CHAPTER- I

1 INTRODUCTION

1.1 *Spodoptera litura* Fabricius, 1775.

Spodoptera litura Fabricius, 1775. (Lepidoptera: Noctuidae) is one of the important Lepidopteran noctuid insect pests having high economical importance. It was previously known as *Prodenia litura* and first reported in 1775 by Fabricius. *Spodoptera litura*, commonly known as tobacco caterpillar, has many names as common cutworm, tobacco cutworm, cluster caterpillar, grey streaked moth, cotton leaf worm. The *Spodoptera litura* moths are found primarily active during night as it comes under family Noctuidae. Due to its high mobility, female oviposition capacity aids survival of *S. litura* individual on different host plants on a broad range of abiotic & biotic factors. *S. litura* is an ubiquitous, polyphagous& voracious lepidopteran pest that feeds on 112 cultivated crops all over the world and on about 60 species from India (Bragard et al., 2019). It is a generalist polyphagus insect pest feeding on more than 290 species of host plants belonging to 99 families (Wu et al., 2004). It has been reported attacking cauliflower, mash/black gram, moong, sunflower, *arvi*, castor and cotton (Kumar et al., 2013). The larva is polyphagus and feeds on mungbean, soybean and various vegetables recorded as hosts (Xue et al., 2010). Fand*et al* (2012) found castor, okra and sunflower suitable equally as food plants while groundnut was less suitable. Ahuja, D.B. & Noor, 1991 reported castor as the most suitable host plant, followed by cabbage, tomato, chili, groundnut, moth bean, green gram, slender pigweed, carpet weed and sesame. It has been identified as a pest of vegetables particularly of family Brassicaceae (Khaliq et al., 2014). In Punjab, the pest causes severe damage to both the main season and late planted cauliflower and cabbage crops between August and November. In Southern India, it is known to be a key pest of cotton and groundnut.

S. litura devastates a large host range of more than 120 plants, the major ones include tobacco, cotton, groundnut, jute, Lucerne/alfalfa, maize, rice, soybean, tea, cauliflower, cabbage, capsicum, potato and castor (Sharma, R. K. ; Bisht, 2008). *S. litura* damages different crops like soybean, pulses, oilseed, cotton and vegetables. (Seema R, 2002). Tobacco caterpillar, *S. litura* is a noxious pest that damages cotton crop extensively by skeletonizing the leaves and thus reducing the photosynthetic capacity of the plant (Selvaraj et al., 2010).

The rapid migration & reproductive capacity has made the pest an economically important one. They are known to invade different geographical range throughout Asia, from North Africa to Japan, Australia and New Zealand. The caterpillar is widely distributed throughout tropical and temperate regions of Asia, Australia and Pacific islands (Monubrulla et al., 2008). In India, *S. litura* is known to present almost in every states and cause losses to wide varieties of economic importance host plants like soybean, cotton, castor, tomato and groundnut. A single larva of *S. litura* per square meter is causing average pod yield loss of 27.3% in groundnut through damaging various plant parts like leaves, flowers and pods (Dhir B C, 1992).

