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Establishment of the Invasive Cactus Moth, *Cactoblastis cactorum* (Berg) (Lepidoptera: Pyralidae) in Pakistan: A Potential Threat to Cultivated, Ornamental and Wild *Opuntia* spp. (Cactaceae)

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Establishment of the invasive Cactus Moth, *Cactoblastis cactorum* (Berg) (Lepidoptera: Pyralidae) in Pakistan: a potential threat to cultivated, ornamental and wild *Opuntia* spp. (Cactaceae).

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ABSTRACT. Subsequent to the significant accomplishment of biological control of *Opuntia* weeds in Australia, the larvae of the cactus moth, *Cactoblastis cactorum* (native to parts of South America), were released in many countries for the biological control of native *Opuntia* species (Simmonds & Bennett, 1966**)**. Inauspiciously, larvae were also released in the Caribbean, where the moth spread naturally and by the human support all over the region (García-Turudi et al, 1971). Its enhanced dissemination rate and the biological potential for invasiveness, suggests that the cactus moth is likely to become an invasive pest of *Opuntia* in the Southeast United States, Mexico and southwestern America. Its damage is restricted mainly to the plants of genus *Opuntia* (plants with the characteristic of flat prickly pear pads of the former genus *Platyopuntia*, now considered to be the part of the genus *Opuntia*). In this region, plants of this genus provide valuable resources for humans, livestock, and wildlife such as food, medicine, and emergency fodder, while in the arid and semi-arid regions, the plants play key roles in ecosystem processes and soil conservation. At present, the cactus moth has developed into a severe threat to the high diversity of prickly pear cacti, all over the world for both the native and cultivated species of *Opuntia* (IAEA, 2002).

During the year 1994, the larvae of *C. cactorum* were also released in Pakistan for the control of naturalized wild *Opuntia* weed in the district Chakwal, Punjab. The establishment of the cactus moth was not confirmed in Pakistan after its release in district Chakwal until December 2016 and various unconfirmed presence records of many authors have been found (e.g., Julien & Griffiths, 1998; Zimmermann et al., 2004; Legaspi & Legaspi, 2010; EPPO, 2021). Twenty-three years after the introduction of *C. cactorum* larvae in Pakistan, presence of larvae was monitored on cultivated prickly pear cactus (i.e., *Opuntia ficus-indica* (L.) Mill.) where *O. ficus-indica* was introduced in three localities of district Chakwal for fodder purposes during 2014. Further surveys were conducted consecutively for wild *Opuntia* in the four tehsils of the district until August 2020 and it was found that all plantations of wild *Opuntia* in the district were severely infested with the larvae of the cactus moth. In 2019, all the three fields cultivated with spineless species (i.e., *O. ficus-indica*) had completely vanished. The occurrence of *C. cactorum* larvae on cultivated spineless species (*O. ficus-indica*) and wild *Opuntia* in the district of Chakwal, Punjab, Pakistan in December, 2016

is the first authentic record after the 1994 release of its larvae, which was not effectively studied after the release.

Additional key words: Invasive species, biological invasion, natural ecosystems, biological control, *Opuntia* cactus.

INTRODUCTION

The natural ecosystems that exist today are impartially different from those that have existed in the past and in many parts of the earth are being significantly changed owing to climate change and enormous alterations of the land for multipurpose activities (Mooney & Cleland, 2001; Sala et al., 2000). However, similarly drastic changes both beneficial and harmful are happening in the population, economic activities and community structure of natural ecosystems due to the occurrence of biological invasions (Pimentel et al., 2005; Vilà et al., 2011; Blackburn et al., 2014; Jeschke et al., 2014).

The phenomenon of biological invasion is characteristic of living organisms and has been occurring since the origin of life (animals, plants and microbes) and long before human existence on this planet. The incidence of biological invasion is of significant scientific attention and recurrently of socioeconomic importance (Mitchell & Gopal, 1991). Such biological invaders are known as "alien species" or invasive taxa occurring outside of their natural range and have potential to disperse. They are non-native, non-indigenous, introduced, foreign or exotic. An alien species which has become established outside its native range, in natural or semi natural ecosystems or habitats, which can threaten native species and biological diversity, is known as an "Invasive Alien Species" (IAS). Impacts of alien or alien invasive species on native fauna and flora can be found in all terrestrial and freshwater environs (Parker et al., 1999; Rahel, 2000).

Historical movement of biological organisms throughout the taxonomic groups, substantial travelling of humans and massive trade of goods and materials, helped the movement of species, worldwide; however, others are being traded among continents or various nations (Bryan, 1996; USBC, 1998). Recently, the introductory rate and the threat of IAS have increased immensely because of human population growth and human activities, which alter the environment at an alarming rate (Pimentel et al., 2000; Mooney & Cleland, 2001). The definite statistics of individuals and species which have transported and are being transported across bio-geographical boundaries daily are probably enormous. Unfortunately, this event has augmented species wealth in numerous places where new species are introduced (Mooney & Cleland, 2001). However, only an insignificant fraction of introduced species become established in a new environment, and among those usually about 1% become pests (Williamson, 1996).

Biological invasions

The world's most destructive 100 IAS include microorganisms, macro fungi, plants, invertebrates, amphibians, fishes, birds, reptiles, and mammals (Lowe et al., 2000). Rapid increase in their ranges is homogenizing the world's flora and fauna (Mooney & Hobbs, 2000) and such biological invasions may be observed as a form of biological pollution and major elements of global changes and one of the major causes of severe species declines that may be followed by extinction (Drake et al., 1999). They cause major economic losses in agriculture, forestry, many other sectors of the world economy and also negatively impact on ecological integrity in countries around the world, either by depressing growth of populations of more valuable species, or by direct impacts on human and animals. Invasive alien species of many weeds, arthropods, and animals are the greatest direct threats to biodiversity (Elton, 1958; Mooney & Drake, 1986; Mack & D'Antonio, 1998; Pimentel et al., 2000; Vilà et al., 2011; Blackburn et al., 2014).

In certain regions of the world enormous land and water bodies are completely dominated by invasive alien species of plants such as *Centaurea solstitialis* (the yellow star thistle) which is native to the Mediterranean Basin region, now found invasive in the rangelands of California; *Bromus tectorum* (cheatgrass) is native to Europe, southwestern Asia and northern Africa, and now invasive in the mountain ranges of the western USA; and *Eichornia crassipes* (water hyacinth) is an aquatic plant native to the Amazon basin, now invasive in numerous tropical lakes and waterways (White, 1985; Mitchell & Gopal, 1991). Besides that, invasive alien pathogens threaten humans and animals by causing emerging infectious diseases such as highly pathogenic avian influenza and swine influenza have the ability to mutate and threaten animals and humans (Hunter, 2009).

