The 2019–2020 upsurge of the desert locust and its impact in Pakistan

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Academic editor: Daniel Petit | Received 15 March 2021 | Accepted 10 May 2021 | Published 7 October 2021

http://zoobank.org/66ADFDBD-4372-4F8C-8374-60DD4C76CFA2

Citation: Sultana R, Kumar S, Samejo AA, Soomro S, Lecoq M (2021) The 2019–2020 upsurge of the desert locust and its impact in Pakistan. Journal of Orthoptera Research 30(2): 145–154. https://doi.org/10.3897/jor.30.65971

Abstract

The recent upsurge of the desert locust *Schistocerca gregaria* (Forskål, 1775) has had an impact on East Africa and the Middle East as far as India. It has affected and slowed down many aspects of the Pakistani economy. Swarms of locusts have infested many areas and caused immense damage to all types of crops. Both farmers and economists are concerned and are trying to get the most up-to-date information on the best strategy to manage this pest. This paper is an attempt to (i) provide insight into the dynamics of this upsurge internationally as well as in the various regions of Pakistan, (ii) briefly assess its local impact and locust control measures, and (iii) clarify the role of the various stakeholders in the management, both nationally and internationally, suggesting various improvements for the future.

Keywords

control strategies, crop damage, desert locust, outbreak, pest, *Schistocerca gregaria*

Introduction

In 2019 and 2020, large swarms of desert locusts again threatened parts of East Africa and large areas as far as India and Pakistan via the Arabian Peninsula. The Food and Agriculture Organization (FAO) of the United Nations has described this locust situation as the most serious in decades (FAO 2019, 2020a). The swarms reached Kenya, Uganda, and Tanzania, which had not faced a threat of this magnitude for 70 years. Although we have already seen classic images of these devastating swarms in the past, their impact is still impressive. Trees can twist and branches can break under the weight of locusts. Without adequate means of control, farmers are made desperate by the loss of their crops. Equipped with manual sprayers and often poorly protected against insecticides, technicians try to fight against these insects where only aerial means would be effective. Fortunately, even if detected too late, this upsurge quickly became the subject of major control operations, with the assistance of various donors and under the coordination of the FAO. However, after two years of intensive fighting, the situation is still not under control. In early 2021, calm returned to Southwest Asia, and in particular Pakistan, but these swarms have yet to be contained in the Horn of Africa (Dowlatchahi et al. 2020b).

The desert locust *Schistocerca gregaria* (Forskål, 1775) (Insecta: Orthoptera: Acrididae) is considered a serious agricultural pest in West and North Africa, the Middle East, and Southwest Asia (Steedman 1990, Cressman 2016, Lecoq 2019), and regular invasions of this insect pose a real threat to agricultural production and have devastating consequences for food security in more than 50 countries (Lecoq 2003, 2004, 2005, Brader et al. 2006). The social impact of an invasion can be visible in the long term, even after 20 years (De Vreyer et al. 2014). Like other locust species, the desert locust exhibits phase polyphenism, a plastic response to population density associated with several changes in behavioral, morphological, anatomical, and physiological traits. Isolated, harmless, and hidden solitary locusts transform into huge hopper bands and devastating swarms of the gregarious form under conditions of overpopulation (Uvarov 1921, 1966, Pener and Simpson 2009, Piou et al. 2017). Of the 31 million km^2 that can be invaded by the desert locust (the invasion area), the remission area (where low-density solitary-phase populations exist during calm periods) covers only 15 million km^2. In this zone, the outbreak areas (where the first outbreaks that could lead to invasions occur due to appropriate ecological characteristics) occupy an even smaller area of about 1.7 million km^2 (Sword et al. 2010, Gay P.E. p.c.).

The lifespan of a locust generation, under optimal conditions, is 40–50 days, and the annual number of generations varies between two and three. Young adults may remain immature (quiescent) for several months until they find moist conditions favorable for egg laying, with 20–25 mm of rainfall being normally sufficient (Duranton and Lecoq 1990, Symmons and Cressman 2001). As rainfall is seasonally distributed throughout the habitat area, this results in the existence of three main breeding seasons—spring, summer, and winter—between which the imagos undertake seasonal migrations to benefit from favorable breeding conditions (COPR 1982, Duranton and Lecoq 1990, Steedman 1990, Symmons and Cressman 2001). During periods of remission, solitary populations are dispersed in desertic areas. There, gregarization (transformation of locusts from solitary to gregarious) begins in the outbreak areas, thanks to rainy sequences favorable to reproduction in grouped vegetation and on mainly sandy or sandy-clay soils (Collett et al. 1998, Despland et al. 2000, Cissé et al. 2013). Outbreaks develop and then, if good conditions persist, follow increasingly severe phases of upsurge and plague (classic terminology defined by FAO 2009a) as populations and the number of occupied sites increase. The invasions develop intermittently and, in the past, have frequently persisted for 5, 10, or more years (Sword et al. 2010).

Since the 1960s, a preventive control strategy has been recommended by the FAO based on the monitoring of outbreak areas and ecological conditions (Showler et al. 2021, Lecoq 2003, 2004, Sword et al. 2010), followed, if necessary, by early intervention and thus limited use of pesticides. The implementation of this strategy helps to maintain low densities and to stop any outbreak as soon as possible (Duranton and Lecoq 1990, Martini et al. 1998, Magor et al. 2008, Sword et al. 2010). Consequently, and with 60 years of hindsight, it is clear that invasions are now less frequent, smaller in scale and, if they cannot be stopped at an early stage, shorter and better managed (Magor et al. 2008, Sword et al. 2010). However, financial and political uncertainties, as well as recurrent insecurity in many areas of desert locust distribution, continue to maintain the threat, and some outbreaks cannot be stopped at an early stage, as was observed again recently (Meynard et al. 2020, Showler and Lecoq 2021, Showler et al. 2021).