Figure 1 *S. litura* on cotton leaf

Figure 2 *S. litura* on cabbage leaf

Figure 3 *S. litura* on capsicum leaf

Since 2002, *S. litura* larvae causing huge damage soybean crop in India. Intensity of change in climatic ecosystem noted by meteorological science has showed a direct and indirect affect on the prey and host relationship, their immune responses and rate of development, their fecundity and various physiological functions (Dhir B C, 1992). Zag, G. M. and Kushwaha, 1983 reported the population of *S. litura* has been showing negatively correlation with average and maximum temperature in cabbage crop. It is a sporadic pest with a high mobility and reproductive capacity (Holloway, 1989). Gopalaswamy, (2012) observed three distinct peaks of tobacco caterpillar brood emergence on urad bean. The first peak occurred in the 4th week of January when an average of 823.5 moths per trap was collected. The trap catches increased progressively during February with 1143.5 moths per trap indicating a second peak. The next marked increase in the trap catch was in the 4th week of February with 1549.75 moths per trap forming the third brood emergence. *S. litura* started attacking cauliflower initially during mid September and its population touched the peak in second week of October during 2003-04 and during 2004-05, it touched the peak twice 1st in first week of October and 2nd in the 1st week of November. Xue et al., 2010 reported that presence of *S. litura* is basically synchronous with the developing period of tobacco, specifically during summer season, providing plenty of food sources for oviposition and larval feeding. The seasonal incidence of *S. litura* on banana revealed that the larval population starts to build up during June-July and its minimum infestation on leaves 3 was recorded in the month of August-September (4.50 and 4.78% infestation) (Shukla and Patel, 2011). Its peak incidence was noticed during the first and second fortnights of August during the vegetative growth of capsicum under protected cultivation (Nandini et al., 2012). The species is migratory on all continents and is a key pest in all of them (Feng et al., 2005). It has become the most destructive pest of cabbage and cauliflower crops in Tamil Nadu (Regupathy, 2001). Several factors were identified by Gao et al.,(2004) that cause outbreaks of *S. litura* in northern China. Out breaks of the *S. litura* occurs due to its resistance to pesticides, different suitable weather conditions, cyclonic weather and heavy rainfall after a long dry spell (S.J. Thanki, 2014). In Punjab, *S.*

litura seems to have developed resistance to insecticides, as the pest is not being managed effectively with the commonly recommended insecticides (Kranthi, 2005).

1.2 Geographical distribution

Due to nocturnal habit, high mobility of adult moths and ability to oviposit on a wide range of host plants, *S. litura* has huge potential to invade new areas and to adapt to wide range of ecological situations (Chelliah, 1985).

EPPO region shows presence in Russia (Far East) & in UK found under glass in 1973 and eradicated at the same time (Aitkenhead et al., 1974).

In Asia different regions like Afghanistan, Bangladesh, Brunei, Cambodia, China (widespread), Christmas Island, Hong Kong, Indonesia (widespread), India (widespread), Iran, Japan (widespread), Korea Democratic People's Republic, Korea Republic, Lao, Maldives, Malaysia (widespread), Myanmar, Nepal, Oman, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, Viet Nam are widely covered.

In Africa mainly seen in Reunion.

In North America particularly in USA& in Hawaii region only.

Oceania region having locations like American Samoa, Australia (Northern Territory, New South Wales, Queensland, Western Australia), Cocos Islands, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, New Caledonia, Niue, Norfolk Island, Northern Mariana Islands, Micronesia, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Wallis and Futuna Islands.

In Europe the presence of *S. litura* is not seen.

Figure 4 Global distribution of *Spodoptera litura*

Figure 5 Distribution of *Spodoptera litura* in Asia

Figure 6 Distribution of *Spodoptera litura* in India

(Source of the figure 4, 5 & 6: EPPO - European and Mediterranean Plant Protection Organization)

1.3 Symptoms of damage on different host plants

Symptoms on different crops, damage arises from extensive feeding by larvae on different plant parts, leading to complete stripping of the plants.

On cotton: Leaves as well as bolls are heavily attacked and have large holes in them from which yellowish-green to dark-green larval excrement protrudes outside which indicates the presence of the pest.

Figure 7 *S. litura* damaging cotton leaf

On tobacco: Leaves develop irregular& brownish-red patches showing stem base gnawed off.

On maize: The larva mines young grains in the ear and damages the gain & yield reduced at the end.

