoicetes terminifera* (Walker, 1870)

terminifera, but its hindwings are pale yellow with a dark band, and it lacks the red shanks on the hindlegs.

1.2.5 The Red Locust, *Nomadacris septemfasciata* (Audinet-Serville, 1838) (Fig. 1.9)

Generally, the colour is brown but deepening and reddening with age. Tegmina are with seven oblique, dark bands. This species is distributed in most of South Africa, south of Sahara, Madagascar and Mauritius.

1.2.6 South American Locust, *Schistocerca paranensis* (H. Burmeister, 1861) (Fig. 1.10)

North American locust extends from Argentina north of 40th latitude through Brazil to Venezuela and Central America, but swarms often penetrate Mexico and West Indies. *Schistocerca americana* is probably the solitary phase of this species. The gregarious phase is greyish white, with large black spots on the tegmina, over 50 mm long. It breeds in spring in damp soil.

Fig. 1.9 Adult and distribution of *Nomadacris septemfasciata* (Audinet-Serville, 1838). (**a**) Adult on wild sorghum in the Wembere Plains in Central Tanzania in February 2003 (Released into the Public Domain by Christiaan Kooyman), (**b**) close-up of anterior region, (**c**) distribution. (Source: CABI datasheet)

Fig. 1.10 *Schistocerca paranensis* (H. Burmeister, 1861)

Fig. 1.11 Adult on bean (**a**) and distribution. (Source: CABI datasheet) (**b**) of *Oedaleus senegalensis* (Krauss, 1877)

1.2.7 Senegalese Grasshopper, *Oedaleus senegalensis* (Krauss, 1877)/*O. abruptus* (Thunberg, 1815) (Fig. 1.11)

It is a medium-sized grasshopper species. Though it is not called a locust, this species shows gregarious behaviour, and some morphological changes are like locust on crowding. It is distributed in Sahel region of Africa, the Canary Island and West Asia.

1.2.8 Bombay Locust, *Patanga* (*Cyrtacanthacris*) *succincta* (Linnaeus 1763) (Fig. 1.12)

It is greyish brown, taking on a reddish tinge and darkening with age. There is a broad median pale yellow band on the head and pronotum, continuing down the tegmina. It is distributed in India, Sri Lanka and Malaysia. In India, it is generally restricted to the area extending from Gujarat to Tamil Nadu. It breeds in the Western Ghats and has one generation per year. Hoppers are found scattered among crops or grasses and do not congregate. Its plagues occurred during 1835–1845, 1864–1866 and 1901–1908, and heavy damage was caused to crops. Hoppers of this species pass through seven to nine instars.

Fig. 1.12 : Bombay locust, *Patanga succincta* (Linnaeus, 1763). (Source: Usmani and Usmani 2018)

Fig. 1.13 Egyptian locust, *Anacridium aegyptium* (Linnaeus, 1764) Libyan Desert. (Source: Usmani and Usmani 2018)

Fig. 1.14 Bird locust, *Ornithacris turbida* (Walker, 1890). (Source: Usmani and Usmani 2018)

1.2.9 Egyptian Locust, *Anacridium aegyptium* (Linnaeus 1764) (Fig. 1.13)

It is brownish grey in colour, hindwings are often pale violet at base, and hind tibial spines are pale and dark at the apex. It is distributed throughout Mediterranean region, West Pakistan, Portugal, Spain, France, Italy, Switzerland, Afghanistan, Iran, Iraq, Israel, Jordan, Lebanon, Libya, Egypt and South Arabia. It is generally a minor pest but becomes a major pest when population is built up.

1.2.10 Bird Locust, *Ornithacris turbida* (Walker 1890) (Fig. 1.14)

Generally, bird locusts are similar externally to *Nomadacris septemfasciata*; however, they can be separated by the presence of a triangular side stripe on pronotum which is parallel in *N. septemfasciata*, and hindwings are orange at the base. They are distributed in Libya, Sudan, Uganda, Tanzania, Zaire, Ghana, Togo, Nigeria, Cameron and Angola.