Pakistan has historically been subject to periodic swarm invasions. The country also contains outbreak areas, where particularly ecological conditions can favor, when suitable rains occur, the concentration, reproduction, and intensive multiplication of locusts and give rise to outbreaks and plagues. In recent years, the greatest outbreaks were noted in 1993 and 1997. These invasions have caused incalculable damage to crops, sometimes leading to severe famines. The recent upsurge in 2019–2020 seriously affected the country (Dowlatchahi 2020a). Here, we present a summary of these two years of upsurge by focusing on its impact in Pakistan, the damage caused in this country, and the surveillance and control operations undertaken. Furthermore, we try to clarify, both nationally and internationally, the role of the various stakeholders in the management of this pest, suggesting some improvements for the future.

Materials and methods

The general pattern of the current global upsurge was taken from the Desert Locust Bulletin produced monthly by FAO-DLIS (Desert Locust Information Service) in Rome based on information from all the countries within the desert locust habitat area (FAO 2019, 2020a). These bulletins also provide information about the likely migration of swarms based on the study of the meteorological situation and the use of migration trajectory models. Meteorological data and remote sensing imagery are used to help estimate rainfall, detect green vegetation, and identify areas where ecological conditions may be favorable for locust breeding (Cressman 2008). Regarding Pakistan, close contacts were maintained with the Department of Plant Protection (DPP)—the lead institution tasked with monitoring and managing the desert locust threat in Pakistan—to obtain information on the ongoing invasion and damage in various regions of the country. Desert locust field information was collected by DPP survey teams according to a standardized procedure recommended by FAO-DLIS and was used to produce monthly locust situation maps (Cressman 2001). Contacts were also maintained with inhabitants, farmers, and local entomologists to obtain more daily information on the presence and migration of locusts. In addition, field surveys were carried out by the authors in different locust-affected localities, mainly in Sindh province; locust samples were collected, and photos were taken in different affected areas of Sindh to document the situation on the ground.

Results

General course of the desert locust upsurge in 2019–2020

The last major desert locust plague ended in 1962 (Magor et al. 2008, Sword et al. 2010). In recent years, for Pakistan, the greatest outbreaks were in 1993 and 1997 (FAO 1993, 1997). Globally, the last major upsurge was in 2004–2005 (FAO 2004, 2005). At the end of 2018, the situation was calm throughout the desert locust habitat area (FAO 2018). The FAO situation bulletins contained almost no observations; in particular, no gregarious formations were reported, and there was a single report of a group of hoppers in northern Somalia during September. Then suddenly, in December 2018, laying swarms were reported on the coast of the Red Sea, in Sudan, and in Eritrea. In January 2019, such laying swarms were also seen on both sides of the Red Sea, and immature swarms were seen in Saudi Arabia (FAO 2019). Iran and Pakistan were warned of the possible migration of swarms. The situation quickly escalated in the following months (Figs 1, 2). Southern Iran was affected in February, Pakistan in March, and India in May. The desert locust situation continued to worsen across the Arabian Peninsula. In June, the Horn of Africa (Sudan, Eritrea, Djibouti, and Somalia) was affected by swarms originating from Yemen. In this region, the cyclonic rains and floods of October and November 2019 created good conditions in which the desert locust could continue to multiply. Kenya was infested as of December 2019. From June to December, the locust situation remained serious in southwest Asia, particularly in Pakistan and western India. In 2020, the desert locust situation continued to worsen (FAO 2020a). Strong spring breeding occurred in April, May, and June. The locust situation remained critical in the eastern region in Iran, Pakistan, and India until August and was only brought under control beginning in September. This was largely a result of the capacity and experience of these countries to monitor and control desert locusts in their outbreak areas. On the other hand, the desert locust situation did not improve on both sides of the Red Sea and the Horn of Africa, where, in December 2020, it was deemed very critical. In the end, and for the moment, only West Africa has been spared.

Although not seen until January 2019, the development of this upsurge was the result of favorable conditions for the desert locust, which were occurring as early as 2018. Two cyclones brought heavy rains in the Rub al Khali, or Empty Quarter of the Arabic peninsula, in May and October 2018 (FAO 2020b). Rains were very heavy in Yemen, Oman, Djibouti, northern Somalia, eastern Ethiopia, and southern Saudi Arabia (Meynard et al. 2020). Favorable conditions for desert locust breeding were maintained for many consecutive months, allowing at least three successive generations to develop. However, locusts went undetected and unchecked for a significant amount of time, mainly due to the insecure conditions in the areas of origin, particularly in Yemen (Showler and Lecoq 2021). Had the initial outbreak in Saudi Arabia's Rub al Khali been detected in the early stage and controlled in the summer of 2018, swarms may not have reached Yemen, the