Many alien species have been introduced for beneficial purposes, and their beneficial impacts cannot be ignored, such as corn (*Zea mays* L.); rice (*Oryza sativa* L.); wheat (*Triticum* spp.); plantation forest; domestic chicken (*Gallus* spp.); cattle (*Bos taurus*); and many others that provide more than 98% of the world's food (Pimentel et al., 2001), with a value of more than US$ 5 trillion per year (USBC, 1998). Similarly, the European honey bee, *Apis melliferais*, native to Africa, Europe and western Asia, vigorously introduced in various countries by humans during the 17th century (Winston et al., 1981; Sammataro & Avitabile, 1998), is a highly valued species all over the world for its production of honey and is a keystone pollinator of many economically important crops and wild plants (Klein et al., 2007; Staveley et al., 2014; Pashte & Said, 2015). However, many alien species are used for landscape restoration, sport, pets, food processing, and biological control agents against pests (Mack & D'Antonio, 1998; Pimentel et al., 2000).

In many cases biological control has been severely prejudiced by abiotic factors, such as climatic factors (Olfert et al., 2016) which play a significant role in the growth and existence of flora and fauna; for example, insect pest species which are minor at their origin may become invasive in their new environment. There are numerous alien species that have been introduced as biological control agents for specific purposes, now have unwanted non-target effects; for example, in weed biological control the musk thistle weevil, *Rhinocyllus conicus* (Coleoptera: Curculionidae), introduced for the biological control of thistle weeds in Canada, 1968; in USA: Montana and Virginia during 1969 and in California, 1971 (Zwölfer & Harris, 1984), is now attacking the seed-heads of native thistles over large areas in the West and Central United States (Turner, 1985; Turner et al., 1987; Guretzky & Louda, 1997; Louda et al., 1997; Strong, 1997). The deliberate introduction of *Opuntia stricta* in Australia and Africa, attained the status of weeds (Dodd, 1940; Greathead, 1971; Foxcroft et al., 2004; Novoa et al., 2016).

The harmful effects of introduced biological control agents on organisms other than the target pest have, rightly, been critiqued and the safety of biological control as a practice has been questioned (Howarth, 1991; Miller & Aplet, 1993; Simberloff & Stiling, 1996; Thomas & Willis, 1998). Great care with strict guidelines is now required for the introduction of herbivores, mainly for plant-feeding insects (Howarth, 1991). Although much has been learned by the impacts of *Cactoblastis cactorum* in Australia, while plenty of evidences predicted the worst, but there are also warnings that preclude a repeat of the Australian experience.

Introduction of *Opuntia* spp. in Australia

In Australia no native prickly pear species were present, where prickly pear cactus (*Opuntia stricta* Haw.) was deliberately introduced in the year 1788 to establish a cochineal industry (Dodd, 1940). Cochineal is a valued source of dye i.e., red pigment carminic acid, mostly extracted from the scale insect species, *Dactylopius coccus* Costa; however, *D. coccus* did not survive there and, by the 1920s, *Opuntia stricta* invaded about 25 million hectares of land that was then useless for agriculture production (Dodd, 1940).

Importance of carminic acid dye

This dye was primarily used in food colouring, cosmetics, drugs, fabrics and many other products (Cañamares et al., 2006; Chávez Moreno et al., 2009), and also used to colour the typical red coats of the British soldiers in the past (Dodd, 1940). Eleven *Dactylopius* species (cochineal insects), in the monogenetic scale insect family Dactylopiidae, commonly known as cochineal scale insects, are a parasite of certain species of prickly pear cactus (Dapson, 2007), flourishing on *Opuntia* plants are mostly known as a natural basis of crimson dye. Fresh cochineal is a red liquid within the body of *Dactylopius* spp. from which crimson or carmine dye is extracted. These insects have been used for commercial purposes since the 16th century in Central and South America, in Mexico and in Spain (Chávez-Moreno et al., 2009; De Lotto, 1974; Pérez-Guerra & Kosztarab, 1992). Out of eleven *Dactylopius* species, *D. coccus* has been the main species which has been cultivated and used commercially because of the quality and quantity of its pigments (Piña, 1977); other species were also used (de Humboldt, 1811; Anderson, 1981). *Dactylopius opuntiaeis*is is also reared in many countries for the production of carmine dye. The economic importance of it is shown through its introduction to South Africa, Australia, India, Sri Lanka, etc. to improve the dye industry (Kumar et al., 2018). However, all the eleven species in the family Dactylopiidae are exclusively pests of cactus species (Caryophyllales: Cactaceae). Currently, there is ongoing research on the antioxidant and antimicrobial properties of carminic acid, to understand its potential applications in immunology, wastewater treatment and solar cells (González et al., 2009; El Moselhy et al., 2011).

Other importance of *Dactylopius* spp.

Some *Dactylopius* species have been used for biological control against invasive cacti (Volchansky et al., 1999; De Felice, 2004); *Dactylopius* spp. can become invasive to *Opuntia* species where they are non-native (Van Dam & May, 2012).

Biological control of *Opuntia* weed (*O. stricta* Haw.) in Australia

The larvae of the cactus moth, *Cactoblastis cactorum* (Berg), (Lepidoptera: Pyralidae) was selected to control the invasive weed, *Opuntia stricta* in Australia in 1926. The cactus moth is native to the South American countries of Peru, Bolivia, Paraguay, Uruguay, Argentina and southern Brazil. Larvae of *C. cactorum* were transported from Argentina to Australia, and deliberately introduced as a biological control agent. The moth successfully controlled the exotic *Opuntia* species (Dodd 1940; Mann, 1969; McFadyen, 1985; Zimmermann et al., 2000 a, b). Within a few years after its release in Australia, millions of hectares of lands infested by prickly pear (*O. stricta)* were given back to agriculture and livestock farming. This was a remarkable achievement that stimulated fruitful developments in the field of biological control of weeds mainly by one species of the insect. After the successful attempt in Australia, the larvae of the cactus moth were released in several other countries for the biological control of invasive *Opuntia* weed. (Dodd, 1940; McFadyen, 1985; Briano et al., 2012).

The cactus moth *Cactoblastis cactorum* (Berg)

The cactus moth, *Cactoblastis cactorum* (Lepidoptera: Pyralidae) (**Fig. 1**) is one of the five species in the genus *Cactoblastis*, namely *C. cactorum, C. bucyrus, C. mundelli, C. doddi* and *C. ronnai*. All of these are native to the southern part of South America, from southern Peru to Bolivia, Paraguay, Uruguay, Argentina and southern Brazil (Heinrich, 1939). Except for *C. cactorum*, the rest of the species have very restricted host ranges with limited distributions. *C. cactorum* has a wide host range within the Cactus genus *Opuntia*, and its larvae have been reported to feed on many species of this genus in the native countries, but its spread is controlled by native pathogens and parasites. The female cactus moth lays eggs, one on top of the other to form spine-like "egg sticks" that comprise, on average, 60–100 eggs and each female usually produces about 300 eggs (Dodd, 1940; Pettey, 1948). The newly hatched larvae jointly make a small hole in the cactus cladode and enter the cladodes through the hole (Hoffmann & Zimmermann, 1989). The larvae feed gregariously inside the cladode on mucilage and repeatedly facilitate secondary pathogenic infections and ultimately, death of the plant (Heinrich, 1939; Dodd, 1940; Mann, 1969; Starmer et al., 1988; Zimmermann et al., 2000, 2004). Larvae remain inside the cladode for about two months in summer and about four months in winter, then exit the damaged cladode for pupation in the soil or in the leaf-litter (Dodd, 1940; Pettey, 1948). However, full grown larvae also exit from the hole during the hot season and can be seen in a large group, in a group of 2-4, or singly (Rafi, personal observation). In Australia and South Africa, *C. cactorum* occurs in temperate latitudes, where it has two or seldom three generations per year (Pettey, 1948; Robertson, 1985). In the warmer tropical climate of the Caribbean and Florida there may be more generations each year (Zimmermann et al., 2004).