Fig. 1.15 Brown locust, *Locustana pardalina* (Walker, 1870). (Source: Usmani and Usmani 2018)

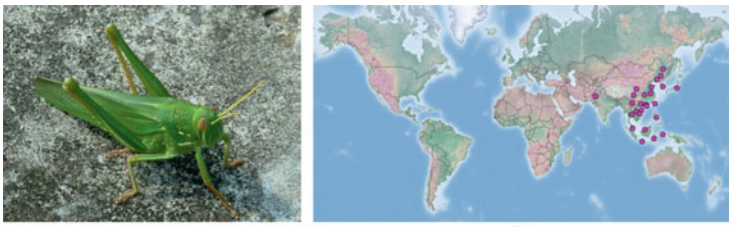

Fig. 1.16 (**a**) Cotton or citrus locust, *Chondracris rosea* (De Geer, 1773). (Source: Usmani and Usmani), (**b**) distribution of cotton or citrus locust, *Chondracris rosea* (De Geer 1773). (Source: CABI datasheet)

1.2.11 Brown Locust, *Locustana pardalina* (Walker 1870) (Fig. 1.15)

Generally, they are brown and rarely green, and tegmina are with scattered brown spots. They are distributed in Zambia, Angola, South Africa, Zimbabwe, Botswana, etc. It is a serious pest in South Africa.

1.2.12 Cotton or Citrus Locust, *Chondracris rosea* (De Geer 1773) (Fig. 1.16)

Wings are tinged green and basally rose. They are distributed in Korea, Japan, Taiwan, China, Hong Kong, Philippines, Thailand, Myanmar, Malaysia, Bangladesh and India. There are many natural enemies of this locust.

1.2.13 Large Coast Locust, *Valanga irregularis* (Walker 1870) (Fig. 1.17)

This is the largest Australian grasshopper species; it is dark greyish brown in colour and with irregular black marks and sometimes with a pale median dorsal stripes. Tibial spines are dark red, and hindwings are with black veins. It is distributed in Australia (New South Wales to Sydney, Queensland, etc.).

1.2.14 The Mediterranean Locust, *Calliptamus barbarus* (Costa, 1836)

It is distinguished from the Italian locust by the single large black spot on the medial side of hind femora. This species occurs abundantly in east Italian and neighbouring regions and extends up to Iran in the east.

1.2.15 The Rocky Mountain Locust, *Melanoplus erectus*

The adults are yellowish brown in colour, with minute dark spots on wings, and are about 35–37 mm. They are distributed in prairies of the eastern slopes of the Rocky Mountains in the USA.

1.2.16 Spur-Throated Locust *Austracris guttulosa* (Walker, 1870) (Fig. 1.18)

This locust is an Australian species. The duration of its life cycle is 1 year. It cannot survive in dried or arid conditions; hence, population buildup of this species takes place during monsoon only. Due to this reason, its plagues are not so frequent as compared to Australian plague locust. However, it may migrate to cultivated fields; if it rains during summer, it may cause severe damage, particularly to seedling stage of sorghum. It may form swarms during overwintered roosting.

The eggs are laid scattered in the fields, not in egg pods. No band formation by hoppers takes place after hatching; hence, the control becomes a bit difficult due to scattered status of nymphs. Hatching takes place from November to February. The overwintered forms become mature during spring, and further egg laying takes place after rainy season in October–November.

The nymphs and adults both possess a peculiar spur between the front legs, hence the name ‘spur-throated locust’. Initially, the colour of nymph is green, but soon a black stripe is developed down the middle of the back. On maturity, the body colour

Fig. 1.17 Large coast locust, *Valanga irregularis* (Walker, 1870)

Fig. 1.18 Spur-throated locust, *Austracris guttulosa* (Walker, 1870)

Fig. 1.19 Yellow-winged locust, *Gastrimargus musicus* (Fabricius, 1775)

becomes light brown. The adults are 50–80 mm in length with pale brown body and longitudinal white stripe. Hindwings are colourless with a blue tinge, and the hindlegs are provided with two rows of white spines with dark tips.