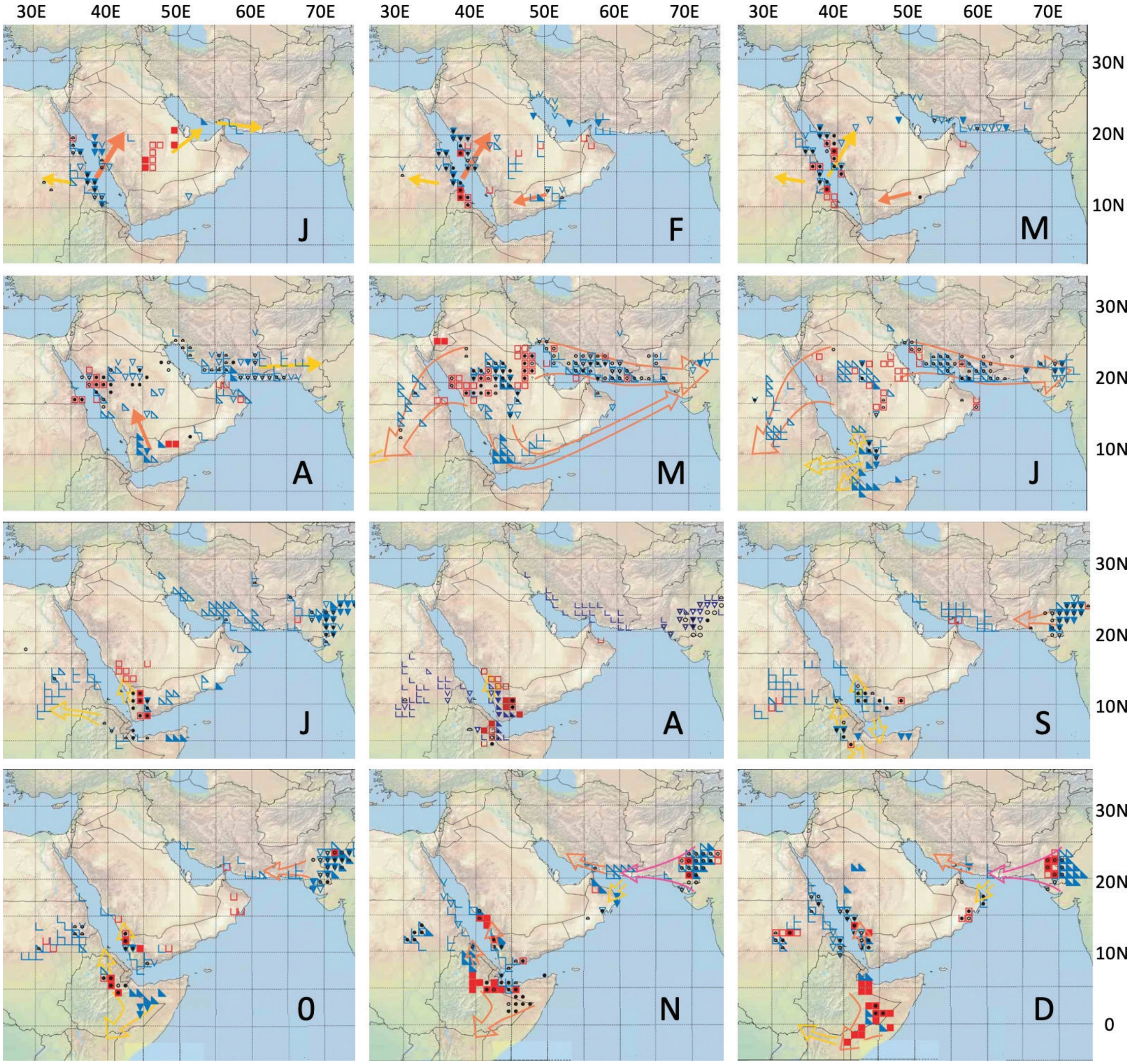

Fig. 1. General situation of the desert locust from January to December 2019 (modified from FAO 2019). Swarms or hopper bands: immature adults, red square; mature adults, blue triangle; maturity unknown, black triangle up; egg laying or eggs, black triangle down; hoppers, black circle; hoppers and adults, combined symbols. Groups of adults or hoppers: same symbols but hollowed out. Density unknown: same symbols, but partial.

African Red Sea coast, and parts of Iran. In addition, an initially weak response in Iran (where very heavy flooding in the southwest of the country allowed two generations of breeding) allowed swarms to move to Pakistan and India (FAO 2020c, d), where an unusually long summer monsoon resulted in three generations of breeding along both sides of the Indo-Pakistan border.

The 2019–2020 upsurge dynamic in Pakistan

In early 2019, no locusts were reported in Pakistan. It was not until March that isolated solitarious adults first appeared on the Baluchistan coast in the Uthal region west of Karachi, presumably coming from Iran, which had been invaded in previous months. On the 16th March, a mature swarm and groups of mating and laying adults were seen on the coast at Pasni, on the Iranian border, and in the Kulanch valley region, west of Pasni (Fig. 3). These arrivals continued in April, and the migrant populations continued to lay eggs. In April, the first larvae of the spring reproduction appeared in Balochistan in the coastal areas of Pasni. Hoppers continued to emerge and develop in May between Turbat and Gwadar, near Uthal, and in the interior near Kharan. Groups of gregarious hoppers of all stages were then found, mixed with scattered adults. The spring breeding ended in early June in Balochistan, with a last report of a laying swarm