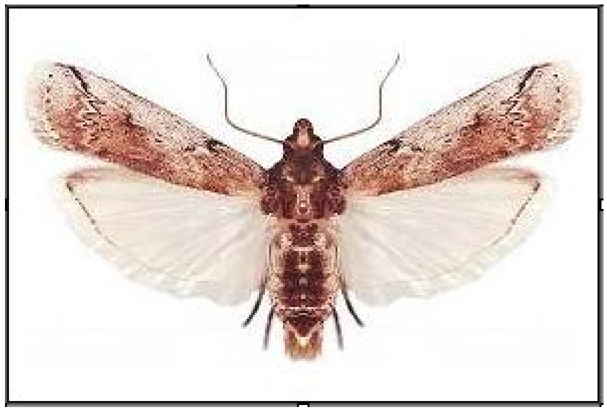

Fig. 1. *Cactoblastis cactorum* (Cactus Moth).
[Image from Wiki Commons]

Release of *Cactoblast cactorum* in several other countries to control *Opuntia* weed

- In 1933, larvae were released to control *O. ficus-indica* in South Africa, where *O. ficus indica* was prominent weed species and the moth became established. In South Africa the moth played only a minor role in controlling invasive cacti *O. ficus-indica* (Pettey, 1948; Hoffmann et al., 1998; Julien & Griffiths, 1998).

- During the same year larvae were sent from Australia to New Caledonia (northeast of Australia), where it became established (Zimmermann et al., 2004).
- In 1950, cactus moth larvae were transported from Australia and released in Hawaii (Fullaway, 1954) where it became established.
- Also in 1950, cactus moth larvae were released in Mauritius, having been transported from South Africa to control *Opuntia* weeds, i.e. *O. ficus-indica*, *O. tuna* and *O. monacantha*, where it became established (Zimmermann et al., 2004).
- In 1957, cactus moth larvae were sent to the Caribbean island of Nevis from South Africa to control native *Opuntia*. The biological control was successful and its population established successfully (Julien & Griffiths, 1998).
- In 1960, after the successful biological control on Nevis Island, larvae of *C. cactorum* were released in the neighboring Caribbean islands (Antigua & Montserrat) from the population of Nevis Island (Julien & Griffiths 1998).
- In 1966, cactus moth larvae were sent from Antigua to Kenya, but its establishment was not confirmed until 2000 (Zimmermann et al., 2000 a, b), with its establishment reconfirmed in 2010 (Legaspi & Legaspi, 2010).
- In 1970, cactus moth larvae were sent from Nevis and Antigua to the Cayman Islands in the Western Caribbean Sea, with its establishment confirmed (Zimmermann et al., 2004).
- In 1971, cactus moth larvae were transported from Nevis and Antigua to Saint Helena Island, with its establishment confirmed (Zimmermann et al., 2004).
- In 1973, cactus moth larvae were sent from Saint Helena to Ascension Island to control the native species of the *Opuntia*, with its establishment confirmed (Zimmermann et al., 2004).
- In 1994, cactus moth larvae were released from Australia to Pakistan to control wild *Opuntia* weed, where this has not been effectively studied; hence, its establishment not confirmed until December 2016 (Julien & Griffiths 1998; Zimmermann et al., 2004; Legaspi & Legaspi, 2010). Its first outbreak was observed in December 2016 on cultivated spineless species of *Opuntia,* i.e. *O. ficus-indica* and wild *Opun*tia in the district Chakwal. After personal communications it was confirmed that cactus moth larvae were released in the district Chakwal and its vicinities in 1994.
- Cactus moth larvae were sent to Israel from South Africa (year not reported), where its establishment is unconfirmed (Julien & Griffiths, 1998; Zimmermann et al., 2004; Legaspi & Legaspi, 2010).

Current dependable records of *C. cactorum* either introduced or naturally spreading throughout the world.

- **North America:** Reported throughout the Caribbean islands (García-Turudi, 1971; Legaspi & Legaspi, 2010; Habeck et al., 2016); Mexico: Most of the area in the Mexico (EPPO, 2021); USA: Florida Keys, Hawaii, Texas, Alabama, Georgia, Mississippi, Louisiana and South Carolina

(CABI, 2022). The cactus moth extended its range in the United States subsequent to introduction with movement westward along the Gulf Coast and northward along the Atlantic Coast (Dickel, 1991; Jezorek et al., 2012).

- **South America:** Native to Peru, Bolivia, Paraguay, Uruguay, Argentina and southern Brazil (Heinrich, 1939; Invasive Species Specialist Group (ISSG), 2011).
- **South Africa:** Saint Helena and Ascension Island (Invasive Species Specialist Group (ISSG), 2011).
- **East Africa:** Kenya (Legaspi & Legaspi, 2010); Tanzania and Mauritius (EPPO, 2021)
- **Oceania:** Australia: New South Wales, Queensland (EPPO, 2021); New Caledonia (Invasive Species Specialist Group (ISSG), 2011).
- **Asia:** India: southern India (Legaspi & Legaspi, 2010; EPPO, 2021).
- **Asia:** Pakistan: Present (presence records are confirmed) from district Chakwal, Punjab Province (this report Rafi, 2022).

Unluckily, in 1957, *C. cactorum* was purposefully introduced into the Caribbean region for the purpose of biological control of cacti species of the genus *Opuntia*. In the Caribbean region the moth spread all over the region naturally (a potential invasion route matches historical hurricane trajectories) and by human-supported introductions (Simmonds & Bennett, 1966; García-Turudi, 1971; Andraca-Gómez et al., 2015**).** The moth conquered the North American continent during the last 20-30 years, threatening the most important center of biodiversity of native *Opuntia* species, where hurricanes are one of the major ecological reasons for the dispersal of *C. cactorum* in the region (Andraca-Gómez et al., 2015**).** The moth was reported from the Florida Keys in 1989 (Dickel, 1991) and has spread throughout most of the Florida peninsula, along the Atlantic Coast to North Carolina, and the Gulf Coast to Texas (Varone, 2020). Outbreaks of *C. cactorum* populations have taken place in Mexico: Quintana Roo and on Isla Mujeres in 2006 and Isla Contoy in 2007, and then eradicated by 2009. Due to its rapid expansion in geographical range and its status as a voracious feeder of *Opuntia* species, *C. cactorum* continues to threaten Mexico's *Opuntia* diversity and its industry (Hight & Carpenter, 2009).

