PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.3078

HORIZON
e-Publishing Group

REVIEW ARTICLE

Insect pest *Spodoptera litura* (Fabricius) and its resistance against the chemical insecticides: A review

Neelam Thakur[1], Anuja Sharma[1], Simranjeet Kaur[1], Kanwaljeet Kaur Ahluwalia[1], Avtar Kaur Sidhu[2], Sanjeev Kumar[3], Sarvesh Rustagi[4], Sangram Singh[5], Ashutosh Kumar Rai[6], Shreaz Sheikh[7] & Ajar Nath Yadav[8, 9, 10]*

[1]Department of Zoology, Akal College of Basic Sciences, Eternal University, Baru Sahib, Sirmaur, Himachal Pradesh, India
[2]Zoological Survey of India, High Altitude Regional Center, Solan, Himachal Pradesh, India
[3]Department of Genetics and Plant Breeding, Faculty of Agricultural Sciences, GLA University, Mathura, Uttar Pradesh, India
[4]Department of Food Technology, School of Applied and Life Sciences, Uttaranchal University, Dehradun, Uttarakhand, India
[5]Department of Biochemistry, Dr. Ram Manohar Lohia Avadh University, Ayodhya, Uttar Pradesh, India
[6]Department of Biochemistry, College of Medicine, Imam Abdulrahman Bin Faisal University, Dammam, Kingdom of Saudi Arabia
[7]Desert Agriculture and Ecosystem Department, Environment and Life Sciences Research Center, Kuwait Institute for Scientific Research, Safat, Kuwait
[8]Department of Genetics, Plant Breeding and Biotechnology, Dr. K. S. G. A. College of Agriculture, Eternal University, Sirmaur, Himachal Pradesh, India
[9]Centre of Research Impact and Outcome, Chitkara University, Rajpura, Punjab, India
[10]Chitkara Center for Research and Development, Chitkara University, Himachal Pradesh, India

*Email: ajarbiotech@gmail.com

OPEN ACCESS

ARTICLE HISTORY

Received: 09 November 2023
Accepted: 18 August 2024

Available online
Version 1.0 : 24 September 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE

Thakur N, Sharma A, Kaur S, Ahluwalia K K, Sidhu A K, Kumar S, Rustagi S, Singh S, Rai A K, Sheikh S, Yadav A N,. Insect pest *Spodoptera litura* (Fabricius) and its resistance against the chemical insecticides: A review . Plant Science Today (Early Access). https://doi.org/10.14719/pst.3078

Abstract

A polyphagous nocturnal pest *Spodoptera litura* (Fabr.) commonly called armyworm, infests about 150 plant species across 44 families worldwide, with nearly 60 plant species affected just in India. The majority of leaf tissues are consumed by the larvae and only the stem and side shoots will remain in the field. They entirely consume the interior content by boring into them, causing squares and young bolls to shed. This insect can badly affect crops and has a wide range of potential hosts, which can lead to financial losses for farmers and food shortages for consumers. The worldwide distribution of *S. litura* as a pest results in significant impact on productivity of many crops. They have the capability to invade new places as a wide-ranging species. Armyworm frequently reappears in India every year and causes evident destruction. Different records on the insect population outbreak have been reported from many countries all around the world. The larvae of insect pests enter the fruits and even contaminate it and this causes yield and economic losses. The low temperatures of winter season are the limiting factors that affect species. It migrates mainly to breed during the summer season but is unable to survive in winters. *S. litura* acquired resistance to several synthetic insecticides, which led to pest outbreaks that were irregular and caused failure of different crops. The resistance and cross-resistance of this pest against insecticide toxin make it more difficult to reduce its population below threshold level. Understanding the mechanisms of resistance is crucial for developing effective resistance management strategies that can restrict or halt the spread of resistance in these pest populations.

Keywords

Identification; climate change; control; distribution; insecticides; pest resistance; resistance; *Spodoptera litura* ; sustainability

Introduction

Spodoptera litura (Fabricius), is also known as the tobacco caterpillar, beet armyworm, smaller armyworm, little mottled willow, cutworm and pigweed caterpillar belonging to the family Noctuidae in the order Lepidoptera (1).

It causes serious damage to the nature and also acts as crucial feeder on a number of agricultural and horticultural crops (2). Next to *Helicoverpa armigera*, the tobacco caterpillar, *S. litura*, is regarded as one of the biggest challenges to modern intensive agriculture and shifting cropping patterns globally. It is an economically significant polyphagous pest in India (3). It feeds on nearly, 112-150 kinds of plants (4). India, Pakistan, Bangladesh, Sri Lanka, South East Asia, China, Korea, Japan, the Philip-pines, Indonesia, Australia, the Pacific Islands, Hawaii and Fiji are among the places where the pest is found (5). This insect pest skeletonizes leaves in the early stages and causes intensive defoliation in later stages, which reduces the ability of affected plants to photosynthesize. The young insect pest larvae/ caterpillars eat the complete leaves, buds, flowers and even contaminate the fruits in the infected fields (6). Caterpillars burrow themselves in the soil up to several centimeters and pupate without the cocoon.

Pest incidence is influenced by various weather parameters like rainfall, wind speed, temperature, relative humidity and sunshine hours (7, 8). It is a serious insect pest in China, Japan, India, Pakistan and South Asia (1, 9) where it causes losses to *Capsicum annuum, Gossypium hirsutum, Solanum lycopersicum, Solanum tuberosum, Allium cepa, Trifolium repens, Abelmoschus esculentus* and *Glycine max* (10). In field and protected conditions, this insect pest caused yield losses of 26-100 % in around 150 plant species (6, 11) Insecticide treatments are thought to be the principal strategy for managing *S. litura* throughout the crop growing seasons because many of its plant hosts are economically significant (12).

The overuse of synthetic chemicals like carbamates, organophosphates and pyrethroids can have negative effects on natural enemies (13). At the same time constant and careless application results in the development of high resistance in different stages of *S. litura* against carbamates, organophosphates, pyrethroids and even against few new insecticides such as abamectin and spinosad in Pakistan, India and China (14, 15). Field control failure is frequently more common as a result of the numerous resistances that many field populations of *S. litura* have developed (16). Since decades, there has been a growing awareness of the harmful impact that insecticides have on non-target arthropods (17). Biopesticides are an eco-friendly management strategy that can replace synthetic chemicals. Microbial, botanical and biochemical pesticides and plant-incorporated protectants (PIPs) are all types of biopesticides (18, 19) which are safe to other living organisms. There is an urgent need to develop a variety of management measures that are unfavorable to the development of resistance and are less dependent on chemical pesticides since *S. litura* develop resistance against a variety of pesticides. This review is an attempt to discuss the damage and kind of resistance developed in the *S. litura,* which is an economically significant pest in the agriculture.

Identification of S. litura

The genus *Spodoptera* has about 30 species, of which *S. litura*, *Spodoptera frugiperda* Smith, *Spodoptera littoralis* Boisduval, *Spodoptera exigua* Hubner, *Spodoptera mauritia* Boisduval, *Spodoptera eridania* Stoll, *Spodoptera exempta* Walker, *Spodoptera ornithogalli* Guenee are significant ones (20). *S. litura* can be identified from its various stages such as egg, larva, pupa and adult based on their morphological features. Its eggs are spherical, with diameter 0.6 mm, laid in groups over 300 eggs in cluster and enclosed partially with scaly hairs (11). Eggs are dirty white or pale orange in colour (5 days duration) and after hatching, the larval forms attain length of 45 mm (21). Larvae can vary in colour patterns and colouration, between and within populations. The fading of bright colour occurs after each moult till the complete chitinisation takes place in the pre-pupal stages. Larvae are initially dark grey to green in colour that becomes dark blackish brown in the advanced stages. The sides of its body have light, dark longitudinal bands and 2 dark crescent spots present on dorsolateral sides of all segments except prothorax. These spots are bigger on the 1st and 8th abdominal segments, intersecting the lateral lines present on the 1st segment. The presence of dark yellow stripes alongside the dorsal surface is the distinguishing feature of larvae. The pupa is deep brownish red in colour, around 15-20 mm in length, possesses 2 spines on its abdominal tip and posterior segment of the abdomen is tapering (22). Adult moth has grey brown body with 15-20 mm length and wingspan of 30-38 mm. Its forewings are grey to dark brown with pale lines and have multi-coloured pattern along the veins. Hind wings are light grey having dark grey veins and margins (23). Males have conspicuous white band as compared to the females (4) (Fig. 1).