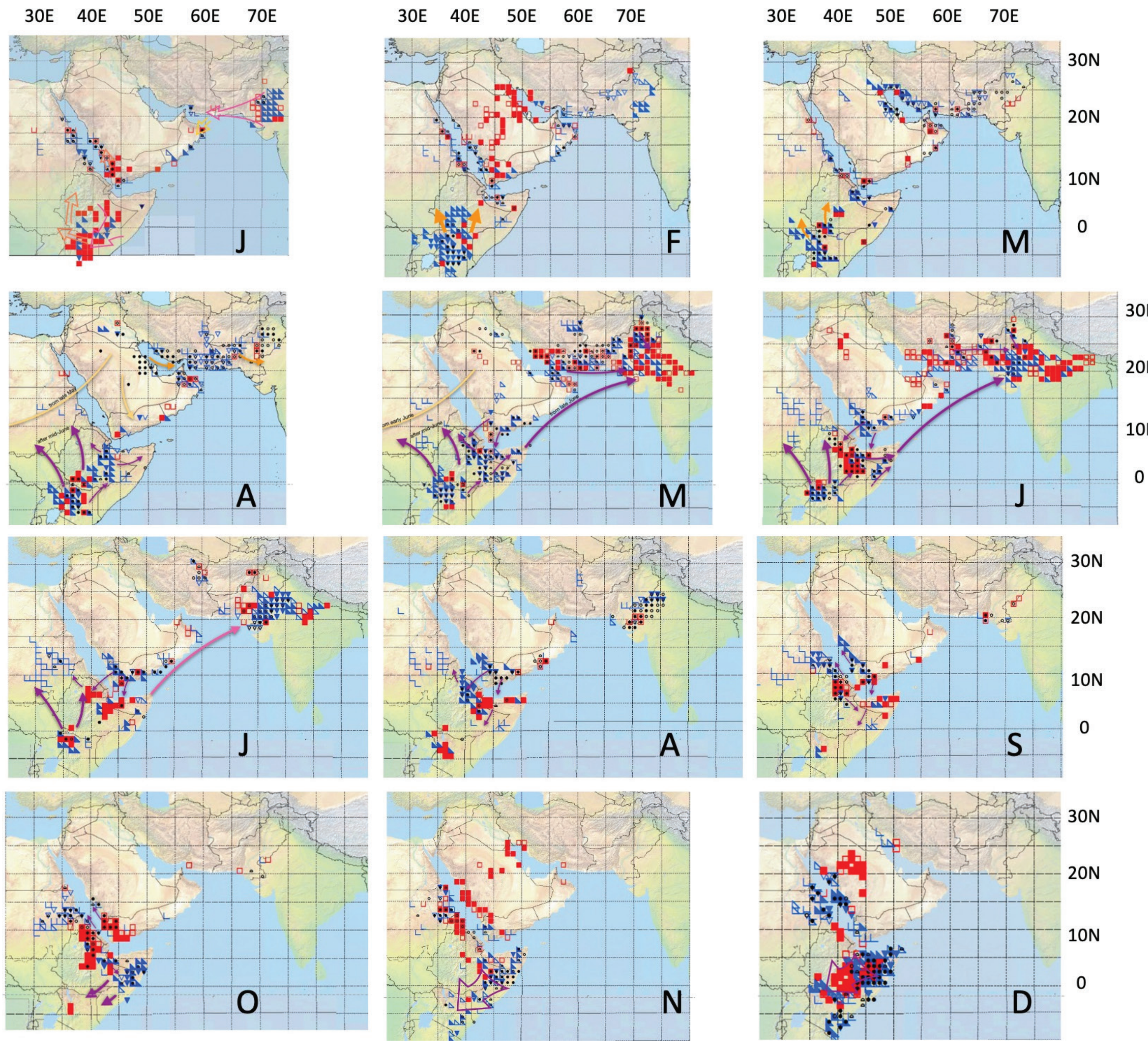

Fig. 2. General situation of the desert locust from January to December 2020 (modified from FAO 2020a). Swarms or hopper bands: immature adults, red square; mature adults, blue triangle; maturity unknown, black triangle up; egg laying or eggs, black triangle down; hoppers, black circle; hoppers and adults, combined symbols. Groups of adults or hoppers: same symbols but hollowed out. Density unknown: same symbols, but partial.

on 1st June near Lasbela, while hoppers and hopper groups persisted near Lasbela, Turbat, Gwadar, and in the northern interior near Dalbandin.

The adults from the spring breeding gradually migrated to the summer breeding area (June–November) on the Indo-Pakistan border. Some swarms may have originated from the Horn of Africa after migrating over the Indian Ocean. This summer breeding started at the end of May with scattered gregarious adults that appeared during the last week of May near the Indian border southeast of Chaman starting to lay. It developed mainly in June, July, and August in the Nara, Cholistan, and Thar deserts east of the Indus Valley. In Cholistan, egg laying continues until August. Thus, from mid-August, outbreaks of a second generation caused locust numbers to further increase. This second generation developed mainly in September, October, and November. Widespread breeding was then observed in the deserts of Cholistan, Nara, and Thar, where numerous hopper bands were forming, giving rise to numerous swarms. During November and December, a third generation of breeding occurred in the Thar, Nara, and Cholistan deserts, where numerous hopper groups formed, resulting in numerous adult groups and immature swarms (FAO 2019) (Fig. 4).

The swarms then began to move westward to the winter-spring breeding areas (February–June). Cross-border movements of swarms from the summer breeding areas of Rajasthan in India occurred. On 11 November, an immature westward swarm was seen flying over Karachi. In southern Balochistan, immature swarms from the summer breeding areas started to arrive in December.