As stated above, the arrival of *C. cactorum* in continental North America is a major concern. It has high potential to destroy native *Opuntia* spp. In the Florida Keys, *Opuntia spinosissima* (Martyn) Mill., and *O. tricantha* (Willdenow) are rare and included in the threatened list. Other native species, such as *O. cubensis* Britton & Rose, *O. stricta* Haw.and *O. humifusa* (Raf.), in addition to the exotic species, either grow wild or as ornaments are also in danger. In the desert regions of Texas and Mexico, wild *Opuntia* and *Cylindropuntia* (Engelmann) Kreuzinger species, which provide food and nesting sites for a variety of wildlife and contribute to soil stability, are at risk (Chavez-Ramirez et al., 1997). In Mexico these plants are harvested on over three million hectares, where they grow naturally (Soberon et al., 2001; Vigueras & Portillo, 2001). In addition, 250,000 hectares of *Opuntia* and *Nopalea* species are cultivated for human and livestock food, for fuel, medicines, crimson dye and fencing etc.; with cultivation has occurred since 9,000 BC in Mexico (Casas et al., 1997; Vigueras & Portillo 2001). In Mexico these plants are valued at over 80 million dollars annually (Soberon et al., 2001). Mexico, with 850 cacti species, has the highest diversity of cacti, with many of them endemic (López Collado et al, 2013; Pérez-De la, 2020).

Control methods

Several tactics have been evaluated for cactus moth control, including control strategies suggested to minimize the risk and consequences of invasion by the cactus moth; for example, hand removal of infested cladodes and egg sticks (Zimmermann et al., 2004). Substantial research has been conducted on the potential use of sterile insect technique "SIT" (Hight et al., 2005), pheromones for the monitoring for the presence and occurrence of the moth (Heath et al., 2006) and insecticidal applications (Bloem et al., 2005). Still, none of these control tactics prevented the spreading of the *C. cactorum.* Painted apple moths (*Teia anartoides*) were successfully eradicated at Auckland, New Zealand, using the release of partially sterilized males in combination with aerial applications of *Bacillus thuringiensis* var. *kurstaki* (Btk) and an intensive trapping program, using virgin female moths (Suckling et al., 2007). The same approach was used to eradicate the outbreaks of invasive cactus moth in Mexico (Bello-Rivera et al., 2021).

The use of exotic biological control agents has been assessed as a management tactic (Pemberton & Cordo, 2001a, b; Stiling, 2002). For example, one parasitoid, *Apanteles opuntiarum* Martinez & Berta (Hymenoptera: Braconidae), has recently been reported as a potential candidate, because its host range is restricted to the genus *Cactoblastis* in its country of origin (i.e. Argentina), where it is a gregarious larval parasitoid of *C. cactorum* (Martinez et al., 2012; Mengoni et al., 2014; Varone et al., 2015). Colonies of *A. opuntiarum* are presently maintained in a quarantine facility in Florida undergoing host specificity testing on North American non-target species (Srivastava et al., 2019). However, the potential areas where this braconid wasp could become established after its release in North America are still unknown, which is an important aspect essential to the success of a biological control agent (Pérez-De la et al., 2020). Other reported natural enemies are the pathogen *Nucleo polyhedrosis* virus (CABI, 2022), the parasitoid *Phycitiplex doddi* (Hymenoptera: Ichneumonidae) (CABI, 2022) and the egg parasitoids *Trichogramma fuentesi* and *Trichogramma pretiosum* (Hymenoptera: Trichogrammatidae) (Paraiso et al., 2011).

FOOD SECURITY IN ARID AND SEMI-ARID REGIONS

The shared effects of climate change and IAS have negative impacts on food security and availability of basic needs, such as water and energy in poorer countries (Masters & Norgrove, 2010), uneven rainfall throughout the growing season, with poor nutrient soils and high temperatures, which limit plant growth, especially of agricultural and forage crops in the arid and semi-arid regions (Teklehaimanot & Tritschler, 2011; Louhaichi et al., 2018). Furthermore, increases in human population, placing the burden on natural resources and livestock production (Seto et al., 2011), result in increased risks of desertification, decline in rangeland resources; overgrazing, ploughing of marginal land, and soil erosion (Owen et al., 2004; Pimentel et al., 2010; Hudson et al., 2014). Increasing cropland worldwide to meet human demands, continuously diminishes rangelands which cannot fulfill the annual feed requirements of livestock (Nefzaoui et al., 2014). Livestock often depend on natural grazing or low-quality crop residues (e.g. straws, stubbles) and expensive feed supplements when forage has been depleted and overgrazed (Aregawi et al., 2008; Islam et al., 2019). Consequently, goats and sheep (the ideal livestock animal and the leading producers of milk, meat, fiber, manure & skins) are facing serious nutrient shortages in arid and semiarid areas and livestock production in such regions facing challenges (Russell & Felker, 1987; Islam et al., 2019).

Raising of livestock is critical for the survival and livelihood for the people in these areas (Gusha et al., 2015). Hence, it is essential to find alternative non-conventional feed resources to sustain food production for human and livestock and improve the feed-water problem during dry and low-producing seasons. The utilization of forage species that adapt to the changing and poor growing conditions contributes to ensure livestock security, in the face of an increase in both livestock and human population (Burke et al., 2009). Under these challenging conditions, planting of drought-tolerant and water- efficient plants, especially under the genus *Opuntia*, that are hardy and well adapted as buffer food reserves, for example as a form of food assurance for the frequent droughts and to bridge a regular annual period of shortage of food for human and improve livestock production in various arid and semi- arid zones of the world, is also a favorable way of lessening the demand for water (Louhaichi et al., 2018). Several studies have been confirmed that cactus cladodes have a good nutritional value when used as supplements in small ruminant diets (Misra et al., 2006; Aguilar-Yáñez et al., 2011; Gusha et al., 2015).

Cactus pears have the benefit of being a source of ample water for animals, mostly during the dry season; these plants are also tolerant of poor soil situations, and yield high biomass with acceptable palatability to animals (Russell & Felker, 1987). Cactus species have the capability to survive prolonged drought, high temperatures, as well as wind and water loss; hence, they are ideal for agricultural and livestock growth in areas affected by the world's two biggest environmental problems: desertification and climate change, as they relate to higher temperatures and reduced soil moistness accessibility (Ben Salem & Abidi, 2009). Cacti are generally used as survival fodder, and, given its availability in conditions not suitable for other agriculture or better forage production, it is important to find options to make their use more efficient, framing it within a context of sustainable animal production (Atti et al., 2009).