Morphological identification

Identification keys upto family level for larvae are given (24) based on the chaetotaxy and morphological structures. The different taxonomic characters such as cilia on antennae, wing venation and thorax, presence or absence of hairs on the eyes, orientations of labial palpi and genitalia presence on male and female adults of *S. litura* and *S. exigua* (25). They also had taken under consideration the morphological traits namely length and width of head and thorax. A comparative comprehensive study on taxonomic ranking of genus *Spodoptera* and identified 3 different species *S. exigua*, *S. litura* and *S. mauritia* on morphological basis namely antennae, compound eyes, frons, labial palpi, ocelli, proboscis, vertex and wing venations (20). Many investigators used genital features for the species identification of *Spodoptera* (26). A report mentioned the importance of male and female genitalia for morphological identification (24). However, there may be overlap in many characters of immature stages of *S. litura* with *S. littoralis* therefore the molecular identification is suggested. A diagnostic compendium for morphological as well as for molecular identification for 4 different species of armyworm; *Spodoptera eridania, S. frugiperda, S. littoralis* and *S. litura* has been published by EPPO (27).

Molecular identification

Many investigators stated that in the present scenario, environmental changes caused a huge destruction in

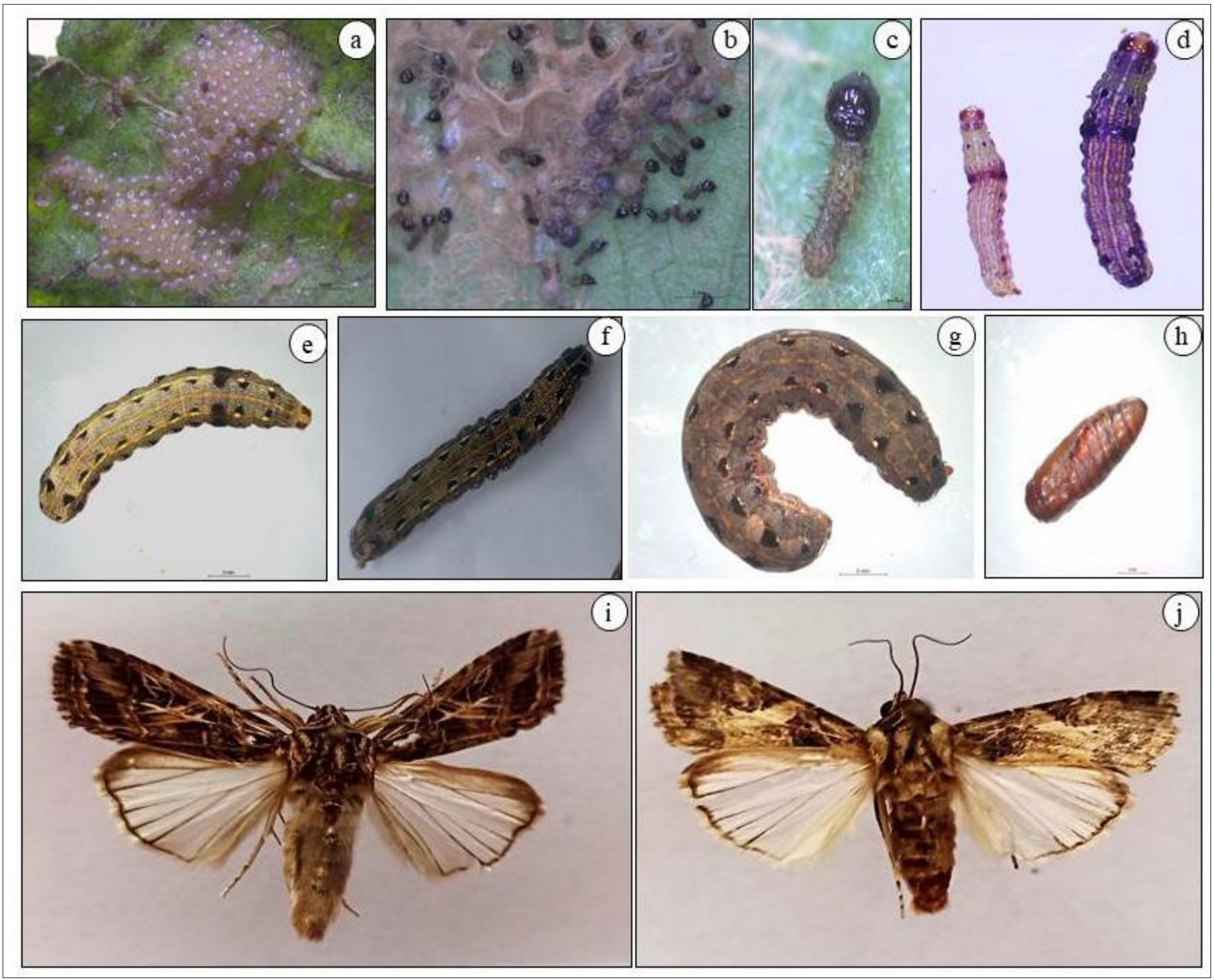

Fig. 1. (**a**) Eggs are round and dirty white or pale orange; (**b**) Emerging neonate larvae; (**c**) Neonate or first instar larva; (**d**) Second and third Instar larvae; (**e**) Fourth instar; (**f**) Fifth instar; (**g**) Last instar; (**h**) Pupa; (**i**) Adult female; (**j**) Adult male.

habitat which led to the requirement of more trustworthy recognition of specimens to study biodiversity (28). The conventional morphological methods based on reproductive structures for adult identification was a difficult task for taxonomists. They advocated the use of DNA barcoding as an admirable technique in identification. Studies reported that DNA barcoding as an efficient way in species identification (29, 30). The DNA barcode orders lead to the unique horizontal genomics observations. They further matched goals and techniques of barcoding with the molecular phylogenetic and population genetics and concluded barcoding as a complement in current research. They also recommended DNA barcoding using accurate genetic markers as effective method for precise and quick identification of species.

Distribution and dispersal of S. litura

Distribution of S. litura

The worldwide distribution of *S. litura* as a pest results in significant impact on productivity of many crops (31). This insect pest is found in Australia, Bangladesh, India, Sri Lanka, Pacific islands, Japan, Pakistan, Philippines, South East Indonesia, Asia, Korea, China, Fiji and Hawaii (32). They have the capability to invade new places as a wide-ranging species. Armyworm frequently reappears in India every year and causes evident destruction. Different records on the insect population outbreak have been reported from many countries all around the world (33). The resistance and cross-resistance of this pest against insecticide toxin make it more difficult to reduce its population below threshold level. Many workers all over the world have noted it as the folivore pest (34). The caterpillars of *S. litura* are agricultural crops pests and are distributed widely throughout the sphere (Table 1). Armyworm was also reported from India in the year 2018 (35), later recorded from Bangladesh, Sri Lanka, Nepal, China and Pakistan (36). The broad host range with high flight speed 100 km/night increased its incidence in the bordering countries. Now, this insect has been identified in various maize growing areas in Pakistan (36) as agro climatic conditions there are almost similar to India.

According to a study, *S. litura* is a common polyphagous pest in India and many other nations (37). As a result of its increased resistance to biotic and abiotic stresses, it has become a greater hazard to Indian and global agriculture. Its hereditary characteristics could be studied in order to formulate effective management techniques. They examined and compared the *S. litura* cytochrome c oxidase subunit I (cox1) gene sequences belonging to 21

Table 1. Worldwide distribution record of *Spodoptera litura.*

Landmasses of the World	Country / province	Variants or Subnational distribution	Status	References
Africa (Mother Continent)	Reunion island	-	Present	(27)
North America	United States of America (USA)	Hawaii and Florida	Restricted distribution	(24)
Asia (Continent of contrasts)	China	Fujian, Guangxi, Guangdong, Anhui, Guizhou, Henan, Hunan, Hubei, Jiangsu, Shandog, Macau, Jilin, Shanghai, Yunnan, Sichuan, Hong Kong, Zhejiang Baise, Hechi, Hezhou and Southern China	Restricted distribution	(38)
	Afghanistan		Present	(39)
	Cambodia		Present	(40)
	Indonesia	Java, Irian Jaya, Sumatra, Kalimantan, Sulawesi and Maluku	Present	(27)
	India	Assam, Andhra Pradesh, Andaman and Nicobar Island, Delhi, Bihar, Himachal Pradesh, Haryana, jammu and Kashmir, Madhya Pradesh, Karnataka, Maharashtra, Kerala, Punjab, Orissa, Sikkim, Rajasthan, Uttarakhand, Uttar Pradesh, Tamil Nadu and West Bengal	Present	(27, 41)
	Japan	Honshu, Shikoku, Kyushu, Ryukyu Archipelago and Hokkaido	Present	(27)
	Iran		Present	(42)
	Korea Republic and Korea DPR		Present	(43)
	Myanmar		Present	(27)
	Taiwan		Present	(44)
	Sri Lanka		Present	(45)
	Thailand		Present	(46)
Oceania	American Samoa		Present	(47)
	Cook Islands		Present	(47)
	Australia	New South Wales, Queensland, Western Australia, Victoria and Northern Territory	Restricted distribution	(24)
	French Polynesia		Restricted distribution	(47)
	Fiji		Present	(47)
	Marshell Islands		Present	(47)
	Kiribati		Present	(47)
	Guam		Present	(47)
	Micronesia		Present	(47)
	Niue		Present	(48)
	New Zealand		Restricted distribution	(49)
	Norfolk Island		Present	(47)
	Palau		Present	(47)
	Northern Mariana island		Present	(27)
	Samoa		Present	(50)
	Papua New Guinea		Present	(51)
	Solomon Islands		Present	(52)
	Tuvalu		Present	(48)
	Tonga		Present	(27)
	Wallis and Futuna Island		Restricted distribution	(47)
	Vanuatu		Present	(47)
	Russia	Far East Russia, Central Russia, Western Siberia and Southern Russia	Restricted distribution	(47)
Europe	Denmark		Absent	(53)
	Germany		Absent	(47)
	Netherland		Absent	(47)