Figure 8 *S. litura* damaging banana plant

Figure 9 *S. litura* damaging tomato

Figure10 *S. litura* damaging cotton

1.4 Extent of damage on different cultivars

S. litura was causing yield loss to 26-100 per cent in groundnut (Dhir*et al* 1992). Patnaik (1998) assessed tomato fruit damage to range from 11.8 to 23.0 per cent in monsoon seasons and 9.4 to 27.4 per cent in winter. In general, the amount of leaves consumed increased with larval age, consumption of 55 to 74 per cent of the total food occurred only during the last instar stage with the female consuming more food than the male (Soon Do 1999). The consumption of leaves of cotton plant by the *S. litura* larvae from hatching to pupation at 27 ± 1°C and 75 ± 5 per cent R.H. was 5.3 g/larva or 264 cm^2 leaf area/larva (Afifi and MesbahI 1990). Single larva of *S. litura* consumes 9350.80 mm^2 leaf area of *P. fortune* @ 325.73 mm^2/day during its larval period (Kumar 2004). Percentage of leaf area damaged by young larvae of *S. litura* at pod development stage of soyabean was found to vary from 14.3 per cent to 23.2 per cent (Higuchi *et al* 2009). Damage potential of the pest was found to be maximum in tomato (5.30 g), followed by cucumber (5.08g), cabbage (4.45g) and was the minimum in sweet pepper (2.89 g) (Vashisth*et al* 2012). On capsicum, under protected cultivation, the lowest per cent defoliation by *S. litura* was noticed on the 60th day, followed by the 21st and 43rd day (Nandini et al., 2012).

1.5 Consumption and utilization of food

The food consumption by the larvae differed on different host plants. Honghyun et al.,(2010) reported that the leaf consumption rate in sweet pepper increased greatly with the larval development. The damaged leaves had several round or oval shape holes on the surface or lost certain parts of them. The food consumption rate for 5th instar larvae of *S. litura* was 150, 330 and 80 mg/larva/day on castor, tobacco and cotton respectively (Singh and Byas1975). Bhat and Bhattacharya (1978) studied consumption and utilization of soybean by *S. litura* at different temperatures. The efficiency of conversion of ingested food was found to be 10.1, 15.2, 10.9 and 8.0 per cent for male and 9.6, 12.5, 10.9 and 9.3 per cent for female larvae at temperatures of 15, 20, 25 and 30°C respectively. Chockalingam et al., (1983) reported that 30°C seemed to be favorable

temperature for food utilization on the basis of low food intake, high conversion rate and net conversion efficiency. They also found that the final instar larvae reared on flowers of *Zinnia elegans* in India at 25-30°C consumed, on an average, 1005, 645 and 667 mg of food/larva respectively and the respective larval duration averaged 6.2, 4.3 and 5.4 days. The daily consumption analyses showed that a single larva of *S. litura* consumed 25 per cent more mulberry leaves in a day than one larva of *Diacrisia obliqua*. Consumption index was 0.294 in case of *S. litura* on mulberry. Growth rate of 0.122 was found in *S. litura.* The larvae reared on C-501 variety of groundnut consumed less food per unit body weight and the growth was slow as compared to Dwarf Mutant variety of groundnut. The food consumption per larva increased gradually from 98.11 ± 1.4 mg on first day to a peak of 309.1 ± 2.9 mg on ninth day. There was a rapid decrease in food consumption during the last instar as compared to earlier instar. The CI values increased from 3.45 ± 0.007 on the first day to 4.47 ± 0.06 on the second day. Thereafter it decreased to minimum of 0.32 ± 0.005 on 12th day of experimental period. It was found that the larvae converted the ingested food more efficiently (7.21%) on Jawalamukhi as compared to other hybrids of sunflower i.e. Mega 363 (3.70%), MSFH8 (2.93%) and PSFH 67 (2.65%) which were at par with each other. The suitability of selected sunflower hybrids for *S. litura* development was compared and RGR was comparatively higher (0.204) on Jawalamukhi compared to Mega 363 (0.173), MSFH8 (0.169) and PSFH 67 (0.158) which were at par. The value of RGR fluctuated due to moulting and advancement of instars (Kumar 1996). The maximum food was ingested by the 5th instar larvae and female larvae consumed more food than the males. The food ingested was proportionally higher than the weight gained in different larval instars. The younger larvae utilized the food better than older larvae. The consumption indices gradually decreased with the advancement of larval age. The co-efficient of digestibility tended to decrease with age of larvae although the food intake increased. The efficiency of conversion of ingested and digested food to body matrix increased with the age of larvae (Ahmad and Shakoori 1994). Bughio et al., (1994) observed that 5th instar larvae ingested most of the soybean and female larvae consumed more than male