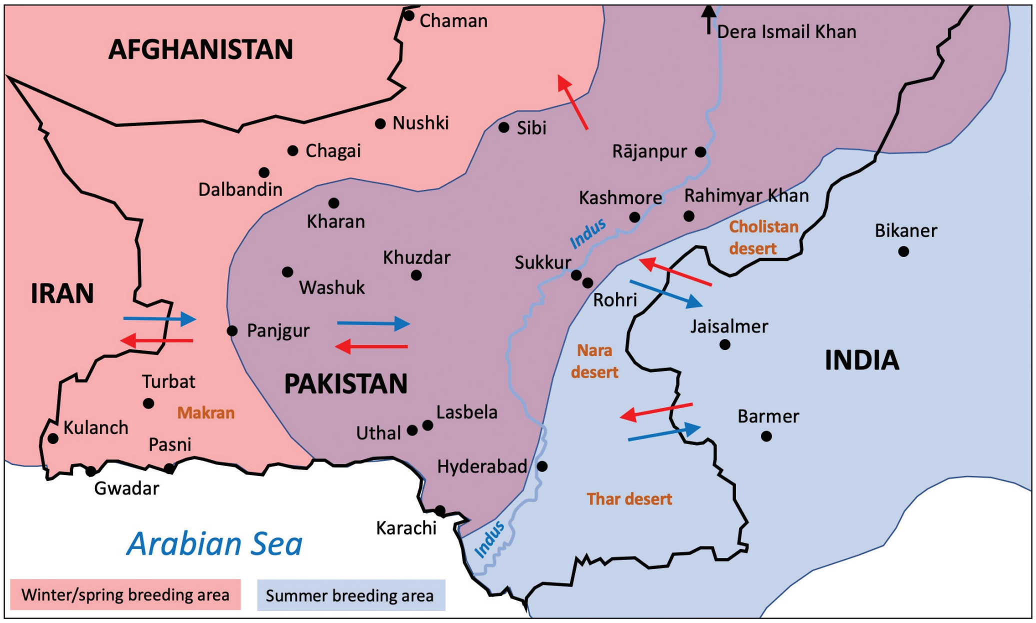

Fig. 3. Desert locust breeding areas in Southern Pakistan during invasions (adapted from Symmons and Cressman 2001). Arrows: main orientation of migrating swarms in March–July (blue) and August–October (red).

In January 2020, a few nymphs of the 3rd generation continued to molt. Groups of immature adults persisted in the Thar, Nara, and Cholistan deserts. Cross-border movements of immature swarms continued westward. On 21 February, three swarms reportedly arrived in the Afghan province of Khost from adjacent areas in northwest Pakistan.

A new spring breeding started in March 2020 and went until May. During March, breeding took place mainly in Balochistan (Khuzdar, Nushki, Washuk, Kharan and Dalbandin, Chagai, Panjgur, Turbat, and Pasni) and in the Indus valley (Rajanpur, Kashmore, Sukkur, Dera Ismail Khan, and Rohri), as well as in the plains of Punjab. Breeding continued into April and May, and a second generation of laying began in mid-April in the north near Dalbandin in Balochistan. As a result of this breeding, an increasing number of adult groups and immature swarms formed and began to mature during May.

During June, as conditions dried out, these swarms moved from the spring breeding areas eastward to the summer breeding areas of the Cholistan, Nara, and Thar deserts in Punjab and Sindh provinces. Some continued to India due to the too-dry conditions. Summer breeding started in late June and continued into July and August. Numerous first-generation hopper groups and bands formed, especially in the Thar desert up to the Indian border in the extreme southeast of Sindh. The imaginal molts began during the first week of August, causing groups of immature adults to form on the Indian border.

Then, in September, the situation improved dramatically. In Sindh, a very limited second-generation breeding occurred in September west of Hyderabad and in Tharparkar. Improvement continued in October, and no locusts were seen in November and December (Dowlatchahi et al. 2020b, FAO 2020a, d).

Damage and control measures in Pakistan

Damage.—The desert locust can consume most plant species and crops (COPR 1982). Only a few plants are not eaten, such as the neem *Azadirachta indica* A. Juss., Genista sp. (broom bush), and *Euphorbia hirta* L. (asthma plant). Indeed, during this upsurge, a great deal of damage was caused to all types of crops, including wheat, cotton, rice, sugarcane, tobacco, corn, chickpea (gram) sunflower, sorghum, pearl millet, mung bean (*Vigna radiata* (L.) R. Wilczek), muth bean (*Vigna aconitifolia* Jacq.), sesame, cluster bean (guar), potato, tomato, cabbage, cauliflower, carrot, peas, onion, melon, cucumber, water-melon, chilies, eggplant (brinjal), okra (lady finger), mango, citrus, apple, grapes, strawberry, peaches, banana, and guava.

This upsurge has been devastating for a country where agriculture represents around 20% of the GDP and where 61% of the population lives and works in agricultural areas (FAO 2016). About 52 districts were reported to have suffered locust damage. According to FAO estimates in May 2020 and assuming that the damage accounts for about 25% of growing crops, losses could reach 353 billion Pakistani rupees (2.19 billion US$) for "rabi crops" (sown in winter and harvested in spring) and about 464 billion Pakistani rupees (2.88 billion US$) for "kharif crops" (summer sown crops) (FAO 2020e). The final balance has yet to be established and, in the end, the damage from this upsurge will undoubtedly be much higher. In 2020, the Government of Pakistan's preliminary estimate of monetary losses due to desert locusts over the two coming agricultural seasons in 2020 and 2021 may range from 3.4 billion US$ to 10.21 billion US$. More than 3 million people in Pakistan are facing severe acute food insecurity, with the situation particularly precarious in Balochistan. It is estimated that approximately 34,000 households will need emergency livelihood and food security assistance due to crop losses. Many more people may be indirectly affected by crop losses, leading to price rises in key commodities (FAO 2020).