locations in 10 agro-climatic zones of India with the cox1 sequences of foreign populations of *S. litura* (retrieved from NCBI) in order to understand the effects of decades of insecticidal pressure on the genetic diversity of the Indian population of *S. litura*. Overall, the Indian and immigrant populations showed little genetic variation and little genetic fixation (FST = 0.0088). According to investigations on the population genetic structure, 5 unusual haplotypes were found in the Indian subcontinent, along with monophyly. Deep interrelations between its populations were indicated by the lack of considerable genetic divergence, which increased gene flow across the analyzed countries and was compatible with its ability to fly far enough to disperse. In the absence of any genetic bottleneck, neutrality tests and mismatch distribution analysis revealed that *S. litura* has had a recent rapid expansion. Rare haplotypes were detected in specific interior regions of India, indicating the absence of bottlenecks or founder effects there. The outcomes of this population genetic research can be used to help create efficient controls for this migratory pest.

Dispersal of *S. litura*

According to a study, dispersal events have a significant impact on population genetic structure, particularly for migratory species (38). Because of this, studying population structure helps us better understand how species disperse. In China, the significant tobacco pest *S. litura* causes significant harm to numerous crops. In this study, 545 samples of the pest from tobacco plantations at 24 locations mostly in Baise, Hechi, Hezhou and Southern China were used to clarify the fine-scale population genetics and investigate the species' dispersal patterns. Using 7 microsatellite loci, they examined the genetic diversity, genetic organization and gene flow of these groups. Their findings showed that the pest has a high genetic diversity and a poor population genetic structure. Geographical distance and genetic distance were unrelated, demonstrating that local population dispersal happened entirely at random. Their findings imply that the mobility range of modern *S. litura* may be considerably greater than the local-level spatial scale, providing a theoretical foundation for pest management (Table 1).

S. litura passively disperses in the windy weather and has the capacity to migrate long distances, even overseas. Pupal stage is present in the soil and can be carried up to a large distance if the body remains undamaged. The establishment of its population in a place depends on the transportation of both sexes. To know more about their dispersal behaviour from an area into the target fields, more studies are required to be conducted. There may be the case of accidental introduction through the means of international trade where the eggs or larval stages attached to the planting materials, vegetables and cut flowers gets transferred. One such case was the introduction of *S. litura* in United Kingdom via imported aquatic plants from Singapore (54).

Biology

S. litura is a holometabolous insect, showing 4 stages including egg, larva, pupa and adult during its life (4). Adult females lay 200–300 eggs in masses in 3–4 layers on the underneath of lower leaves (20, 21, 41). A layer of brown hairy scales usually cover the eggs (55). During its life span of 6–8 days, a female can lay approximately 2000 eggs. Generally the incubation period of the eggs ranges from 4-5 days. However, the hatching time also depends on temperature and can vary from 2 days to 14 days at 35 °C and 15 °C respectively (56). Newly hatched slow moving pale green larvae are cylindrical in shape with a wide head size and tapering abdomen towards caudal region (57). Moth larva moults 4-6 times during life producing 5-7 larval stages. Larval development stage is completed in 15–23 days at temperature 25–26 °C (23). Later larval instars spread to the nearby fields for feeding and pupate underneath the surface soil (55). Adults emerge from pupae within 5-14 days depending on the temperature (Fig. 2).

Diapause is not shown by any developmental stages in this insect pest. In about 5 weeks, the life span of the insect is completed (23). Armyworm, *S. litura* is multivoltine means has many generations per year. Three generations per year of this insect are reported in northern China whereas this number is approximately 9 in Southern China (58). As per CABI, 2022 report, 12 generations per year occur in the South Eastern coastal regions of India.

In the year 2019, a study scrutinized the biology of tobacco caterpillar on agricultural crops and detected the duration of life cycle 43, 37, 35 and 34 days and sex ratios (female: male) of 2:1, 1.6:1, 1.6:1 and 1.3:1 on host plants *Brassica oleracea* var. *capitata*, *Brassica oleracea* var. *botrytis, Solanum lycopersicum* and *Vigna mungo* respectively (59). The percent eggs viability as well as the percent adult emergence was highest on cabbage (60). Different larval forms of *S. litura* feed on more than hundred different economically important plant species of cultivated crops. The larvae feed voraciously in groups on the underneath parts of young leaves, stem, fruits resulting in skeletonization/ damage of the foliage as well as fruits (61).

Symptoms caused by pest in the field

Major symptoms caused by *S. litura* include skeletonization of leaves, defoliation, windowing etc. in open fields as well as in protected conditions. In India and Japan, it is a main pest in glass and vinyl houses too (62). The early symptom of this insect pest infestation is the presence of egg mats i.e. egg covered by hairy scales forming a sort of mat, on plant parts above the ground usually on lower surfaces of leaves. Once the larvae emerge from the eggs, they can be seen on various parts of the host in large numbers in the farm easily and the destruction caused by them becomes noticeable. Early larval instar stages scrape the digestible and softer parts from the lower side of the leaves without eating upper epidermis which result in a condition called windowing. It causes injury to crops such as *Solanum lycopersicum*, *Solanum tuberosum*, *Gossypium hirsutum*, *Abelmoschus esculentus*, *Capsicum annuum*, *Allium cepa*, *Glycine max* and *Trifolium* spp. (63).The older/ advanced larval instar stages eat the entire leaf lamina except the hard parts leaf midrib and veins; ultimately causing 'skeletonization' and thus results in weakening the photosynthetic ability of plants. They feed mostly on external parts however sometimes bore into the different parts