1.2.17 Yellow-Winged Locust *Gastrimargus musicus* (Fabricius, 1775) (Fig. 1.19)

It is a common grasshopper in Australia. It displays its yellow back wings during flight only, when it also clicks with loud clicking sound. It is found in all mainland states. The population is found at its maximum from spring to autumn causing severe damage. At higher population density, the nymphs (hoppers) form bands and the adults swarm. The females lay eggs in the soil in dense egg beds. At normal temperature in summer, which is 28 to 33 °C, its development duration is minimum.

1.2.18 Desert Locust, *Schistocerca gregaria* (Forskal, 1775) (Fig. 1.20)

Schistocerca gregaria is the most widely distributed locust and destructive species of locusts and hence deserves more detailed account. It occurs in a great part of North Africa, southwest (excluding the extreme part of meridional) and most of tropical Africa, Arabia, Iraq, Iran, Afghanistan and northwest India. The heavy swarms may penetrate Spain, Portugal and also the eastern part of India. The distributional range is distinguished into a permanent breeding station and a temporary station into which the gregarious phase migrates. The gregarious form of this species was formerly described as *S. peregrine*. There are generally two annual

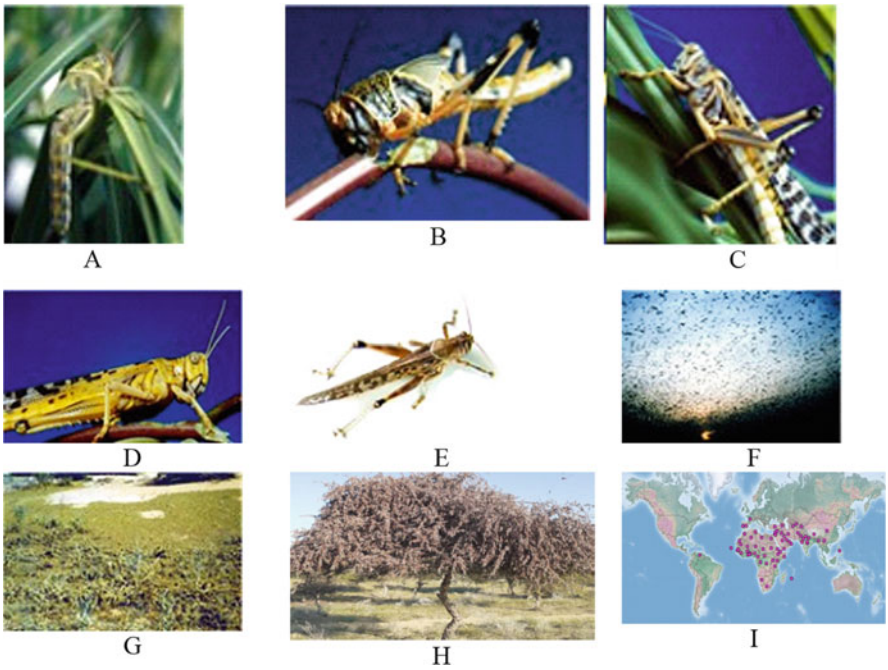

Fig. 1.20 (**a**) Fifth instar nymph of solitary *S. gregaria* (Forskal, 1775), (**b**) fifth instar nymph gregarious, (**c**) adult solitary, (**d**) adult gregarious (Bilkent University, Ankara, Turkey), (**e**) adult (museum set specimen), (**f**) swarm in flight, (**g**) hopper band, (**h**) swarms (adult) on *Acacia* tree, Rajasthan, India, (**i**) worldwide distribution. (Source: CABI datasheet)

generations. The egg stage may last for 15–40 days, and the nymphal (hopper) duration may be comprised of 40–60 days. They breed in permanent breeding grounds, but breeding may be limited due to natural enemies depending on the meteorological or environmental conditions. Essentially, it is hot desert species and is the most destructive. Its ravages have been discussed in biblical times.