Control measures.—To better coordinate control operations, the Government of Pakistan declared the locust invasions to be an emergency. Many anticipatory measures have been taken in collaboration with the FAO, in coordination with neighboring countries, and with the support of international partners to face the threat and be ready to respond quickly and effectively (FAO 2019, 2020a). In addition, the Space and Upper Atmosphere Research

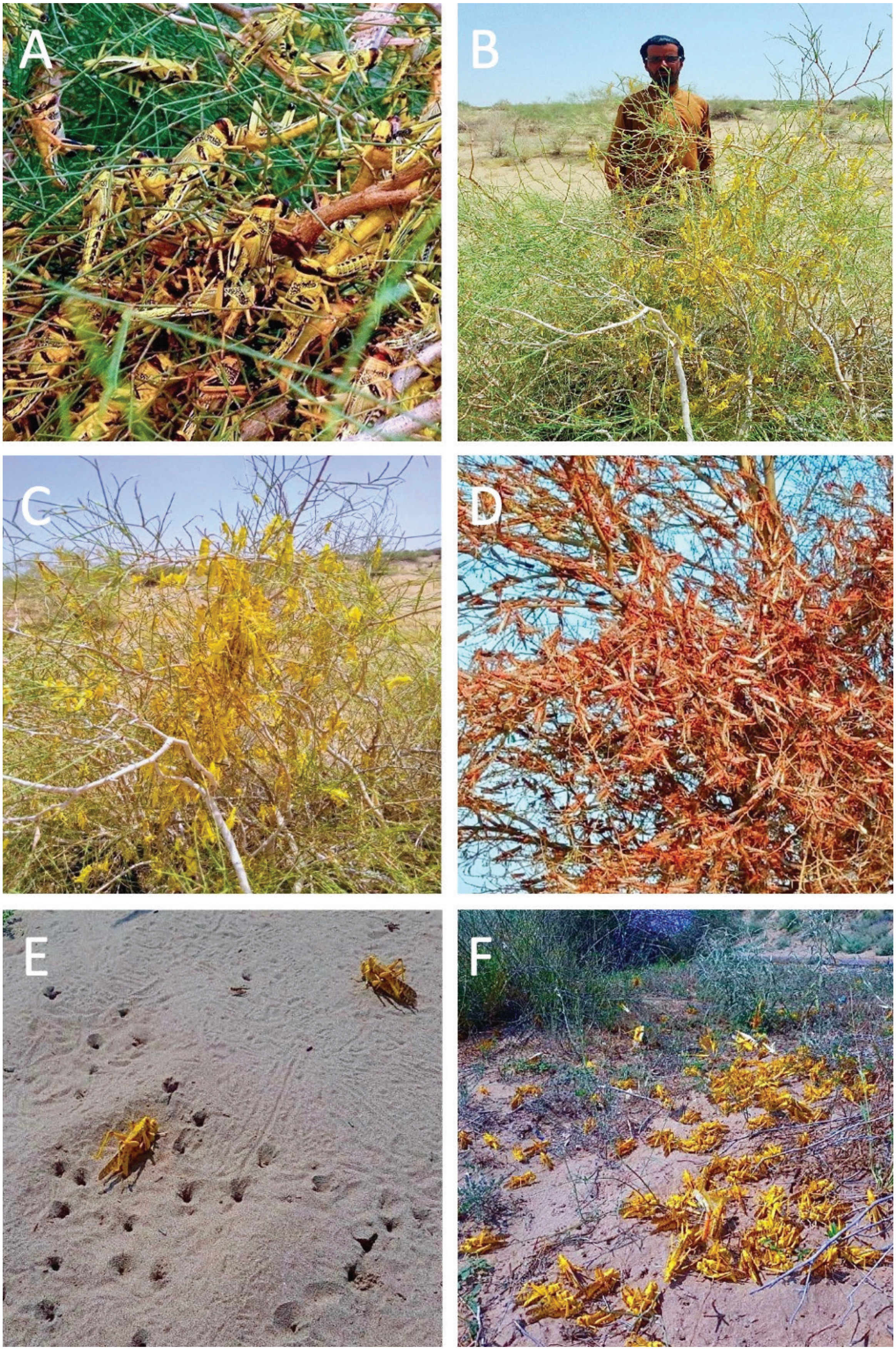

Fig. 4. Photos of the desert locust in Pakistan. **A–D.** Outbreaks in various localities during the 2019–2020 upsurge; **E, F.** Individual and group mating in the Thar desert (photos from the authors).

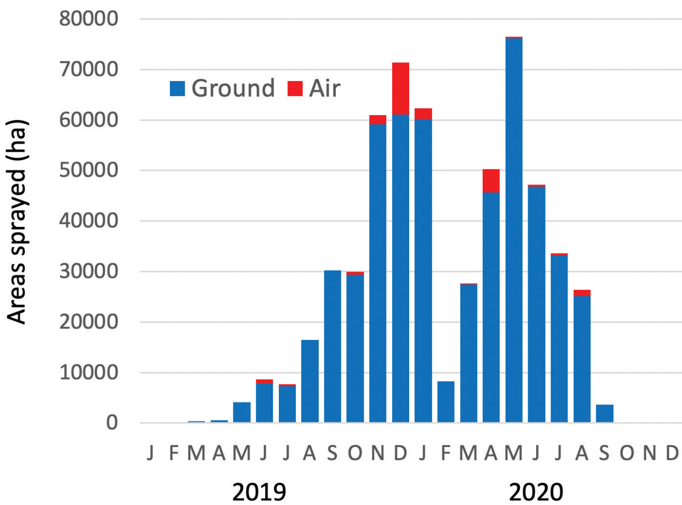

Fig. 5. Areas sprayed with pesticides in Pakistan to control the desert locust upsurge in 2019–2020 (source FAO 2019, 2020a).

Commission (SUPARCO) has helped through the use of remote sensing used to delimit the areas more vulnerable to locust attacks in the various affected districts of Pakistan based on vegetation, soil type, and other factors.