larvae. As reported by Chitra and Ramakoteswara (1996), food consumption, faeces and weight gain increased with advancement of larval age. Consumption index (CI), growth rate (GR), approximate digestibility (AD) showed negative relationship with larval age while efficiency of conversion of ingested food fluctuated between increase and decrease. Banerjee and Ray (1997) observed that the rates of ingestion and digestion of food increased linearly with age of the larvae. The food consumption was lower (0.201g/larva/day) on arboretum cotton LD 327 than that on hirsutum cultivars LHH144 and LH 1556, while it was maximum (0.764g/larva/day) on F 846. The consumption index on three cotton cultivars *viz*. LHH 144, LH 1556, LD 327 was found to be 0.896, 0.805, 1.004 respectively and the AD (%) as 52.86 per cent, 43.34 per cent and 37.29 per cent, the ECI (%) was 4.54 per cent, 3.74 per cent and 3.02 per cent and the RGR was found to be 0.238, 0.335 and 0.119 respectively. Significant differences were observed in RGR when reared on different cultivars of cotton, being minimum on LD 327 (0.119) followed by 0.238 on hybrid LHH 144, 0.335 on LH 1556 and maximum in F 846 (0.417). Ghumare and Mukherjee (2003) reported the dry weight gain to vary from 26.64 mg on mint, 40.93 mg on cotton, 46.30 mg on tomato, 49.92 mg on cabbage and 86.80 mg on castor. The AD (%) was found to be 35.37 on mint, 46.85 on tomato, 54.45 on cabbage, 54.61 on cotton and 55.11 on castor. The ECI (%) varied from 10.62 on mint, 14.42 on cotton, 20.81 on cabbage, 20.98 on tomato and 25.71 on castor. Zhu *et al* (2005) studied that *S. litura*larvae not preferring banana leaves and had very low relative growth rate, as well as relative consumption rate and approximate digestibility but at the same time it had a significantly higher efficiency of conversion of ingested food and an extremely higher rate of efficiency of conversion of digested food. Therefore higher intake of food indirectly indicated inadequacy of plant for the insect. Mondal and Bhattacharya (1998) reported higher CI for male larvae feeding on castor, cowpea, pigweed or soybean while a reverse trend was recorded on tomato and wild pear. A perusal of literature indicates that a great degree of variation exists in AD (Approximate digestibility), ECI (Efficiency of conversion of ingested food) and ECD (Efficiency of conversion of digested food) when insects

were allowed to feed on plants of diverse botanical origin Waldbauer 1968, Bhattacharya and Pant 1976). These studies conducted by Mondal and Bhattacharya (1998) on food utilization by *S. litura* on castor, cowpea, pigweed, soybean, tomato and wild pear revealed that ECI and ECD varied with sex, instars and even within an instar. For whole population the AD varied from 27.0 to 44.3 percent. Similarly, Chhibber et al., (1985) reported 47.5 and 33.3 per cent AD when larvae of *S. litura* were reared on castor and soybean var. Bragg, respectively. The ECI on these plants ranged from 6.4 to 23.3 percent.

Rearing of larva on castor resulted in significantly high ECI while comparatively low ECI was observed on tomato followed by pigweed and cowpea. In wild pear ECI was 9.0 per cent which was significantly higher than soybean. This appears due to lower digestibility on soybean. Similarly, Bhat and Bhattacharya (1978) reported low ECI of *S. litura* on soybean. A comparison of sexes revealed that ECI for male and female larvae were almost same on different food plants. The whole population revealed that ECD ranged from 24.5 to 53.2 percent on all the plants tested. A significantly higher ECD was recorded on castor followed by pigweed and tomato. A low AD on pigweed, however, was compensated by high ECD Higher AD, ECI and ECD on castor and tomato plants indicated that they are highly acceptable food plants for this insect. Similarly Chibber *et al* (1985) also reported that castor was utilized more efficiently by the larvae of *S. litura*. However, high CI and low and ECI and ECD were observed on soybean and wild pear. This indirectly indicates that these plants were not suitable for *S. litura*. A comparison of sexes showed that ECD for female larvae on cowpea, tomato and wild pear were 3.0, 2.1 and 9.1 per cent higher, respectively, as compared male larvae. But for male larvae ECD.were 2.9, 0.8 and 2.7 per cent higher than female larvae on castor, pigweed and soybean, respectively. Such differences may be due to suitability of food plants by different sexes (Mondal and Bhattacharya 1998). The response on leaves of banana *cv* Grande Naine on food utilization indices particularly on fifth instar larvae showed that the ECI, ECD and AD were 16.56 ± 0.48, 30.41 ± 1.01 and 54.54 ± 0.53 % respectively (Shukla and Patel 2011). In a study on impact of elevated CO2 on larval indices of *S. litura* on peanut, it was