The desert locust easily shifts from a harmless solitary form to a damaging gregarious phase. Its ability to move, the high density of its swarms and its voracious appetite are a serious threat to agriculture in many countries. The desert locust habitat covers Africa, north of the equator, the Middle East, the Arab and Indo-Pakistan peninsulas and, sometimes, Mediterranean Europe. It represents 57 countries in all and covers over 20% of the world land area. Between two successive invasions, the locusts retreat to the most arid areas of their usual habitat, where they can go unnoticed for several years. The desert locust does not spare a single crop. It also severely damages the natural vegetation, which has a serious impact on livestock production, as the animals are unable to find enough food. It can also cause havoc on wheat, barley, vines, citrus crops, date palms, millet, sorghum, vegetables, etc., in which countries rely on for food.

1.3 Life History of Desert Locust

Like all other locusts and grasshoppers, the life stages in life cycle of the desert locust are egg, nymph (hopper) and adult (Fig. 1.21). Mature females lay eggs after copulation. Eggs hatch into wingless nymphs called hoppers. Hoppers moult five or six times and each time grow in size. The stage between moults is called as an instar. Wingless final instar (fifth or sixth) moults into winged adult (fledgling), and the process is called fledging. Adults do not show moulting and thus do not grow in size but increase in weight. Initially, adults that can fly are sexually immature but become sexually mature in about 10–13 days, copulate and lay eggs.

1.3.1 Egg Laying

The female lays eggs in bare sandy and moist soil. Female often determines the moisture in soil by probing the ovipositor before laying and, once it finds enough moisture, starts laying eggs in batches called egg pods (Fig. 1.22, A). The eggs appear like rice grains and are arranged as finger bananas (Fig. 1.22, B). Above the pod, which is about 3–4 cm long and 5–10 cm below the surface, a plug of froth is

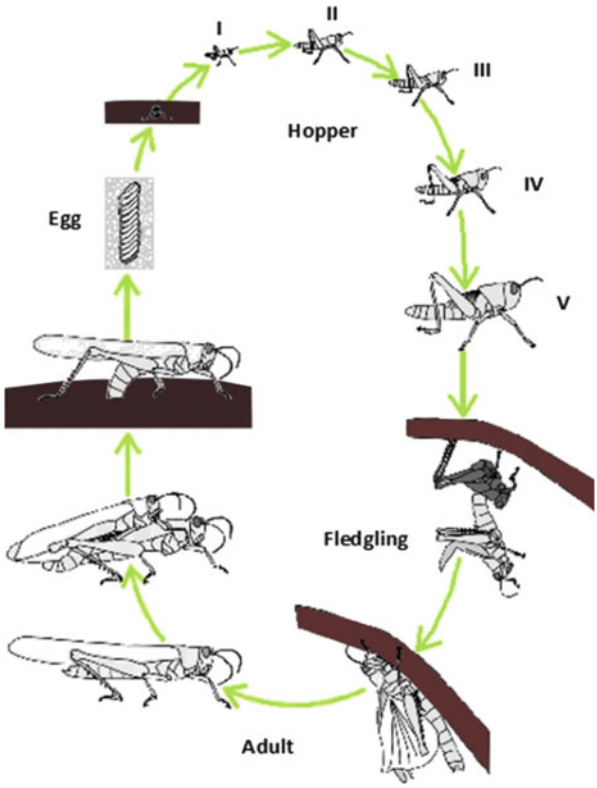

Fig. 1.21 Life cycle and different stages of desert locust. (Source: FAO 2001)