Large areas, about 65 M ha, were surveyed by the DPP, and in 2 years, based on data collected by the FAO (2019, 2020a), a total of 566,390 ha was treated (FAO 2019, 2020b). Most of the treatment was done using specialized ultra-low volume (ULV) vehicle-mounted sprayers, mainly with malathion (ULV formulation) in desert areas and lambda-cyhalothrin (EC formulation) for protection against desert locust attacks in crop production areas; 543,370 ha were treated by land (Fig. 5). Only a small part was treated by air (23,020 hectares). According to DPP, aerial spraying was carried out on locust hoppers when large areas were involved; otherwise, ground spraying was considered more effective. As with other neighboring South Asian countries, Pakistan was unprepared for the scale of the upsurge (Balakrishnan 2020). One challenge DPP had to deal with was obsolete or non-functional equipment for control operations, as the last serious desert locust outbreak was over 25 years ago (Dowlatchahi et al. 2020b). Small aircrafts for pesticide spraying were unavailable or not operational. Some also expressed regret that control operations started too late and that the federal government did not take the threat seriously enough from the start in 2019, when locusts were confined to Balochistan (Ellis-Petersen and Baloch 2020, Nawaz 2020). When operations finally started, despite the efforts of government authorities, DPP, local authorities and local inhabitants/farmers, it took 16 months, from March 2019 to September 2020, for the upsurge to be brought under control in Pakistan and in the whole eastern region, including India and Iran. Ultimately, the control of this upsurge was a success, which was the result of extensive, strategically planned, and technically well-executed control operations in the country. Strong coordination at federal and provincial levels and with all relevant actors carried out under the National Locust Control Centre set up in Islamabad increased the effectiveness of the response (Dowlatchahi et al. 2020b). For all the countries affected by this upsurge, 4,891,150 ha were treated for the years 2019 and 2020 (Table 1). However, at the start of 2021, the situation remained very worrying in the Horn of Africa and in the Arabian Peninsula. It is not yet time to put down our guard, and vigorous monitoring to detect any signs of breeding desert locust is necessary (Dowlatchahi et al. 2020b).

Table 1. Areas sprayed with pesticides to control the desert locust upsurge in 2019–2020 over all affected regions (source FAO 2019, 2020a).

Countries	ha sprayed	Countries	ha sprayed	Countries	ha sprayed
Afghanistan	2969	Jordania	2900	Saudi Arabia	505829
Algeria	1138	Kenya	168484	Somalia	170495
Bahrain	3	Kuwait	15841	Sudan	331368
Egypt	24206	Libya	70	South Sudan	250
Eritrea	113794	Mali	40	UAE	6102
Ethiopia	1177607	Mauritania	1056	Uganda	7154
India	682790	Niger	3897	Yemen	58709
Iran	1036510	Oman	13907		
Iraq	2610	Pakistan	566390	TOTAL	4891150

In some areas, local governments have announced compensation measures for farmers who have suffered from locust attacks. Amid the current COVID-19 pandemic, farmers have found it difficult to control locusts on their own due to restrictions on transport and communication. The supply of reliable, affordable pesticides and spraying equipment has been insufficient. There are no crop insurance programs in the country, and in some areas, farmers have had to plant crops twice, as the first crops were completely eaten up by locusts. Locusts were not only attacking crops, but also damaging rangelands and other vegetation. Thus, livestock keepers and nomadic communities were also suffering. Such damage was most visible in arid regions like Balochistan, where rangelands were already in poor condition. Many affected areas were not treated due to a lack of small airplanes that can be used for spraying pesticides.

Farmers have been known to adopt different ways to protect their crops besides insecticide treatments. For instance, one measure taken by many was beating drums at high volume to scare the locusts. In some areas, farmers also used smoke from burning bushes and vegetation to repel them. According to some local people, since the last major attack was 58 years ago, the current generation has no direct experience of handling locusts using local knowledge (Nawaz 2020). They may not be fully aware of methods to catch locusts or about how to use them as a food source, a compensatory measure that can reduce the number of locusts locally and provide a food supplement to poor and undernourished rural populations (Samejo et al. 2021).

Discussion

The way forward—Institutional aspects and preventative actions for the future

The situation Pakistan faced in 2019–2020 was the most serious in many years. Nevertheless, desert locust invasions are now better controlled, being less frequent, less important, and of shorter duration than in the past (Sword et al. 2010, Zhang et al. 2019). The large invasions that followed one another with a high frequency ended at the beginning of the 1960s with the establishment of a proactive/preventive strategy and thanks to increasingly effective surveillance and continuously improving control methods (Magor et al. 2008, Sword et al. 2010, Lecoq 2019).

Clearly, the problem remains. These invasions are, as always, the result of exceptionally big rains that occurred in the past and that are certain to continue to occur. Presently, climate change cannot be blamed for the ongoing upsurge, even though it will undoubtedly have consequences for outbreaks of this insect in the future (Meynard et al. 2020). Thus, these desert locust invasions will continue to occur. Upsurges over the past 50 years that were not stopped at an early stage were the result of gaps or a lack of vigilance in the prevention system implemented at the international level (Lecoq 2001, 2005). Most often, insecurity in key areas or the too-late provision of emergency funds are the cause of these upsurges. Then, control operations start too late, often in countries that are still poorly prepared, and the swarms disseminate rapidly (Showler and Lecoq 2021). Therefore, the countries concerned, and Pakistan in particular, must remain mobilised to improve the prevention system. Addressing these challenges requires investment into making the country capable of handling the menace (Dowlatchahi et al. 2020a, b). For more information on prevention system failures, see Showler (2019) and Showler et al. (2021).