analyzed that at ambient CO2 concentration the RCR was 281.42 mg/mg/day, AD was 51.69 ± 3.32%, ECI was 40.46 ± 3.183, ECD was 78.65 ± 9.40% and the RGR was 109.12 ± 8.19 mg/mg/day (Rao*et al* 2012).

1.6 Means of movement and dispersal

The moths flight has long range of1.5 km flight during a period of 4 h per night, facilitating dispersion and oviposition on different hosts (Salama and Salem., 1970). The moth can fly quite long distances to invade new areas. In international trade, eggs or larvae may be travel long distance on planting material& cut flowers or vegetables. The presence of *S. litura* into the UK was because transferring on aquatic plants imported from Singapore (Aitkenhead et al., 19774). *S. littoralis* has been reported outside its normal conditions in Europe (Hachler, 1986), as a result of entry on imported of different commodities.

1.7 Economic impact

S. litura is an extremely serious pest, the larvae of which can defoliate and destroy many economically important crops. *S. litura* attacks numerous important crops throughout the year& in different seasons. On cotton plants, the pest may cause considerable damage by feeding on the different parts of plants like leaves, fruiting points, flower buds and, occasionally, also on bolls. When groundnuts are infested, larvae select primarily the young folded leaves for feeding but, in severe attacks, leaves of any age are stripped off. Sometimes, even the ripening kernels in the pods may be attacked. Pods of cowpeas and the seeds they contain are also often badly damaged. In tomatoes, larvae bore into the fruit which is thus rendered unsuitable for consumption which ultimately reflected in yield loss to the farmers. Numerous other crops are attacked, mainly on their leaves.

In one the field experiments on soybeans in India, crops sprayed with insecticides and protected from *S. litura* yielded 42% greater than compared to crops which were not sprayed. On tobacco, in India, it was estimated that two, four and eight larvae per plant reduced yield by 23-24, 44.2 and 50.4%, respectively. On *Colocasia esculenta*, an average of 4.8 4th-instar larvae per plant reduced yield by 10%, while 2.3 and 1.5 larvae reduced yield of aubergines and *Capsicum* in

glasshouses by 10% also (Nakasuji and Matsuzaki, 1977). In Europe, damage due to *S. littoralis* seen particularly minimal until about 1937. In 1949, there was a catastrophic larval population explosion in southern Spain. The main crops affected were Lucerne/alfalfa, potatoes and other vegetable crops. At present, this noctuid is of great economic importance in different regions like Cyprus, Israel, Malta, Morocco and Spain (but not in the north, e.g. Cataluña). In Italy, it is especially important on protected crops of ornamentals and vegetables. In Greece, *S. littoralis* causes slight damage in Crete on Lucerne/alfalfa and *Trifolium* only (Inserra, S & Calabretta, 1985).

1.8 Control

The insecticidal control of *S. littoralis* has been widely reported in different relation especially to cotton crop in Egypt, and of *S. litura* in relation to various crops and regions in India. Until 1968, *S. littoralis* was held in controlled by methyl-parathion, but then it has been reported to developed resistance to this compound. Since then, numerous other insecticides like organophosphorus, synthetic pyrethroid and other botanical insecticides have been used, with appearance of resistance and cross resistance in many cases (Abo-El-Ghar et al., 1986). Compulsory limitation of the spray application of synthetic pyrethroids to one per year on cotton crop was observed in Egypt that has been stopped the appearance of new resistance (Sawicki, 1986). Chemicals used against *Spodoptera* spp. also include different insect growth regulators& molting inhibitors. The interest, especially in India, in various antifeedant compounds or plant extracts, and in natural products such as azadirachtin and neem extract used to control *S. litura*.