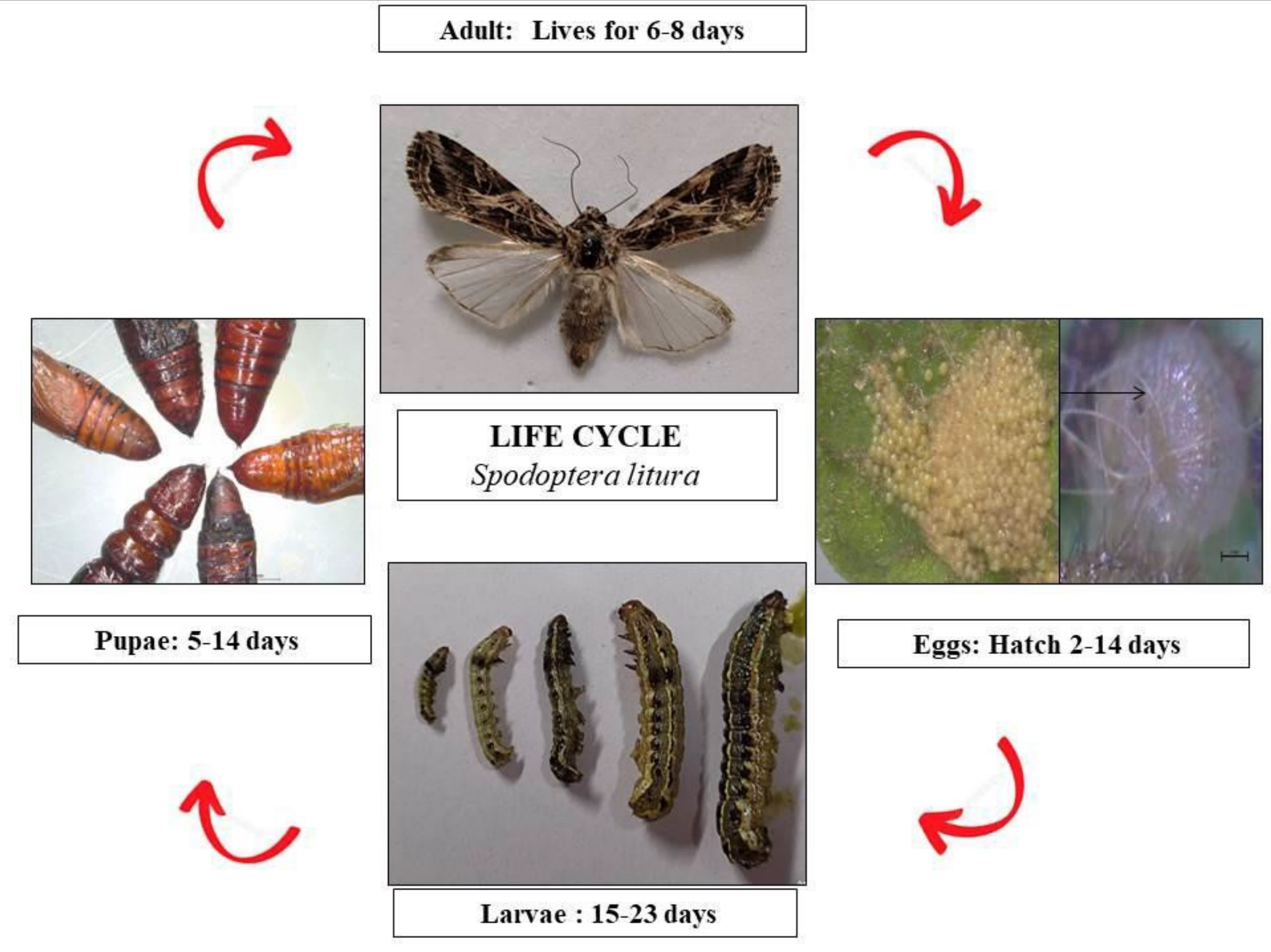

Fig. 2. Life cycle of *Spodoptera litura*. Shows multiple generations (2-7) per year and damaging stage of insect is caterpillar.

of the plant (23) which resulted in a large quantity of visible frass. A mature larva enters rhizospheric soil and pupates there and subsequently problematic to notice. The adult moths being nocturnal can be seen hovering around lights at night. They can migrate to new places easily which can be prevented using pheromone baited light traps (64). The larvae of insect pests enter the fruits and even contaminate it and this causes yield and economic losses (Fig. 3).

Climatic conditions affecting population

Pest incidence is influenced by various weather parameters like wind speed, rainfall, temperature, sunshine hours and relative humidity (8). The low temperatures of winter season are the limiting factors that affect species dissemination without aestivation or diapause phase (65). *S. litura* occurs in the Pacific and Asian regions where climate fluctuates from temperate to tropical regions (56). This species of moth is an efficient flier that could move to different far off areas. There are few studies that stated the presence of armyworm in the temperate regions where frost occurs. This may be due to occurrence of its transitory populations, found in the North region of China at approximately 30 ºN. It migrates there mainly to breed during the summer season but is unable to survive in winters (58).

Many other studies have shown that dispersal of *S. litura* is also temperature dependent (66). It is found to establish itself in the New Zealand (North Island) around Auckland and Northland in 1970s (67). The summers in Northland are humid summers with mean temperatures of 22 °C to 26 °C whereas winters are slight wet with 4 °C temperature all over the place and ground frostiness is generally rare or unusual (68). This species in Australia, is recorded as the dangerous pest especially in the seaside zones of New South Wales (NSW) where it might be problematic during the late summer when rainfall is beyond the average and temperature is warm and humid. *S. littoralis*, sibling of *S. litura* feeds on the same hosts, occurs in the tropical and temperate Africa and overwinter in southern Greece, southern Spain and in southern Italy (23) where the winter frosts are occasional. Both species are reported to cause equivalent risk to the different crops cultivated under the protected conditions in Europe (23). Different results indicated that the distribution and growth of *S. litura* is mainly temperature dependent and any deviation in it can lead to its shift to other suitable areas (69).

Due to extreme cold in winters, mortality of the insect is more and therefore, its population is reduced (70). The climate warming also has impact on its dispersal behavior (65). Warm climate helps in spreading of insects from mid to high latitudes. It was revealed that development and incidence of *S. litura* on cotton showed positive correlation with the relative humidity, dewfall and sunshine hours, but showed a negative correlation with the wind velocity (7).

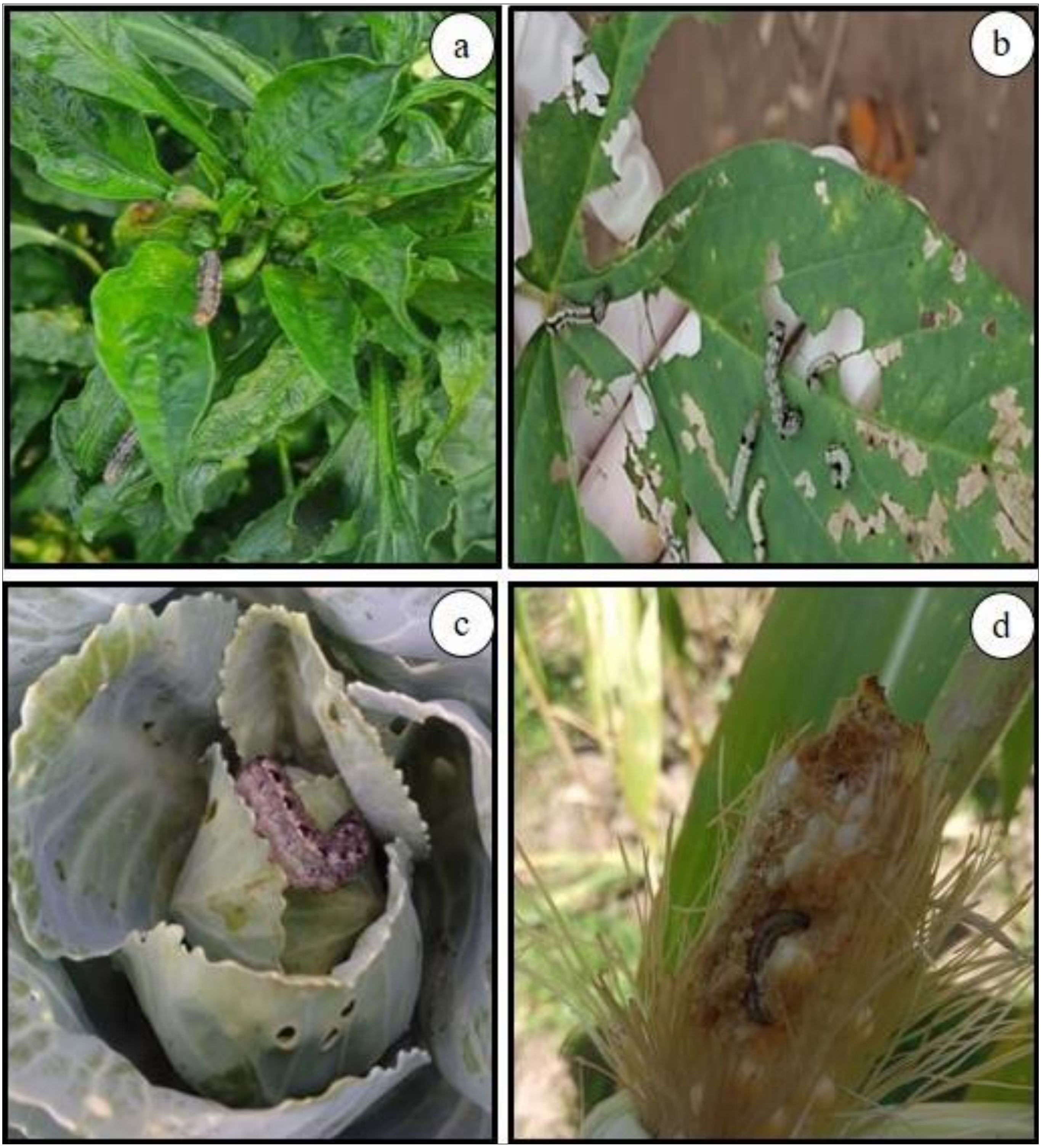

Fig. 3. Symptoms caused by the caterpillars on different host plants: (**a**) *Capsicum annuum*; (**b**) *Glycine max;* (**c**) *Brassica oleracea*; (**d**) *Zea mays*.