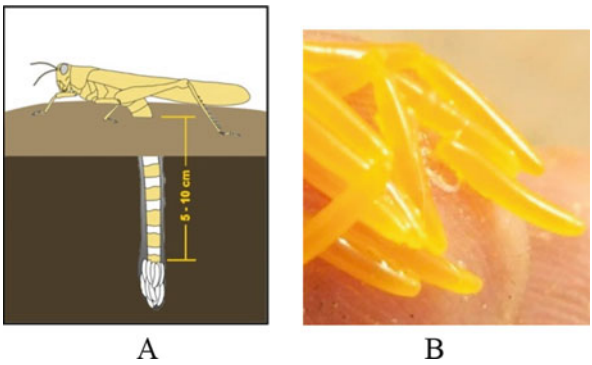

Fig. 1.22 (**a**) The female bores into the ground with the valves at the rear of her abdomen and lays a pod of eggs. The pod is about 3–4 cm long and is laid about 5–10 cm below the soil surface. (Source: FAO 2001). (**b**) Eggs like rice grains

laid. The gregarious phase locust lays pods with 80 eggs, whereas the solitarious phase lays pods with 90 to 160 eggs. Swarms lay egg pods with tens and even hundreds/thousands of pods per square metre. The scent and sight are important in attracting females to egg-laying females. Generally two to four egg pods are laid by females with the difference of ten days between the laying. However, due to natural mortality, a single female produces 16–20 viable locusts in a single generation.

The rate of development depends on the temperature of soil at pod depth and air. The mortality is more if the soil temperature is high. The survival of eggs up to hatching is also affected by habitat conditions, presence of egg parasites and predators. About 13 and 33% mortality is observed in solitarious and gregarious populations, respectively.

1.3.2 Nymphs/Hoppers

After incubation period is over, hatching occurs at dawn, and hatchlings make their way up through the froth plug to the surface. They immediately moult to the first instar. There are five instars in gregarious phase and sometimes six in the solitary phase. After fledging (or final moult), the young adult emerges. The rate of development of hopper is also dependent on temperature. However, the hoppers can manage their body temperature to a considerable extent by basking or seeking shade. There is no evidence that hoppers in relatively dry vegetation develop more slowly.

Hopper's Solitary Behaviour

Hoppers crawl over vegetation or ground and climb up to the top of plants before sunrise, and after sunrise, they descend from the plants to the ground. Hoppers climb back onto the vegetation during early morning and take shelter inside the plants or rest on plants. Hoppers descend again from the plants and bask on the sunny side of the plant in the afternoon. Near dusk, hoppers stop basking and climb back into the vegetation. The nature of habitat also influences the behaviour of hoppers. In bare land, hoppers most of the time move over the bare ground. In the area with uniform low vegetation, hoppers prefer moving along with movements under and out of the

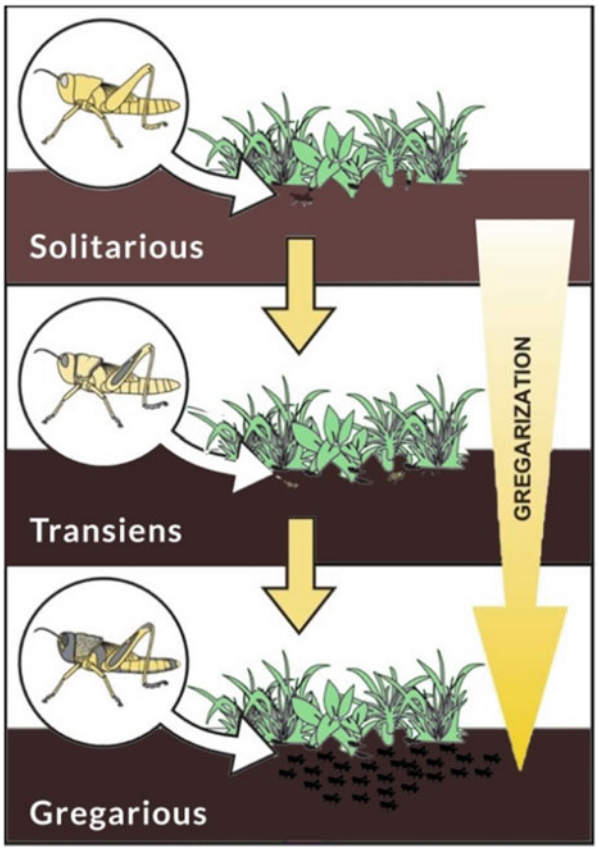

Fig. 1.23 When solitarious nymphs/hoppers of desert locust increase in number, their behaviour changes, and they become concentrated and can form groups. This often happens when vegetation starts to dry out. Their colour also changes and dark spots appear. (Source: FAO 2001)