Numerous studies have been carried out on possible biological control of the two species. Parasites (braconids, encyrtids, tachinids, ichneumonids) and predators have been extensively documented. A nuclear polyhedrosis virus has been evaluated against *S. litura*, while fungi and microsporidia have also been recorded as parasites. Parasitic nematodes such as *Neoaplectana carpocapsae* have also been evaluated. However, direct use of these biocontrol agents has not apparently

passed into practice. Treatment with *Bacillus thuringiensis* has been used (Navon et al., 1983), but only some strains are effective since *S. littoralis is* resistant to many strains (Salama*et al.*, 1989).

Integrated pest management techniques, favoring beneficial arthropods, are applied especially against *S. littoralis is* on cotton in Egypt. These involve hand collection of egg masses, use of microbial pesticides and insect growth regulators and slow-release pheromone formulations for mating disruption. If these measures are taken, relatively few applications of conventional insecticides are necessary (Campion and Hosny, 1987). Damage thresholds have been studied by Hosny*et al.* (1986). Pheromones have also been used for mass trapping by the lure and kill technique (McVeigh & Bettany, 1987) and for monitoring populations. Das & Roy (1985) review the use of pheromones against *S. litura*. Souka (1980) has experimented with irradiation for sterile-insect release, but this technique does not appear to have been applied at a large scale in the field situation.

1.9 Phyto-sanitary risk

EPPO (European and Mediterranean Plant Protection Organization) has listed *S. litura*in category of A1 (OEPP/EPPO, 1979), and at the same time *S. littoralis* as an A2 quarantine pest (OEPP/EPPO, 1981). Different organizations like CPPC, NAPPO and OIRSA also consider the two species of quarantine significance. *S. littoralis* is already been known to be widespread in Mediterranean countries and does not present a phyto-sanitary risk there. Since *S. litura* is very similar and attacks essentially the same host plants, it is not obvious that it could establish in the presence of *S. littoralis* or present an additional risk. The real phyto-sanitary risk for both the species is their possible introduction into glasshouses& greenhouses in most parts of Europe, where they may damage many ornamental and vegetable crops. Although control with insecticides is possible, there have been many cases of resistance. There is no available biological control methods, which means the spread of the pest & introduction of *Spodoptera* spp with stand at different conditions. It could require insecticide treatments& that might interfere with existing biological control of other pests.

1.10 Phyto-sanitary measures

Planting material& cultivated crops, EPPO recommends (OEPP/EPPO, 1990) absence of the pests from the place of production during the last 3 months, or treatment of the consignment coming from different locations. For cut flowers, pre-export inspection is considered sufficient to check infestation.

Cold storage of chrysanthemum and carnation cuttings for at least 10 days at a temperature not exceeding 1.7°C will kill all stages of *S. littoralis*, and presumably also *S. litura*, but may damage the plants. Storage at slightly higher temperatures or shorter durations does not eradicate *S. littoralis*, but differences in response to cold have been observed both between strains and within developmental stages of the pest (Powell & Gostick, 1971; Miller, 1976). The standard treatment now used in the UK is cold storage for 2-4 days at less than 1.7°C, followed by methyl bromide fumigation at 15-20°C with a CTP of 54 g h m^3 (Mortimer, E.A.; Powell, 1988). *S. litura* adopted as an EPPO quarantine pest procedure (OEPP/EPPO, 1984). Irradiation has been investigated by observing different plant parts like cut flowers (Navon et al, 1983). For cut chrysanthemum flowers, suggest enclosing buds in perforated polythene bags to exclude the pest and dipping the cut stems in insecticide solutions.

1.11 Biology & morphology of *Spodoptera litura*

Period of 2 and 5 days after emergence, females lay nearly 1000-2000 eggs in egg masses of 100-300 on the lower leaf surface of the host plant (Miyahara et al., 1971). Insect's abdomen have hair like scales that covers the egg masses. Fecundity is adversely affected by different parameters like high temperature and low humidity (about 960 eggs laid at 30°C and 90% RH and 145 eggs at 35°C and 30% RH). Newly laid eggs of one strain of *S. littoralis* were reported to survive exposure to 1°C for 8 days. Partially developed eggs survived longer than newly laid ones under equivalent conditions (Fand et al., 2015).