Like other front-line countries, Pakistan contains certain desert locust outbreak areas, located in desertic areas on the Indo-Pakistan border and in the Makran region on the border with Iran (Symmons and Cressman 2001, Cressman 2016). Pakistan, therefore, plays a key role in the prevention strategy by conducting regular surveillance of these areas. However, the country can also be invaded by swarms that originate outside its borders, as was the case in 2019. International cooperation is essential to better control these migratory insects. As mandated by its Member States, the FAO ensures the coordination of monitoring and control activities of the desert locust on an international scale (Lecoq 2003). Via its Desert Locust Information Service (DLIS), it issues a monthly locust situation and forecast bulletin (FAO 2009b). This bulletin is based on reports from the affected countries, as well as on the analysis of the ecological conditions in the habitats of the locust (using satellite remote sensing data, weather reports related to rains and direction of the winds, etc.) (Cressman 2008, 2013). In addition, the FAO provides a forum for the meetings of the Desert Locust Control Committee (DLCC), formed by representatives from all the countries affected by desert locust as well as those that take part in locust control campaigns.

Since 1955, Pakistan has been a member of both the DLCC and the South West Asia Commission (SWAC), established in 1964 under Article XIV of the FAO Constitution. SWAC has four member states: Afghanistan, India, Iran, and Pakistan. All activities of SWAC contribute to the strengthening of the national capacities of its member countries in desert locust survey, control operations, reporting, training, preparedness, contingency planning, emergency response, biopesticides, and health and safety (FAO 2021a). SWAC also promotes cooperation among its member countries and, in particular, the conduct of regular joint surveys for desert locust surveillance and early warning, as well as the exchange of information on the locust situation. It supports training and capacity building activities and the promotion of new technologies (FAO 2021a). SWAC is also collaborating with the other two FAO commissions—CRC for the central region and CLCPRO for the western region (FAO 2021b, c)—with regard to the use of biopesticides, the development of risk management plans, setting up inventory systems, and environmental monitoring. Obviously, all of these measures should be developed at the level of each member state, and it is in Pakistan's interest to strengthen its cooperation with SWAC.

As a result, monitoring and preventative organization against desert locust invasions is a leading example in the field of crop protection (Hamouny 2021). However, while this prevention system is genuinely effective, it also has its flaws, as the current situation unfortunately reminds us. Various reasons for failure have been given: inexperience of field survey teams and campaign organizers, insufficient or inappropriate resources, inaccessibility of some important breeding areas for security reasons, deterioration of survey, and control capacities during recession periods (WMO & FAO 2016). Some issues, such as security concerns, are beyond Pakistan's control. Others may find solutions locally. We give details on three main points below.

1. Desert locust require concerted monitoring and on-the-ground control effort across borders, along with the resources, expertise, and infrastructure to support those actions. Moreover, these efforts must be kept in place over the long term to build resilience, despite the apparent lack of imminent threats (Lecoq 1991, Gay et al. 2018). The lack of such coordinated and sustained efforts is likely to put human populations at higher risk. Pakistan had to fight the recent upsurge with insufficient funding, operational resources, obsolete equipment, and an eroded expertise that left the DPP with only a few high-level experts (Dowlatchahi et al. 2020a, b). The highest priorities should therefore be (a) to ensure that the political and socio-economic conditions are in place so that vulnerable human populations can adapt to new large-scale threats and (b) to maintain a long-term risk assessment culture with ongoing financial, material, and expertise support (Meynard et al. 2020). Perhaps maintaining funding mechanisms that provide sustainable support during periods of recession, when priorities are elsewhere, is one of the most difficult but key points to be solved. Yet, it has been shown that funding institutions (governments, donors) could considerably improve the effectiveness of the prevention system by increasing their support by only a few percent (Gay et al. 2018).

2. Pakistan, as with all countries concerned with the desert locust, must remain ready and develop compensatory measures for the local populations in the event of an invasion that is not controlled early on. Farmers are most often helpless in the face of the threat from locusts. Prevention remains the best rampart, but if this fails, local populations must have access to information, advice, and support, both technical and financial. It is advisable, for instance, to develop desert locust control material for the education of farmers and agriculture extension staff and organize farmers' schools for desert locust control.

3. Finally, current treatments are based almost exclusively on traditional chemical insecticides that pose various risks to both human health and the environment (Everts and Ba 1997, Samways and Lockwood 1998, van der Valk 1998, Peveling 2001, FAO 2014). The end result of these quick control measures is still massive damage, both to crops and, perhaps worse, to the ecosystem, from the enormous amounts of pesticides sprayed (Balakrishnan 2020). Alternative products such as mycopesticides, which have been used for some time by countries such as Australia and China, should be able to find a larger audience globally (Lomer et al. 2001, Hunter 2004, 2010, Zhang and Hunter 2005, Zhang 2011). These products are currently commercially available, and the ongoing upsurge has given rise to their use in various countries (Zhang et al. 2019). In 2020, mycopesticides were successfully applied to at least 10,845 ha in Somalia against desert locusts (FAO 2020g, h). In collaboration with the FAO, trials focused on the introduction of mycopesticides in Pakistan have been done, which should obviously be encouraged.

Acknowledgments

We greatly appreciate the constructive and valuable support of Dr. M. Tariq Khan, Director Technical, Department of Plant Protection Karachi, for providing updated information and data. This study was funded by the Higher Education Commission Islamabad, Pakistan (Project No. 6737 SINDH /NRPU /R & D/ HEC). The authors also thank the Orthopterists' Society for supporting the publication of this article.

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