vegetation, whereas in habitat with nonuniform vegetation, hoppers spend most of the time on vegetation instead of moving on the ground.

Hopper's Band Behaviour

When a number of hoppers increase in certain habitat, their behaviour is observed to be changed (Fig. 1.23). Hoppers are attracted during basking, feeding, roosting, moving on the ground or sheltering in vegetation and start forming groups in habitats that are less uniform with patches of dense vegetation and large bare soil areas. This grouping (transiens) can be regarded as an intermediate stage between hoppers of solitary phase and gregarious phase, whereas groups are less likely to form in habitats of uniform low vegetation and bare soil areas or uniform dense vegetation. Black markings on the green solitary hoppers also start appearing along with behavioural changes. Groups of hoppers found in the field are indication of onset of gregarisation and formation of bands. As the egg laying occurs at interval and all the eggs in a pod do not hatch at the same time, hopper bands are a mixture of instars in the same area at the same time of a recession period.

Shortly after hatching, hatchlings turn black and move to the nearest clump of vegetation but usually do not feed and move much for the first day and thus form small dense black patches of more than several thousand individuals per square metre (Fig. 1.24). Hoppers roost and march in an alternative manner during warm and sunny days. Densities of band depend on the behaviour stage of instars, habitat and weather. Hoppers on the ground form more dense bands as compared to roosting and marching hoppers. The density in bands on ground ranges from 30,000 to 1000 hoppers per square metre in case of first and fifth instar, respectively. However, the band area increases with age by merging of nearby bands together, and it continues till the fourth instar. But band area of fifth instar stage tends to be less cohesive. The movement of band is dependent on temperature, vegetation cover, size and consistency of the band about 200 to 1700 m in a day by bands of fourth instar hoppers. Usually, bands move during day, but night movements have also been reported on full moon night or exceptionally high temperature or in search of green vegetation. Heading path of band is often downwind and does not change, but at midday they are usually seen roosting under the vegetation.

1.3.3 Adults

After fledging, wings of fledgling take about ten days to harden sufficiently to take sustained flight (Fig. 1.25). Initially, adults that can fly are sexually immature and remain immature until favourable maturation conditions, usually rainfall in already infested area or locust-invaded area. Maturation occurs in about 10–13 days under favourable conditions. It is well synchronised in swarms, as mature locust triggers immature locust to get mature. Mature adult females lay eggs within 3 weeks of fledging in a rainfed area with green vegetation and 35 °C temperature. Sexually Immature adults can survive for 6 months or more in dry conditions with ample of vegetation to eat, although in West Africa, south of Sahara, some are known to survive in winters, which are comparatively warmer with no breeding. Males mature sexually before females. The females remain sexually immature at the temperature below 20 °C.

Solitary Adults

A short-range displacement and migration due to brief low-level flight and sustained high-level flight, respectively, have been observed in solitary adult. The flights up to 1800 m have been detected by radar. The temperature range, 20–22 °C, for night flight is the same as that for day flight.

Gregarious Adults

Solitary adults also change their behaviour according to environment and numbers like the nymphs or hoppers do (Fig. 1.26). The increase in the number of solitary adults due to excessive previous breeding and shrinking of habitat due to dry conditions forces adults to concentrate in comparatively small areas suitable for their feeding and survival. This concentration of adults results in the formation of groups. Therefore, in addition to behavioural changes, change in the colour also