Cultivation of prickly pear cactus in Pakistan

In arid and semi-arid regions of Pakistan livestock production remains a critical source of income for the rural population. Sheep and goats raised in these areas are mostly confronted with severe malnutrition, in addition to the negative impacts of climate change (Devendra, 1998; 1999; McDermott et al., 2010). Increasing numbers of livestock is one of the vital changes for the survival and sustainable livelihood for the people of these areas. To examine the effects of adding cacti as a supplement to sheep grazing on degraded rangelands of the district Chakwal, Pakistan. Spineless cactus (*Opuntia ficus-indica*) was introduced to the farmers in the village of Chakwal, as a succulent and drought-tolerant species with great potential to provide fodder reserves to fill the gap during the periods of low feed accessibility and provision of spineless cactus. As a supplement to sheep, this has a positive impact on live-weight gain, compared with only grazing poor rangeland conditions, and it was found that cactus is important to develop diets that maximize the full potential of low-nitrogen, yet water- and carbohydrate-rich as this unconventional feed source

(Islam et al., 2019).

After these promising results to promote cactus cultivation in the arid and semi-arid regions of Pakistan, in 2014, the Pakistan Agriculture Research Council (PARC) (an apex scientific and research organization at the national level in the agriculture sector) imported many cultivar/varieties of spineless cacti from Brazil (**Table 1, Fig. 2**). Cladodes of all imported cultivar/varieties of spineless cacti were initially planted at National Agricultural Research Centre (NARC), Islamabad under the Rangeland Research Institute (RRI), NARC. The growth of all the cultivar/varieties was found satisfactory and a plan was prepared to cultivate the spineless prickly pear i.e., *Opuntia ficus-indica* in the arid and semi-arid areas of the district Chakwal.

Table 1: List of varietal/cultivars clones of cactus imported from Brazil

Serial No.	Scientific name	Common Name	Origin
01	*Opuntia fícus-indica*	Giant or Large	Caruaru
02	*Opuntia* ssp.	Round	Caruaru
03	*Opuntia fícus-indica*	IPA clone 20	Caruaru
04	*Nopalea cochenillifera*	Small or Sweet	Caruaru
05	*Nopalea cochenillifera*	IPA Sertânia or Bahi	Caruaru
06	*Nopalea cochenillifera*	Jaguar ear	Arcoverde
07	*Opuntia stricta* Haw.	Mexican elephant ear	Caruaru
08	*Opuntia undulata* Griffiths	African elephant ear	Caruaru
09	*Opuntia atropes* Rose	F 8 - Forage	Caruaru
10	*Nopalea cochenillifera*	F 21- Forage	Caruaru
11	*Opuntia fícus-indica*	Copen-F1	Caruaru
12	*Opuntia fícus-indica*	Copen -V1	Caruaru
13	*Opuntia fícus-indica*	IPA -90 - 18	Caruaru
14	*Opuntia fícus-indica*	IPA - 90 - 73	Caruaru
15	*Opuntia fícus-indica*	IPA - 90 - 92	Caruaru
16	*Opuntia fícus-indica*	IPA - 90 - 111	Caruaru
17	*Opuntia fícus-indica*	IPA – 90 - 115	Caruaru
18	*Opuntia fícus-indica*	IPA – 90 - 156	Caruaru
19	*Opuntia larreyi*	Blue-V 19	Arcoverde
20	*Opuntia fícus-indica*	Additional - 1258	Caruaru
21	*Opuntia fícus-indica*	México Folder - 1278	Caruaru
22	*Opuntia fícus-indica*	Mexico Vegetable	Caruaru
23	*Opuntia fícus-indica*	Mamillon Fodder - 1	Arcoverde
24	*Opuntia fícus-indica*	México Unknown - 12	Arcoverde
25	*Opuntia fícus-indica*	Jalpa – F23	Arcoverde

 

Fig. 2. Imported Cacti germplasm at National Agricultural Research Centre (NARC), Pakistan.

The district Chakwal is located at 32°56'17"N, 72°51'30.71"E., on the Pothohar Plateau, Punjab, Pakistan (**Fig. 3**). It is situated in the north of the Punjab province, bounded by district Khushab to its South, district Rawalpindi to its northeast, district Attock to its northwest, district Jhelum to its East and district Mianwali to its West. District Chakwal is comprised of four tehsils namely Kallar Kahar, Chakwal, Choa Saidan Shah and Talagang. Dominant flora of the Chakwal districts consists of *Acacia modesta*, *Acacia nilotica* and *Dalbergia sissoo*. Approximately 50% of the area is uncultivated and primarily used for grazing animals, and about 11% is natural grasses and shrubs. District Chakwal is the largest peanut producer in Pothohar region, where the peanut is largely grown in the tehsil of Chakwal and Talagang, and peanut stubble is the main stock to the small ruminants in the area. Due to high demand of peanut straw in large cities, the shrubby vegetation mainly supports the grazing of goats and sheep.

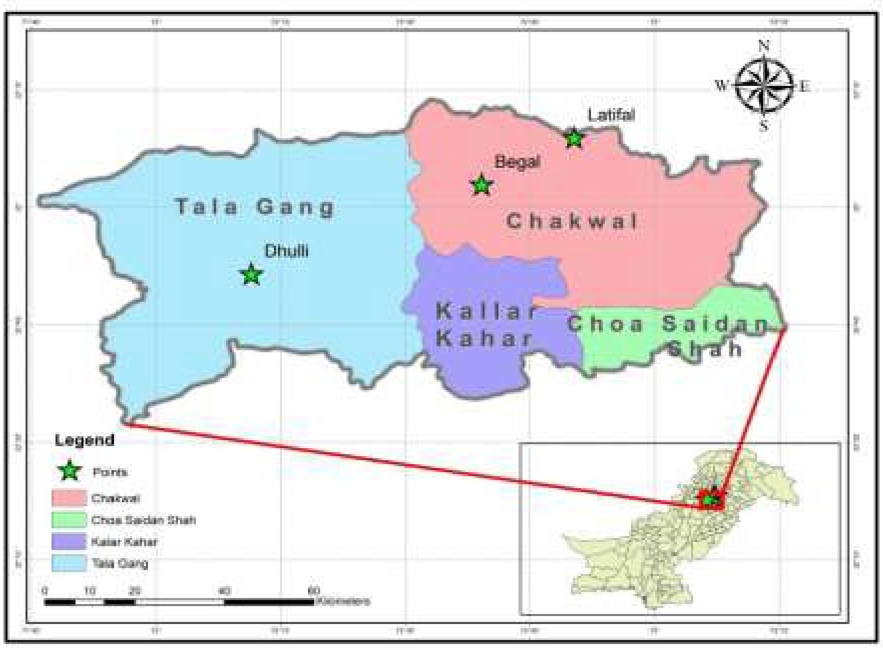

Fig. 3. District Chakwal, Punjab-Pakistan

MATERIALS AND METHODS

Selection of study areas

For the cultivation of spineless cactus pear, i.e. *Opuntia ficus-indica***,** three fields were selected in the vicinities of the villages Latifal and Beghal within the tehsil and district Chakwal and the village Dhulli in tehsil Talagang, district Chakwal. The fields were selected by three gradients of rainfall, high, medium, and low, and population of small ruminants in selected areas, in consultation with local livestock extension departments of each tehsil. Selected villages represented the larger territory of Pothohar regions. The main purpose for selection of different sites was to identify the situations that are representative of the larger domain of rain-fed Pothohar regions with respect of small ruminant farming.