The eggs hatch in about3-4 days in warmer conditions, or up to 11-12 days in winter season. The larvae pass through six larval instars in 15-23 days at 25-26°C. Particularly at lower temperatures, for example *S. littoralis* on glasshouse

chrysanthemums in Europe, larvae often go through an extra instar, and maturation may take up to 3 months. The young larvae (first to third instar) feed mainly in groups, leaving the opposite epidermal portion of the leaf intact. Later, the (4th to 6th instar) larvae disperse and spend the day in the ground under the host plant, feeding at night and early in the morning (Fand et al., 2015).

The pupal period is spent in covered cell in the soil and lasts about 11-13 days at 25°C. Longevity of adults is about 4-10 days, being reduced by different conditions like high temperature and low humidity. Thus, the life cycle can be completed in nearly 5 weeks. In Japan (Nakasuji, 1976), four generations develop between May and October, while in the humid tropics there may be eight annual generations. In the seasonal tropics, several generations develop during the rainy season, while the dry season is survived in the pupal stage (Fand et al., 2015).

Egg stage

The eggs were usually round and laid in groups on the lower surface of the chilly leaves and sometimes on the wire mesh of the cage (Singh et al., 2001). Pandey, (1970) reported that eggs were laid mostly at night or early morning within 3 to 6 hours of copulation and were covered with hairs shed from female anal tuft. A higher fecundity was observed on hosts which had a high protein and nitrogen content in leaves (Sankarperumal et al., 1989). Copulation occurred at night for 3 to 5 times in one life span (Kharub et al., 1993). According to Kumar, et al(1993), eggs were round, light green or white, mostly covered with hairs. The eggs were laid in clusters.

Figure 11 Egg mass of *S. litura* covered with scales

The incubation period for the eggs varied in different countries depending upon host plants and environmental conditions. Egg stage was observed to be 4-5 days long in India (Patel et al., 1986). Mann et al.,(1995) reported that the eggs hatched after 2- 4.5 days during June to October and after 27 days in December on cotton. Sudhakar et al., (1993) reported that the incubation period ranged from 4.0, 3.8 and 3.9 days on castor, green gram and groundnut, respectively at 27 ± 1°C and 75 per cent relative humidity. According to Kumar, et al(1993) incubation period varied from 3.73 days in July to 5.24 days in October on cotton leaves. The incubation period was observed to be 3 days on groundnut at 28 ± 2°C (Kharub et al., 1993), 3-4 days on rice variety Jaya at 29.5 ± 2°C and 80 ± 5 per cent relative humidity (Patil et al., 1991) and on germinating seeds of wheat and linseed, the period was 3.00 and 3.30 days respectively, at a temperature of 15-25°C (Sharma D, 1994). As reported by Arora (1993) mean incubation period on cotton variety F 414 was 3-4 days. According to Kumar (1996) the period varied from 3.10 to 3.30 days on different hybrids of sunflower. There were non-significant differences in the incubation period on the four different cultivars of cotton i.e. F 846, LHH 144, LH 1556 and LD 327. The period varied from 2.5 ± 0.022 days on LH 1556 to 3.00 ± 0.028 days on LD 327, 2.7 ± 0.020 and 2.6 ± 0.021 days on

LHH 144 and F 846 respectively. The incubation period was related to environmental conditions and ranged from 2 to 13.2 days. Soni et al., (2001) reported the mean diameter of egg to be 0.534 mm and the mean incubation period to be significantly highest on cabbage (5.60 days) and the lowest on castor (3.40 days). The incubation period of 4.21 ± 0.99 days was recorded on Banana cv Grand Naine (Shukla et al., 2011). Sanjrani (1989) reported cent per cent hatchability when rearing was done at 19.5°C. Patel et al., (1986) reported 87 per cent hatchability on cotton in Gujarat. A maximum hatchability of 100 per cent was observed on F 846 and minimum of 92 per cent on LD 327 (Kaur, 2013). Arora (1993) also reported cent percent hatchability of eggs on F 414 variety of cotton. The hatchability of eggs on sunflower varied from 94.18 to 99.9 per cent on different hybrids (Kumar 1996). 100 per cent hatchability of egg masses of *S. litura* was observed on leaves of soybean and sweet potato (Bae SD, 1999). 100 per cent egg hatchability was found on F 846 followed by 99 per cent on LH 1556, 97 per cent on LHH 144 and 92 per cent on LD 327. Thomas and Bilapate (2007) found an egg hatching percentage of 84, 86 and 89 and 83 per cent on sunflower cultivars LS-35, KBSH-1, Morden and LS-11, respectively.