Damage caused by S. litura to crops

The pest has a broad range of potential hosts and is capable of seriously harming crops, which can result in financial losses for producers and food shortages for consumers. It is a harmful pest causing enough damage to standing crops. It has caused approximately 26-100 % yield losses in 150 different hosts in the open field conditions (71). In Asia-Pacific region this pest has resulted in the reduction in the productivity in field crops and vegetables (23). It destroys many crops such as tomatoes, sweet peppers and eggplants in the polyhouse cultivation in Himachal Pradesh, India (62). The larvae caused high destruction to buds, flowers and bolls of cotton. It was estimated that yield losses of about 5-100 % in potato, *Solanum tuberosum* due to *S. litura* in India (72). This pest reduces crop value of soybean both qualitatively and quantitatively and maximum damage occurs during or just after humid and warm conditions (73).

It is one of the regular pests of cauliflowers and cabbages in NSW, Australia and attacks others crops viz tomatoes, cotton and apples (74). In New Zealand, it feeds on beans, cabbage and celery. In India, impact of this pest has been evaluated and reported to cause 12-23 % damage to tomato crop during the monsoon and 9-24 % damage during the winter season (75). In 40-45 days old potato crop, damage caused was reported to be 20-100 % in various regions depending on the availability of moisture. The incidence of larval populations was highest at 60-70 days old crop (76). *S. litura* is also a pest of sugarbeet, with peaking in the late March and April month (77). In late harvested crops, 100 % of roots were damaged leading to considerable yield reduction every year. *Colocasia esculenta* suffered yield losses upto 29 % as a result of infestation caused by *S. litura*, spider mites and *Aphis gossypii* (78). In groundnut, *S. litura* is one of the pests during the podding, pegging and at the pod maturation stages (79). It also causes damage to trees, forest and shrubs (80). The pest caused a disease called brown flag syndrome in banana (81) and in grapes caused 5-10 % fruit damage (82). In teak, it attacks all stages from the seedlings to the mature trees (80).

S. litura attacks many weeds, *Ammannia baccifera, Marsilea quadrifolia* and *Eclipta alba* too. In Pakistan, it is one among the several lepidopteran pests that is attacking wide range of crops including rice and cotton tobacco, cabbage, groundnut, lucerne, soyabean, gram, tomato, cowpea, carrot, cauliflower, brinjal, onion, radish, spinach and turnip (83). In Japan, it was estimated the leaf area reductions 14.3-23.2 % and the yield losses 13.9-24.7 % respectively as compared with the control in soybean field plots which are artificially infested with *S. litura* eggs at 1-2 egg masses/plant. In Korea, under protected crops, 10 % yield loss was reported with threshold densities of *S. litura* 4.6-15.4 neonates or 0.8 and 2.6 egg masses per meter square for sweet peppers and aubergine respectively. In *Allium fistulosum*, the spring onion crops of Korea, less damage by this pest as compared with other lepidopteran; *Liriomyza chinensis* was recorded (84). In Taiwan, *S. litura* caused damage to the foliage of sword lily (Gladiolus), adzuki bean (*Vigna angularis*) and soybean (*Glycine max*) (85). Damage has been recorded between 3-13 % in the 3 consecutive years. In Thailand, Malaysia, Philippines and Indonesia this pest was recorded to damage mungbean, tobacco and tree legumes (86).

Field resistance against insecticides

S. litura developed resistance against a variety of synthetic insecticides that ultimately resulted in intermittent outbreaks of the pest causing failure of various crops (87). This pest was cosmopolitan in nature that's why its damage has been increasing continually per year. Farmers mainly depend on conventional insecticides application to manage its population. Multiple resistances against regularly used insecticides have been developed as a result of the frequent application of different insecticides intended to control it. A high resistance is also reported against the conventional pesticides such as organophosphates, pyrethroids and carbamates (87). The management of this pest has become tough worldwide as frequent use of these has turned incompetent. Resistance against organophosphates in this insect is recorded from many Asian countries as India, China and Pakistan (88). The susceptibility of *S. litura* field populations to various chemical classes was observed in Pakistan. These chemical classes included insect growth regulators (chlorfluazuron, lufenuron, flufenoxuron, triflumuron, methoxyfenozide), diamides (chlorantraniliprole, flubendiamide), spinosyns (spinosad, spinetoram), avermectins (abamectin, emamectin benzoate), indoxacarb and thiocyclam (89). Resistance against the insecticides has become problematic for the survival of insect. The selective pressure so produced due to insecticides increased the frequencies of the genes which resulted in resistance within the population (s). Several abiotic factors like temperature etc. are found to influence the evolution of resistance against conventional insecticides (90).

In China, the broad use of these insecticides against the *S. litura* triggered high resistance (91). New insecticides and insect growth regulators (IGRs) are being utilised to manage the population of this pest. Amongst IGRs, chlorfluazuron, flufenoxuron, methoxyfenozide and tebufenozide which are used against this insect pest, methoxyfenozide and flufenoxuron was hardly found to develop resistance in the insect (91). The newly introduced insecticides endure novel mechanisms of action against the insect pest. Abamectin, benzoate, emamectin, fipronil, spinosad and indoxacarb in recent times were introduced for the management of this pest. The wider application of these insecticides to control this pest has also created an appropriate environment for the evolution of insect resistance. Some data are also available that showed resistance developed in *S. litura* against the newer insecticide from the cash crops and vegetables in Pakistan (88). Exposure as well as insecticides selection can deliberate resistance against the insecticides by cross-resistance and thus decreasing their efficiency (92).

Mechanisms of insecticide resistance

Insecticide resistance in *Spodoptera* develops through a variety of mechanisms and is a complicated process. Target site resistance, behavioral resistance and metabolic resistance are 3 main categories for these mechanisms. Target site resistance happens when changes in an insecticide's target site prevent the pesticide from attaching properly, lessening its harmful effects. The voltage-gated sodium channel, which is the target site for pyrethroid pesticides, has shown target site resistance in this pest. This channel's structure can be altered by mutations, which makes it harder for pyrethroids to attach to it and results in resistance.

When insects create systems to detoxify or get rid of pesticides from their bodies, metabolic resistance happens. This can happen through upregulating enzymes that can degrade or alter insecticides, such as cytochrome P450s, esterases, and glutathione S-transferases. Metabolic resistance has been noted in *S. frugiperda* to a number of pesticide classes, including carbamates and organophosphates. When insects alter their behavior to avoid being exposed to insecticides, behavioral resistance occurs. This can occur through a range of mechanisms, including altered feeding patterns, migration to different areas or changes in mating behavior. Behavior resistance to pesticides like *Bacillus thuringiensis* (Bt), which can prevent feeding on treated crops, has been seen in *S. frugiperda* (93). Depending on the pesticide class and the local selection pressure, the processes of insecticide resistance in armyworms can change. For instance, pyrethroid resistance is more frequently seen where pyrethroids are used frequently, whereas organophosphate resistance is more frequently seen where these insecticides are still in use. In order to create efficient resistance management techniques that can limit or stop the spread of resistance in these pest populations, it is essential to understand the mechanisms of resistance (93).

Resistance development factors

In South Asia, it has been observed that field populations of *S. litura* are resistant to common pesticides like organochlorine, organophosphate, carbamate and pyrethroids (2). Additionally, there are instances of *S. litura* populations in Pakistan developing resistance to novel chemistries (88). Insecticide resistance in *Spodoptera* populations is a result of a number of causes. Insecticide use is one of the main reasons, along with genetic variability, cross-resistance, migration, overlapping generations and agricultural practices. An intense selection pressure for the emergence of resistance in populations can result from the intensive use of pesticides to control armyworm. Insecticide use can result in the death of susceptible individual, but resistant individuals can live and procreate, resulting in the establishment of resistant populations. A significant level of genetic heterogeneity may exist in these pest populations, which may have an impact on how resistance develops and spreads. Individuals can differ genetically in their susceptibility to pesticides and those who are resistant may have a genetic advantage that enables them to survive and reproduce. When one insecticide's resistance confers resistance to other insecticides with a similar mode of action, this is known as cross-resistance. For instance, pyrethroid resistance can also confer resistance to other pesticides that target the sodium channel, such as dichlorodiphenyltrichloroethane (DDT) and organochlorines. In terms of overlapping generations, this insect pest has numerous overlapping generations each year, which can hasten the emergence of resistance. A population's resistance can quickly rise as a result of resistant individuals passing their resistance genes to their offspring (94, 95).

The rapid spread of resistance can be caused by resistant individuals migrating to new locations and introducing resistance genes into vulnerable groups. Monoculture and the use of high-input cropping systems are 2 agricultural methods that can encourage the emergence of resistance in populations of fall armyworms. These procedures may result in a greater reliance on insecticides for pest control, increasing the strain on resistance development (96). These variables must be taken into account when creating integrated pest management plans in order to manage pesticide resistance in *Spodoptera* populations. To reduce the strain on resistance development in pest, alternate control strategies like biological and cultural control as well as prudent pesticide use could be involved. The detection of emerging resistance and the direction of management actions can both benefit from routine monitoring of resistance levels (97, 98).