Target villages:

- Village Latifal was selected in the high rainfall zone, located at 33°09'48”N, 72°50'28”E, and situated in tehsil Chakwal about 41 kilometres from Chakwal city near the boundary of Rawalpindi and Chakwal districts.
- Village Begal was selected in the medium rainfall zone, located at 33°2'57”N, 72°39'11”E. This village is also a part of tehsil Chakwal.
- Village Dhulli was selected in the low rainfall zone, located at 32°51'31.02”N, 72°11'28.22”E. This village is a part of tehsil Tatagang.

Plantation of *Opuntia ficus-indica* in fields of selected Villages

After the 2014 monsoon, Rangeland Research Institute, NARC under Agriculture Innovation Program (AIP) introduced spineless prickly pear species, i.e. *Opuntia ficus-indica* to cultivate in the fields of the targeted villages on approximately 30 ha (**Fig. 4**).

Fig. 4. Cultivation of spineless cactus *O. ficus-indica* under AIP in Chakwal for fodder purposes.

Survey after plantation

After planting, all fields were visited once a month. The growth of *O. ficus-indica* was found to be excellent in all the targeted fields until November 2016. However, during the December 2016 survey it was observed that a few cladodes of *O. ficus-indica* were found dead with infestation of an unknown pest (**Fig. 5**). All infested pads were removed and burned. In December 2017, the same infestation was again reported and the majority of the cladodes were found to be infested. Infested cladodes were examined in the field and some lepidopterous larvae were found inside the cladodes (**Fig. 6**). Larvae were brought to the laboratory of the National Insect Museum for identification. However, in July 2019 it was found that cultivated *O. ficus-indica* at all the three localities had completely vanished due to the heavy attack by cactus moth larvae (Figs. 7 & 8).

Fig. 5. Infested cladode of spineless *O. ficus-indica* in cultivated field in District Chakwal.

Fig. 6. Larvae inside the cladode of *O. ficus-indica* in District Chakwal.

Fig. 7. Dead cladode of *O. ficus-indica* in vanished field in District Chakwal.

Fig. 8. Completely vanished field of *O. ficus-indica* in District Chakwal.

RESULTS

The field collected larvae were brought to the laboratory of the National Insect Museum at the National Agricultural Research Centre for identification. On the basis of morphological characteristics and with the help of published literature (i.e., Mann, 1969; McFadyen, 1985; Zimmermann et al., 2004; Habeck et al., 2016; and Folgarait et al., 2018), the field collected larvae were confirmed to be the renowned cactus moth (*C. cactorum*). Adult *C. cactorum* look very similar to several other native species of the subfamily Phycitinae, and identification of the adults is often difficult (Heinrich, 1956). However, the best means of identification can be accomplished with confirmation of the fully grown larvae.

Surveys for wild cactus in vicinities of study areas:

After confirmation that the cladodes of cultivated *O. ficus-indica* were infested by the invasive moth, *C. cactorum*, plans were made to conduct detailed surveys for the whole district of Chakwal. Surveys were conducted for all tehsils of district Chakwal to discover the level of infestation of *C. cactorum* on wild *Opuntia* species which was introduced naturally/deliberated (**Figs. 8 & 9**). Surveys were consecutively conducted from July 2019 to July 2021. During consecutive surveys over two years, it was found that sporadic plantation of wild cactus throughout the district Chakwal was in the stage of re-growing (**Fig. 11**) from the debris of the cactus, which were damaged through the heavy attack of the larvae. However, larvae were found at various localities in tehsil Talagang of district Chakwal on wild cactus. In all surveyed localities wild cactus was severely infested by the cactus moth and threatened (**Figs 7 & 10**). During this study establishment of *C. cactorum* has been confirmed after the introduction of the cactus moth larvae in the district Chakwal, Pakistan during 1994.

Fig. 9. *C. cactorum* infested cladode of wild cactus in District Chakwal.

Fig. 10. Damaged wild cactus in District Chakwal.

Fig. 11. Regrowth of cladode from debris/damaged cactus in District Chakwal.

STATUS OF *OPUNTIA* CACTI IN INFESTED REGIONS

Cacti (Caryophyllales: Cactaceae) are a large and diverse group of succulent plants, Latin American in origin. Historically, they are among the most popular horticultural plants having close relationships with the local population, with different life forms such as arborescent, columnar, globular, barreliform, articulated, cylindrical and flat cladode (Gibson & Nobel, 1986; Terrazas-Salgado & Mauseth, 2002). Cacti have been used by native peoples as food for humans and animals, medicines, cochineal dye (red pigments), and fencing (Vigueras & Portillo, 2001). Cacti are a very famous component of America's deserts and inhabit a wide range of ecosystems such as plains, deserts, sandy beaches, savannas, dry broad-leaved forests, high alpine-steppes, and tropical rain forests. However, they mainly occur in warm and arid lands of North and South America, excepting the high latitude boreal forest and tundra vegetation of North America and the temperate rain forests of southern Chile (Nyffeler, 2002; Barthlott et al., 2015).

Economic importance of Cacti

Cacti have evolved physiological and morphological adaptations which allow them to grow in habitats which are too dry for other plants (Mauseth, 2000). Despite the various challenges, cacti are distinctive and unusual plants, which can adapt to extremely arid and hot environments (Shetty et al., 2012). They are a well-known crop for cultivation in arid and semi-arid regions, mostly for their expressive adaptive capability, through the prompt defense mechanisms against abrupt changes in temperature, CO2 atmospheric concentration, soil water accessibility and photosynthetic active radiation (Ferraz et al., 2017). Most of the cactus species have been recognized for Crassulacean Acid Metabolism (CAM) due to the high-water use efficiency found in fast growing species of the genus *Opuntia* such as *O. ficus-indica*, *O. megacantha*, and *O. amychlea*, which are usually considered drought resistant species because they store considerable amounts of water in their shoots (Nobel, 1994, 1995). The morphology and anatomy of the shoots have evolved to serve this function.

Cacti are especially drought-tolerant plants (Casas et al., 1997). They are highly productive even though they consume very little water and are extremely tolerant of dehydration when it occurs (Sowell, 2001; El Obeidy, 2004). Throughout the world outside their native ranges many species of columnar cacti have been widely introduced as a drought tolerant crop in arid and semi-arid lands. For example, Australia has water limitations in many cities; hence, among drought-tolerant plants, cacti are gaining popularity there (Shetty et al., 2012). Similarly columnar cacti have been planted as drought-tolerant plants in United Arab Emirates (El Obeidy, 2004). Cacti are very important to eliminate desertification; for example, cactus pears are able to grow on land where no other crops are able to grow; they can be used to restore degraded land and, in many countries, such as Ethiopia, it is the only crop that can be relied on when everything else fails (Inglese et al., 2017). In Eritrea and Ethiopia, where it is cultivated on a small scale or in natural stands; cactus pear is a needed source of food (fruits and its derivatives) for the rural poor and fodder for their livestock (Mora, 2017). Furthermore, cacti are widely introduced for ornamental purpose as well (Barthlott & Hunt, 1993; Mizrahi, 1999; FAO, 2001).