Conclusion

The spread of pesticide resistance in *Spodoptera* populations has important repercussions for food security and agricultural output. It is crucial for farmers, researchers and policymakers to work collaboratively in order to create and implement integrated pest management techniques that can efficiently control this pest's populations while limiting the emergence and spread of pesticide resistance. Insecticide resistance in autumn armyworms must be managed using a multifaceted strategy that combines chemical and non-chemical control techniques as well as monitoring and outreach initiatives. To limit pesticide usage, it is vital to preserve its parasitoids, including braconids, encyrtids, tachinids and ichneumonids. Pheromones have also been utilized in lure-and-kill pest. Rotation of novel chemicals including emamectin benzoate and insect growth regulators (IGRs), particularly benzoylphenylureas (BZUs) diflubenzuron, chlorfluazuron, and teflubenzuron, with still-effective conventional chemicals can be opted. Continued research and development are essential for creating fresh, cutting-edge control plans to deal with this significant pest.

Acknowledgements

The authors express their gratitude to Hon'ble Vice Chancellor and Pro Vice Chancellor, Eternal University Baru Sahib, Himachal Pradesh, India for their continuous guidance and motivation.

Authors' contributions

Conceptualization- NT, KKA, AKS and ANY; Writing- original draft preparation-NT, KKA, AS and S.K; Writing, review, editing- NT,AS, SK, KKA, AKS, ANY; Final editing and Making of Figures and Tables-SR, SK, Funding-SR, SS, AKR.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

References

1. Qin D, Zhang P, Zhou Y, Liu B, Xiao C, Chen W, Zhang Z. Antifeeding effects of azadirachtin on the fifth instar *Spodoptera litura* larvae and the analysis of azadirachtin on target sensilla around mouthparts. Arch Insect Biochem Physiol. 2020;103:e21646. https://doi.org/10.1002/arch.21646
2. Saleem MA, Ahmad M, Ahmad M, Aslam M, Sayyed AH. Resistance to selected organochlorin, organophosphate, carbamate and pyrethroid, in *Spodoptera litura* (Lepidoptera: Noctuidae) from Pakistan. J Econ Entomol. 2008;101:1667-75. https://doi.org/10.1093/jee/101.5.1667
3. Dhaliwal G, Jindal V, Dhawan A. Insect pest problems and crop losses: changing trends. Indian J Ecol. 2010;37:1-7.
4. Ramaiah M, Maheswari TU. Biology studies of tobacco caterpillar, *Spodoptera litura* Fabricius. J Entomol Zool Stud. 2018;6:2284-89.

5. Cameron P, Hill R, Bain J, Thomas W. Analysis of importations for biological control of insect pests and weeds in New Zealand. Biocontrol Sci Technol. 1993;3:387-404. https://doi.org/10.1080/09583159309355294

6. Czepak C, Albernaz KC, Vivan LM, Guimarães HO, Carvalhais T. First reported occurrence of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) in Brazil. Pesqui Agropecu Trop. 2013;43:110-13. https://doi.org/10.1590/S1983-40632013000100015

7. Selvaraj S, Adiroubane D, Ramesh V, Narayanan A. Impact of ecological factors on incidence and development of tobacco cut worm, *Spodoptera litura* Fabricius on cotton. J Biopestic. 2010;3:43. https://doi.org/10.57182/jbiopestic.3.1.43-46

8. Babu SR, Kalyan R, Ameta G, Meghwal ML. Analysis of outbreak of tobacco caterpillar, *Spodoptera litura* (Fabricius) on soybean. J Agrometeorol. 2015;17:61-66. https://doi.org/10.54386/jam.v17i1.987

9. Thakur N, Tomar P, Kaur J, Kaur S, Sharma A, Jhamta S, *et al*. Eco-friendly management of *Spodoptera litura* (Lepidoptera: Noctuidae) in tomato under polyhouse and field conditions using *Heterorhabditis bacteriophora* Poinar, their associated bacteria (*Photorhabdus luminescens*) and *Bacillus thuringiensis* var. *kurstaki*. Egypt J Biol PestControl. 2023;33:2-13. https://doi.org/10.1186/s41938-023-00649-4

10. Thakur N, Tomar P, Sharma S, Kaur S, Sharma S, Yadav AN, Hesham AE-L. Synergistic effect of entomopathogens against *Spodoptera litura* (Fabricius) under laboratory and greenhouse conditions. Egypt J Biol Pest Control. 2022;32:1-10. https://doi.org/10.1186/s41938-022-00537-3

11. Ranga Rao G, Wightman J, Ranga Rao D. World review of the natural enemies and diseases of *Spodoptera litura* (F.) (Lepidoptera: Noctuidae). Int J Trop Insect Sci. 1993;14:273-84. https://doi.org/10.1017/S1742758400014764

12. Mishra P, Balaji A, Dhal P, Kumar RS, Magdassi S, Margulis K, *et al*. Stability of nano-sized permethrin in its colloidal state and its effect on the physiological and biochemical profile of *Culex tritaeniorhynchus* larvae. Bull Entomol Res. 2017;107:676-88. https://doi.org/10.1017/S0007485317000165

13. Dey K, Choudhury P, Dutta B. Impact of pesticide use on the health of farmers: A study in Barak valley, Assam (India). J Environ Chem Ecotoxicol. 2013;5:269-77. https://doi.org/10.5897/JECE2013.0296

14. Thakur N, Tomar P, Kaur S, Kumari P. Virulence of native entomopathogenic nematodes against major lepidopteran insect species of tomato (*Solanum lycopersicum* L.). J Appl Biol Biotechnol. 2022;10:6-14. http://dx.doi.org/10.7324/JABB.2022.10s102

15. Wang P, Yang F, Wang Y, Zhou L-L, Luo H-B, Zhang S, Si S-Y. Monitoring the resistance of the beet armyworm (Lepidoptera: Noctuidae) to four insecticides in Southern China from 2014 to 2018. J Econ Entomol. 2021;114:332-38. https://doi.org/10.1093/jee/toaa290

16. Kranthi K, Jadhav D, Kranthi S, Wanjari R, Ali S, Russell D. Insecticide resistance in five major insect pests of cotton in India. Crop Protec. 2002;21:449-60. https://doi.org/10.1016/S0261-2194(01)00131-4

17. Prasanth MI, Sivamaruthi BS, Chaiyasut C, Tencomnao T. A review of the role of green tea (*Camellia sinensis*) in antiphotoaging, stress resistance, neuroprotection and autophagy. Nutrients. 2019;11:474. https://doi.org/10.3390/nu11020474

18. Thakur N, Kaur S, Tomar P, Thakur S, Yadav AN. Microbial biopesticides: current status and advancement for sustainable agriculture and environment. In: New and Future Developments in Microbial Biotechnology and Bioengineering. Edited by Rastegari Ali Asghar and Yadav Ajar Nath (ed). Elsevier, 2020:243-82. https://doi.org/10.1016/B978-0-12-820526-6.00016-6

19. Thakur N, Tomar P, Kaur S, Jhamta S, Thakur R, Yadav AN. Entomopathogenic soil microbes for sustainable crop protection. In: Soil Microbiomes for Sustainable Agriculture: Functional Annotation. Edited by Nath YA (ed). Springer, Cham, 2021:529-71. https://doi.org/10.1007/978-3-030-73507-4_17

20. Muddasar V. Taxonomic description of the genus *Spodoptera* (Lepidoptera: Noctuidae) from Karnataka. J Entomol Zool Studies. 2017;5:1854-58.

21. Cardona EV, Ligat CS, Subang M. Life history of common cutworm, *Spodoptera litura* Fabricius (Moctuidae: Lepidoptera) in Benguet. BSU Res J. 2007;56:69-80.

22. Pinhey EC (Eds). Moths of Southern Africa. Descriptions and Colour Illustrations of 1183 Species. AA Balkema. Cape Town; 1975.

23. Smith SM. Biological control with *Trichogramma*: advances, successes and potential of their use. Annu Rev Entomol. 1996;41:375-406. https://doi.org/10.1146/annurev.en.41.010196.002111

24. Pogue GM (Eds). A world revision of the genus *Spodoptera* Guenée: (Lepidoptera: Noctuidae). American Entomological Society, Philadelphia. 2002;vol 43.

25. Kumar R, Khokhar K. Identification of *Spodoptera litura* (Fabricius) and *Spodoptera exigua* (Hubner) (Amphipyrinae: Noctuidae: Lepidoptera). J Entomol Res. 2003;27:157-65.

26. Todd E, Blanchard A, Poole R. Revision of the genus *Aleptina* (Lepidoptera: Noctuidae). Proc Entomol Soc. 1984;86:951-60.