Prickly pear cacti preserve high moisture (88-91%), high protein and fiber contents in their cladodes. Their nectar is an excellent source of dietary fiber, potassium, vitamin C & B, calcium, magnesium, copper, taurine, flavonoids, polyphenols, and betalains (Pimienta, 1990; Fuentes-Rodriguez, 1997; Kumar et al., 2018). The main components are carbohydrate-containing polymers, which comprise a mix of mucilage and pectin (Gabriel et al., 2014). Moreover, prickly pears are also comprised of crude protein (CP), crude fiber (CF), ether extract (EE), and nitrogen free extract (NFE). Fiber fractions including neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) have been reported (Van Soest et al., 1991). Prickly pear possesses antioxidant, anti-lipidemic and antimicrobial properties (Gengatharan et al., 2015). The prickly pear pulp contains 7.61% CP, 3.88% Ash, 85.75% carbohydrates, and 1.92% EE (Rodriguez-Garcia et al., 2007; Atef et al., 2013; Hassan et al., 2019) and about 60% of the total energy necessities of animals can be provided by prickly pear (López-Garcia et al., 2001). Prickly pear pulp (PPP) and prickly pear fruit (PPF) are rich in vitamins A and E and free from alkaloids that are well-known anti-nutritional factors (Guevara-Figueroa et al., 2010; Yahia & Mondragon-Jacobo, 2011; El-Mostafa et al., 2014). Antioxidant activities of different colored PPF are strongly associated with total phenolics, betalains and ascorbic acid concentrations (Fernández- López et al., 2010; Yahia and Mondragon-Jacobo, 2011).

Cactus pears are a very flexible food source; fresh cladodes/nopales of spineless varieties are mostly used as vegetables by chopping young cladodes, while the flour of cladode, jams and juices are used as processed food (Mora, 2017). The most widely used and economically important species of *Opuntia* for food is *O. ficus-indica* (L.) Mill., known as Indian fig or forage palm (Spodek et al., 2014; Ferraz et al., 2017). *O. ficus-indica* has been used traditionally in central Mexico as a vegetable (nopalitos) and a fruit (tunas) (Maki et al., 2015). Many other edible species are used in Mexico, including *O. megacantha* Salm-Dyck, *O. stricta* Haw., *O. dillenii* (Ker Gawl.) Haw., *O. schumannii* Weber, *O. robusta* Wendl., and *O. albicarpa* Scheinvar (Márquez et al., 2012; Arba et al., 2017). Mexico leads the world in prickly pear cactus food production (74%) and is also the principal consumer. Demand for nopalitos is increasing in foreign markets such as in the United States and Canada (Maki et al., 2015). Mexico grows nopalitos on 12,853 hectares (SYBAP, 2020), with a food supply chain that supports many families across the country. In the northeast region of Brazil, plantations totalling over 400,000 ha serves as a key element in supporting livestock production in the country's semi-arid regions. In the United States of America, cacti are grown mainly as ornamentals in Arizona, California, Nevada, New Mexico, and Texas (Perez- Sandi, 2001; Vigueras & Portillo, 2001).

Among prickly pear cacti, plants of *Opuntia* species are undoubtedly truly multipurpose and their ability to adapt to different environments and has allowed these plants to be cultivated in many continents such as Africa, North and South America, Asia, Australia and Europe (Barbera, 1995). Cacti were introduced to the Indian subcontinent by the British as host plants for cochineal scale insects (*Dactylopius coccus*) for the production of cochineal dye, but these plantations steadily vanished due to pests and flooding of the areas (Singh, 2006).

Important cactus-pear producing countries are Italy, South Africa, Argentina, Chile, Bolivia, Peru, Colombia, United States of America, Brazil, Malta, Mexico, Morocco, Algeria, Libya, Yemen, Lebanon, Syria, Saudi Arabia, Tunisia, Egypt, Jordan, Pakistan, Israel, Greece, Spain, Portugal, Turkey, France, Bulgaria, Albania, and Cyprus (Novoa et al., 2015; Mora, 2017; Kumar et al., 2018). However, in a significant number of these countries, particularly in Africa, cactus pear fruits are considered a by-product, for example the plant is mainly used for the conservation of degraded soils (Mora, 2017). Other countries, including Morocco, Ethiopia, South Africa, Kenya, India and Pakistan, are increasing their production and usage (Inglese et al., 2017). The cultivation of cactus pear for use as fodder is also being adopted in sub-Saharan Africa and South Asia. Furthermore, its medicinal properties and industrial uses are being researched and promoted (Inglese et al., 2017). Prickly pear cacti are receiving attention throughout the world (Hoffmann, 1995; Soberón et al., 2001; Makumbe, 2010; Louhaichi et al., 2018) because of their huge potential with a wide range of applications; have the enormous potential to be a future food (Shetty et al., 2012). Among cactus pears, *Opuntia ficus-indica* is gradually achieving the status of recognized crop and cultivated on a commercial scale in many countries (Inglese et al., 2017; Mondragón Jacobo & Méndez Gallegos, 2017).

Cacti as an invasive weed

In spite of economic gains, the cacti are among the most damaging alien invasive species (AIS) by establishing a noteworthy tangible and imaginable vulnerability to conservation and agricultural production (Cronk & Fuller, 1995; Bright, 1998), causing economic losses throughout the world (Novoa et al., 2015). The tolerance of its vegetative growth, short root structure, and the ability for CAM photosynthesis make it a harmful weed, which competes with many other native species (Cronk & Fuller, 1995; FAO, 2001). Its management and elimination is problematic due to the existence of large and small hairlike spines. Hence, before the introduction of cacti species, appropriate knowledge of the diversity of introducing cactus species, management and its potential utilization, especially in arid and semi-arid lands where they have become adopted are vital. The deliberate introduction of prickly pear in Australia, South Africa, and Europe, attained the status of weeds (CABI, 2016; Foxcroft et al., 2004; Greathead, 1971; Novoa et al., 2015; Novoa et al., 2016; Shackleton et al., 2017).