27. Global distribution of *Spodoptera litura* (2015) EPPO European and Mediterranean Plant Protection Organization. . https://gd.eppo.int/taxon/PRODLI/distribution. Accessed Assessed in March 2023.

28. Joshi R, Gaur N, Mathpal S. Distribution of *Spodoptera litura* (F.) in Uttarakhand. Indian J Entomol. 2023;389-92. https://doi.org/10.55446/IJE.2022.796

29. Hajibabaei M, Singer GA, Clare EL, Hebert PD. Design and applicability of DNA arrays and DNA barcodes in biodiversity monitoring. BMC Biol. 2007;5:1-7. https://doi.org/10.1186/1741-7007-5-24

30. Kress WJ, Erickson DL. DNA barcodes: genes, genomics and bioinformatics. Proc Natl Acad Sci. U.S.A. 2008;105:2761-62. https://doi.org/10.1073/pnas.0800476105

31. Meagher RL, Brambila J, Hung E. Monitoring for exotic *Spodoptera* species (Lepidoptera: Noctuidae) in Florida. Fla Entomol. 2008;91:517-22. https://doi.org/10.1653/0015-4040-91.4.517

32. Hill DS (Eds). Agricultural insect pests of the tropics and their control. Second Edn. Cambridge University Press. Cambridge, UK;1987.

33. Dhaliwal G, Koul O (Eds). Quest for pest management: from green revolution to gene revolution. Kalyani Publishers, New Delhi; 2010.

34. Sharma D. Biology and food preference of tobacco caterpillar, *Spodoptera litura* Fabricius, on five different hosts. J Entomol Res. 1994;18:151-55.

35. Sharanabasappa S, Kalleshwaraswamy C, Poorani J, Maruthi M, Pavithra H, Diraviam J. Natural enemies of *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), a recent invasive pest on maize in South India. Fla Entomol. 2019;102:619-23. https://doi.org/10.1653/024.102.0335

36. Naeem-Ullah U, Ansari MA, Iqbal N, Saeed S. First authentic report of *Spodoptera frugiperda* (JE Smith) (Noctuidae: Lepidoptera) an alien invasive species from Pakistan. J Appl Econ Bus Stud. 2019;6:1-3.

37. Ganguly S, Srivastava CP, Premkumari S, Meena RS, Singh RN, Srivastava K, Prakash P. Has insecticidal pressure influenced

Spodoptera litura (Fabricius, 1775) population genetic structure and genetic diversity in India? Biologia. 2023;78:837-49. https://doi.org/10.1007/s11756-022-01288-0

38. Hu Z, Yang F, Zhang D, Zhang S, Yu X, Yang M. Genetic diversity and fine-scale genetic structure of *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae) in Southern China based on microsatellite markers. Animals. 2023;13:560. https://doi.org/10.3390/ani13040560
39. Srivastava K, Sharma D, Anal A, Sharma S. Integrated management of *Spodoptera litura*: a review. Int J Life Sci Res. 2018;4:1536-38. https://doi.org/10.21276/ijlssr.2018.4.1.4
40. Pol C, Belfield S, Martin R. Insects of upland crops in Cambodia. ACIAR Monograph No. 143. Australian Centre for International Agricultural Research, Canberra; 2010.
41. Natikar P, Balikai R. Present status on bio-ecology and management of tobacco caterpillar, *Spodoptera litura* (Fabricius)–An update. Int J Plant Prot. 2017;10:193-202. https://doi.org/10.15740/HAS/IJPP/10.1/193-202
42. Saeidi K, Mirfakhraei S, Mehrkhou F, Valizadegan O. Biodiversity of insects associated with safflower (*Carthamus tinctorius*) crop in Gachsaran, Iran. J Eontomol Acarol Res. 2015;47:26-30. https://doi.org/10.4081/jear.2015.1910
43. Jung JM, Byeon Dh, Jung S, Lee WH. Effect of climate change on the potential distribution of the common cutworm (*Spodoptera litura*) in South Korea. Entomol Res. 2019;49:519-28. https://doi.org/10.1111/1748-5967.12398
44. Tuan SJ, Lee CC, Chi H. Population and damage projection of *Spodoptera litura* (F.) on peanuts (*Arachis hypogaea* L.) under different conditions using the age-stage, two-sex life table. Pest Management Science. 2014;70:805-13. https://doi.org/10.1002/ps.3618
45. Wiltshire E. Middle East Lepidoptera. XXXVII: notes on the *Spodoptera liura* (F.) group (Noctuidae Trifinae). Proc Br Entomol Nat Hist Soc. 1977;10:92-96.
46. Sepswasdi P, Pitaksa S, Chareonrak T, Phapoom V, Heuel-Rolf B. Crop loss assessment for major mungbean pests in rice-based cropping systems. In: Proceedings of the Mungbean Meeting. Tropical Agriculture Research Centre. 1991;90:pp 259-67.
47. Pests not known to occur in the United States or of limited distribution. Rice cutworm, *Spodoptera litura*. USDA APHIS-PPQ. 1982;No. 24.
48. Dharmaraju E. Pest problems of crops in Tuvalu. Alafua Agric Bull. 1980;5:7-9.
49. Dugdale JS. Lepidoptera-annotated catalogue and keys to family-group taxa. Fauna N. Z. 1988;14:262. https://doi.org/10.7931/J2/FNZ.14
50. Fatuesi S, Tauili'ili P, Taotua F, Vargo A. Cultural methods of pest control on targo (*Colocasia esculenta* Schott) in American Samoa. Micronesica. 1991;34:123-27.
51. Dodd J. Effects of pests and diseases on the yield and quality of tomatoes in the Port Moresby area, Papua New Guinea. J Agric. 1979;30:53-59.
52. Macfarlane R. Annual report 1989, Ministry of Agriculture and amp; lands. Dodo Creek Research Station, Honiara, Solomon Islands. 1987.
53. Karsholt O, Nielsen PS (Eds). Revised checklist of the lepidoptera of Denmark. Lepidopterologisk forening. Copenhagen (DK); 2013.
54. Aitkenhead P, Baker C, De Chickera G. An outbreak of *Spodoptera litura*, a new pest under glass in Britain. Plant Pathol. 1974;23:117-18. https://doi.org/10.1111/j.1365-3059.1974.tb02921.x
55. Gupta M, Tara J, Sharma S, Bala A. Biology and morphometry of *Spodoptera litura* Fabricus, a serious defoliator of Mango (*Mangifera indica*) in Jammu Region (J and K). Mun Ent Zool. 2015;10:215-21.
56. Fand BB, Sul NT, Bal SK, Minhas P. Temperature impacts the development and survival of common cutworm (*Spodoptera litura*): simulation and visualization of potential population growth in India under warmer temperatures through life cycle modelling and spatial mapping. PLoS One. 2015;10:e0124682. https://doi.org/10.1371/journal.pone.0124682
57. Latha M, Shivanna B, Manjunatha M, Kumaraswamy M. Biology of *Spodoptera litura* on chewing tobacco *in vitro*. J Eco-friendly Agric. 2014;9:43-47.
58. Fu X, Zhao X, Xie B, Ali A, Wu K. Seasonal pattern of *Spodoptera litura* (Lepidoptera: Noctuidae) migration across the Bohai Strait in Northern China. J Econ Entomol. 2015;108:525-38. https://doi.org/10.1093/jee/tov019
59. Kumar H, Bhattacharya S. Biology of *Spodoptera litura* (Fabricius) on different crop plants. J Entomol Res. 2019;43:165-68. http://dx.doi.org/10.5958/0974-4576.2019.00032.X
60. Ramzan M, Sultan Y, Sabir MW, Shafiq M, Murtaza G, Shahid M, Umair M, Asif HM. Effect of host plants on the biology of *Spodoptera litura* (F.). Indian J Entomol. 2020;82:408-11. http://dx.doi.org/10.5958/0974-8172.2020.00090.5
61. Deole S, Paul N. First report of fall army worm, *Spodoptera frugiperda* (JE Smith), their nature of damage and biology on maize crop at Raipur, Chhattisgarh. J Entomol Zool Stud. 2018;6:219-21.
62. Vashisth S, Chandel Y, Kumar S. Biology and damage potential of *Spodoptera litura* Fabricius on some important greenhouse crops. J Insect Sci. 2012;25:150-54.
63. Saleem M, Hussain D, Ghouse G, Abbas M, Fisher SW. Monitoring of insecticide resistance in *Spodoptera litura* (Lepidoptera: Noctuidae) from four districts of Punjab, Pakistan to conventional and new chemistry insecticides. Crop Protec. 2016;79:177-84. https://doi.org/10.1016/j.cropro.2015.08.024
64. Punithavalli M. Light trap as a monitoring tool for common cutworm *Spodoptera litura* (f.) in soybean. Indian J Entomol. 2018;80:356-60. http://dx.doi.org/10.5958/0974-8172.2018.00071.8
65. Bale J. Insects and low temperatures: from molecular biology to distributions and abundance. Philos Trans R Soc B Biol. 2002;357:849-62. https://doi.org/10.1098/rstb.2002.1074
66. Wang R, Jiang C, Guo X, Chen D, You C, Zhang Y, *et al*. Potential distribution of *Spodoptera frugiperda* (JE Smith) in China and the major factors influencing distribution. Glob Ecol Conserv. 2020;21:e00865. https://doi.org/10.1016/j.gecco.2019.e00865
67. Hoare RJ. Adventive species of Lepidoptera recorded for the first time in New Zealand since 1988. N Z Entomol. 2001;24:23-47. https://doi.org/10.1080/00779962.2001.9722079
68. Chappel P. The climate and weather of Auckland. NIWA Science and Technology Series. 2013;56:40.
69. Khan A, Choudhury M, Dash C, Khan U, Ehsanullah M. Insect pests of country bean and their relationships with temperature. Bangladesh J Ecol. 2020;2:43-46.
70. Lombardero MJ, Ayres MP, Ayres BD, Reeve JD. Cold tolerance of four species of bark beetle (Coleoptera: Scolytidae) in North America. Environ Entomol. 2000;29:421-32. https://doi.org/10.1603/0046-225X-29.3.421
71. Rao R, GV, Wightman J, Rao R, DV. World review of the natural enemies and diseases of *Spodoptera litura* (F.) (Lepidoptera: Noctuidae). Int J Trop Insect Sci. 1993;14:273-84. https://doi.org/10.1017/S1742758400014764
72. Oerke EC, Dehne HW, Schönbeck F, Weber A (Eds). Crop production and crop protection: Estimated losses in major food and cash crops. Elsevier Science; 2012.