CONCLUSIONS

The bio-control agents which are specialist consumers turn into active invaders, known as escaped bio-control species such as *Cactoblastis cactorum*, which is an oligophagous species, i.e., consumes plants of only the genus *Opuntia* (Schartel & Brooks, 2018). The areas presently invaded by the cactus moth, have adequate levels of host plants of the genus *Opuntia* (Johnson & Stiling, 1996; Schartel & Brooks, 2018). The successful establishment and spread of invasive species depends on the presence of an appropriate host in the new environment, particularly those with some level of host specificity such as *C. cactorum* (Schartel & Brooks, 2018). For instance, the adverse effects on non-target species through the introduction of *C. cactorum* for biological control of weeds were seriously apparent through the introduction of prickly pear in Australia in 1926 (Dodd, 1940), after the successful biological control of *Opuntia* weed. Later on, the larvae of *C. cactorum* were introduced in many countries, including Pakistan to control the *Opuntia* weed. The larvae of the cactus moth were released during 1994 in the district Chakwal, Pakistan, where it was not well studied after its release and unconfirmed presence record(s) of the cactus moth from Pakistan were reported by many authors (e. g. Julien & Griffiths 1998; Zimmermann et al., 2004; Legaspi & Legaspi, 2010 & EPPO, 2021). On the other hand, 21 years after its introduction, the first incidence of larvae of this moth was observed in cultivated spineless species of *Opuntia ficus-indica*. Further surveys were conducted consecutively for wild *Opuntia* in the four tehsils of district Chakwal until October 2021, and it was found that the whole district was severely infested with the larvae.

The main concern is the fast rate of its dispersal in surveyed localities of the district Chakwal, Punjab province of Pakistan. This rate of dispersal is significantly faster than the first observations of *C. cactorum* in December 2016 in Chakwal. Further studies on *C. cactorum* dispersal will provide some clues of its dispersal either by natural spread, anthropogenic activities, or by any other means, particularly in the district Malakand, which is located between mountain ranges, despite the fact that the mountain ranges may have prevented the cactus moth from spreading even if suitable *Opuntia* host-species is in abundance (Hoffmann, 1989). However, it has not spread naturally due to the large cultivation of *O. ficus-indica*in in its native range, i.e., Argentina, Paraguay, Uruguay and southern Brazil (Arruda et al., 1999). Nevertheless, its larvae are able to move short distances from one host plant to another, but these insignificant movements are irrelevant in the situation of the overall spread of the moth. If suitable hosts are in abundance, the adults rarely range far, but as food plants decrease in density the moths travel more widely (Dodd, 1940; Pettey, 1948; Robertson, 1985). There is a record of individual females flying as far as 24 km (15 miles) to oviposit (Dodd, 1940). In Australia, the cactus moth spread unaided, from the release points, for about 16–24 km (10-15 miles) in dense *O. stricta* infestations in 2.5 years (Dodd, 1940).

The cactus moth has tolerated a wide climatic range in many countries including Pakistan. In temperate latitudes of Australia and South Africa, where *C. cactorum* occurs, there are two or three generations per year (Pettey, 1948; Robertson, 1985), whereas in the warm tropical climate of the Florida and the Caribbean there might be more generations annually. Existing information suggests that the cactus moth's establishment and its devastating effects are likely across huge areas throughout the world, with cactus plantations particularly in the southwest U.S. and Mexico.

Cacti plants of the genus *Opuntia* are commonly, increasingly grown as 'wonder-plants' in various countries, i.e., North, South and East Africa, the Mediterranean countries, the Middle East, India, China, and Pakistan. But, the cultivated prickly pears in these countries are vulnerable to attack by *C. cactorum* (Zimmermann, 2000; Inglese et al., 2017). In the future there is a high risk of economic, social, and environmental damages in the areas where *Opuntia* plants (cultivated, ornamental and wild) maintain a valuable role in agriculture, and in areas sustaining unique ecosystems and wildlife in Pakistan.

The establishment of a *C. cactorum* population in the district of Chakwal is alarming. Consequently, the future prospects of large-scale cultivation of prickly pears cacti in Pakistan, for fodder and other purposes will be seriously affected. Besides that, throughout Pakistan, countless nurseries imported several expensive species of ornamental *Opuntia,* which are under threat by the attack of cactus moth. Moreover, throughout the world several cacti spp. of the genus *Opuntia*, commonly are grown as 'wonder- plants' in various countries, i.e., North, South and East Africa, the Mediterranean countries, the Middle East, India, China including Pakistan. However, the cultivated prickly pear in these countries is at present vulnerable to the attack of *C. cactorum.*

The potential impact of *C. cactorum* on economic and social environment, ecosystems and biodiversity requires immediate action to monitor and prevent the spread of this major environmental pest affecting both agriculture and the environment (Stohlgren et al., 2005). Response options are limited as chemical pesticides are largely ineffective and potential biological control organisms pose risks to native species. Although the impact was only partially assessed, available data clearly indicate that social, environmental and economic costs of invasion are likely to be high. An active response depends on the best available knowledge of history, biology, identification, surveillance, and dispersal range, and control of the moth is inevitable.

Key findings of this initial study

1. Prevalence of *Cactoblastis cactorum* is established in district Chakwal, Punjab-Pakistan, where it was introduced 22 years ago in 1994. Moreover, it prevails in the districts of Malakand, Mardan, and Nowshera during 2019.
2. Cultivated spineless species of *Opuntia* (i.e., *O ficus-indica* (L.) Mill.) and naturalized wild cactus experienced a severe attack of *C. cactorum*. Resultantly, both the cultivated and wild

Opuntia species have completely vanished in district Chakwal.

3. Highly significant economic, social, and environmental damage is foreseen if *C. cactorum* spreads and establishes in other parts of Pakistan.
4. Large scale cultivation of *Opuntia* spp. in arid and semi-arid regions of Pakistan for fodder and various other purposes will also be badly affected.
5. Immediate remedial action is inevitable to curb the further spread of *C. cactorum*.
6. In near future, *C. cactorum* can also pose a serious threat to the ornamental *Opuntia* in several nurseries throughout Pakistan.
7. Robust surveillance programs are required for early detection of further spread of the invasive moth on naturalized, cultivated and ornamental *Opuntia* species.
8. Integrated, effective response based on data exchange on an international level, situation analysis, and rapid response programs is immediately required.

CONTRIBUTIONS

The following scientists conducted field surveys throughout District Chakwal for two years (July 2019 to July 2021): Dr. Muhammad Ather Rafi Ex. Director; Dr. Ahmad Zia, Senior Scientific Officer, National Insect Museum, National Agricultural Research Center, Islamabad, Pakistan; Dr. Muhammad Islam; Dr. Falak Naz, Principal Scientific Officer; and Dr. Muhammad Qasim, Assistant Professor. Dr. Muhammad Islam Ex. Director and Mr. Jalal Hayat Khan Scientific officer, Rangeland Research Institute also helped in monitoring larvae of *C. cactorum* in cultivated fields of *Opuntia ficus-indica* at three localities of District Chakwal. Mr. Haseeb Kamran, Mr. Jalal Hayat Khan and Dr. Nazeer Ahmed, Assistant Professor helped in GIS mapping. Dr. Muhammad Ather Rafi, Dr. Muhammad Ashfaq, Principal Scientific officer, Muhammad Saeed, Associate Professor, Dr. Gul Naz Parveen, Associate Professor, Dr. Muhammad Tariq Khan, Director Plant Protection and Dr. Riffat Sultana, Associate Professor helped in preparation of the manuscript. Thanks to Crispin Guppy for final review of the manuscript. Following students Miss Walija Fayaz, Mr. Waqar Ahmed and Mr. Qudrat Ullah keenly participated in surveys and collection for their future research.

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