73. Bhattacharjee N, Ghude D. Effect of artificial and natural defoliation on the yield of soybean. Indian J Agric Sci. 1985;55:427-29.

74. Imran M, Kanwal Hanif MA, Nasir M, Sheikh UAA. The impact of different levels of nitrogen fertilizer on maize hybrids performance under two different environments. Asian J Agric Biol. 2017;5:88-98.

75. Patnaik H. Pheromone trap catches of *Spodoptera litura* F. and extent of damage on hybrid tomato in Orissa. In: Advances in IPM for Horticultural Crops. Proceedings of the First National Symposium on Pest Management in Horticultural Crops: Environmental Implications and Thrusts, Bangalore, India, 15-17 October 1997. Association for Advancement of Pest Management in Horticultural Ecosystems. 1998;pp 68-72.

76. Trivedi T. Incidence of caterpillars on potato in Kolar, Karnataka. Curr Res-Univ Agric Sci. (Bangalore). 1988;17:121.

77. Chatterjee P, Nayak D. Occurrence of *Spodoptera litura* (Fabr.) as a new pest of sugar-beet in West Bengal. Pesticides. 1987;21:21-22.

78. Reddy PP. Taro, *Colocasia esculenta*. Plant Protection in Tropical Root and Tuber Crops. 2015;143-92. https://doi.org/10.1007/978-81-322-2389-4

79. Singh K, Sachan G. Phenols and phenolic acids in groundnut (*Arachis hypogaea*) resistant to tobacco caterpillar (*Spodoptera litura*). Indian J Agric Sci. 1992;62:717-19.

80. Roychoudhury N, Shamila K, Joshi K. Pest status and larval feeding preference of *Spodoptera litura* (Fabricius) Boursin (Lepidoptera: Noctuidae) on teak. Indian For. 1995;121:581-83.

81. Ranjith A, Haseena B, Nambiar S. *Spodoptera litura* causes brown flag syndrome in banana. Insect Environ. 1997;3:44

82. Balikai R, Bagali A, Ryagi Y. Incidence of *Spodoptera litura* Fab. on grapevine, *Vitis vinifera* L. Insect Environ. 1999;5:32.

83. Maree J, Kallar S, Khuhro R. Relative abundance of *Spodoptera litura* F. and *Agrotis ipsilon* Rott. on cabbage. Pakistan J Zool. 1999;31:31-34.

84. Ahn S, Kim I, Cho W, Lee M, Choi K. The occurrence of the crop insect pests from Korea in 1988. Kor J Appl Entomol. 1989;28:246-53.

85. Liu T. Insect pests of gladiolus and lily plants. Special Publication-Taichung District Agricultural Improvement Station. 1998;139-50.

86. Tojo S, Mishima H, Kamiwada H, Ngakan PO, Chang K-S. Variations in the occurrence patterns of male moths of the common cutworm, *Spodoptera litura* (Lepidoptera: Noctuidae) among Southeastern Asian countries, as detected by sex pheromone trapping. Appl Entomol Zool. 2008;43:569-76. https://doi.org/10.1303/aez.2008.569

87. Ahmad M, Sayyed AH, Saleem MA, Ahmad M. Evidence for field evolved resistance to newer insecticides in *Spodoptera litura* (Lepidoptera: Noctuidae) from Pakistan. Crop Protec. 2008;27:1367-72. https://doi.org/10.1016/j.cropro.2008.05.003

88. Shad SA, Sayyed AH, Fazal S, Saleem MA, Zaka SM, Ali M. Field evolved resistance to carbamates, organophosphates, pyrethroids and new chemistry insecticides in *Spodoptera litura* Fab. (Lepidoptera: Noctuidae). J Pest Sci. 2012;85:153-62. https://doi.org/10.1007/s10340-011-0404-z

89. Ahmad M, Gull S. Susceptibility of armyworm *Spodoptera litura* (Lepidoptera: Noctuidae) to novel insecticides in Pakistan. Can Entomol. 2017;149:649-61. https://doi.org/10.4039/tce.2017.29

90. Torres-Vila L, Rodrıguez-Molina M, Lacasa-Plasencia A, Bielza-Lino P. Insecticide resistance of *Helicoverpa armigera* to endosulfan, carbamates and organophosphates: the Spanish case. Crop Protec. 2002;21:1003-13. https://doi.org/10.1016/S0261-2194(02)00081-9

91. Huang S, Xu J, Han Z. Baseline toxicity data of insecticides against the common cutworm *Spodoptera litura* (Fabricius) and a comparison of resistance monitoring methods. Int J Pest Manag. 2006;52:209-13. https://doi.org/10.1080/09670870600673962

92. Sayyed AH, Ahmad M, Saleem MA. Cross-resistance and genetics of resistance to indoxacarb in *Spodoptera litura* (Lepidoptera: Noctuidae). J Econ Entomol. 2014;101:472-79. https://doi.org/10.1093/jee/101.2.472

93. Guo Z, Jin R, Guo Z, Cai T, Zhang Y, Gao J, *et al*. Insecticide susceptibility and mechanism of *Spodoptera frugiperda* on different host plants. J Agric Food Chem. 2022;70:11367-76. https://doi.org/10.1021/acs.jafc.2c04189

94. Rizali A, Oktaviyani O, Putri S, Doananda M, Linggani A. Invasion of fall armyworm *Spodoptera frugiperda*, a new invasive pest, alters native herbivore attack intensity and natural enemy diversity. Biodiversitas. 2021;22:3482-88. https://doi.org/10.13057/biodiv/d220847

95. Guo Z, Ma H, Tang J, Wu M, He S, Wan H, *et al*. Chlorantraniliprole resistance in *Spodoptera frugiperda*: Resistance monitoring, resistance risk and resistance mechanisms. J Agric Food Chem. 2024;72:16651-60. https://doi.org/10.1021/acs.jafc.4c03361

96. Wang J, Huang Y, Huang L, Dong Y, Huang W, Ma H, *et al*. Migration risk of fall armyworm (*Spodoptera frugiperda*) from North Africa to Southern Europe. Front Plant Sci. 2023;14:1141470. https://doi.org/10.3389/fpls.2023.1141470

97. Bird L, Miles M, Quade A, Spafford H. Insecticide resistance in Australian *Spodoptera frugiperda* (JE Smith) and development of testing procedures for resistance surveillance. Plos One. 2022;17:e0263677. https://doi.org/10.1371/journal.pone.0263677

98. Posos-Parra O, Mota-Sanchez D, Pittendrigh BR, Wise JC, DiFonzo CD, Patterson E. Characterization of the inheritance of field-evolved resistance to diamides in the fall armyworm (*Spodoptera frugiperda*) (Lepidoptera: Noctuidae) population from Puerto Rico. Plos One. 2024;19:e0295928. https://doi.org/10.1371/journal.pone.0295928