Larval stage

Newly hatched larvae are pale green in colour and gregarious in habit. Full grown larvae vary in colour from light brown to dark grey or black. The larvae passed through five or six instars (Kumar 1996). The first two or three instars fed gregariously and then moved in different directions (Shaikh F, 1994). The larval period was found to vary with the prevailing conditions of environment and the kind of host plant. Thobbi (1961) reported the larval period to be 14 days on castor whereas it was found out to be of 15-19 days on cotton (Patel *et al* 1986). Rattan and Nayak (1963) observed the larval period of 30, 20 and 18 days at 23°C on tobacco, cabbage and castor, respectively. Singh and Byas (1975) observed that larval period was shortest (18.3 days) on castor and longest (27.6 days) on cotton at 27°C and 70+5 per cent R.H. According to Balasubramanian *et al* (1984), larval period varied from 15.64 days on castor, 16.90 days on sunflower,

followed by 18.59 days on green gram, 18.90 days on cotton and longest on groundnut (21.43 days). Singh *et al* (1989) reported the larval duration of 29.3 and 11.8 days during August and September, respectively on sesame in Punjab. Bhalani (1989) recorded the larval period to range from 17.80 to 26.83 days on cotton. Ahuja and Noor (1991) observed that the larval period at 30°C and 70-80 per cent R.H. was the shortest (12.9 days) on castor, followed by that on chili and cabbage, while it was longest (20.3 days) on sesame. Larval duration was recorded to be 19.8 ± 1.04 days on cotton variety F 414 (Arora 1993). Kharub*et al* (1993) observed that on castor *S. litura* completed 6 instars in 3.0, 3.7, 5.5, 4.6, 4.1 and 5.6 days at 28+2°C. Kumar *et al* (1993) reported the larval duration to vary from 18.04 days in July to 19.40 days in August on cotton. Total larval period on cotton varied from 17.53 ± 0.36 to 25.75 ± 0.64 days during June to October (Mann *et al* 1995). Larval period was found to be 20 days on groundnut (Gahukar, 1992). An experiment on larval development of *S. litura* on leaves of 11 different leguminous plant varieties and cultivars showed an average larval duration to range between 11.5 to 15.7 days with the shortest on soyabean cv Geomjeongkong-1 and the longest on groundnut cv Dark wangddangkong. Also, among the 6 larval development stages, the 1st instar stage was the longest (3.2 – 5.0 days) while the 4th instar was the shortest (1.0 – 1.5 days) (Soon. Do. 1999). Shortest larval period of 16.30 days was reported on cauliflower amongst castor and cabbage (Soni et al., 2001). A minimum larval duration (12.27 days) was found on LS–11 sunflower cultivar from amongst LS–35, KBSH–1 and Morden (Thomas and Bilapate 2007). On tobacco, larval development was of 19.3 days at 26°C (Chen et al., 2002). Xue et al., 2010 found the development time of 12.8 days at 29°C on cowpea. According to Kumar (2004), there were 6 larval instars in 28.80 days on *Paulownia fortunei*. Zhu *et al* (2005) observed duration of 10.1 days on cowpea. Elbadry et al.,(2009) found that the larvae took approximately 19 days to develop on sweet potato and cotton. Xue*et al* (2010) reported the overall larval development to be significantly affected by host plants and it was the longest on tobacco (23.2 days) followed by sweet potato (17.5 days), cowpea (15.8 days), and shortest on Chinese cabbage (13.3 days). Different larval instar

of *S. litura* particularlyfirst, third and fourth instars development took longer time on tobacco. In contrast, the second instar development took longer time on sweet potato than on other three host plants and for the fifth and sixth instars development time was not significantly different for tobacco and sweet potato. The larval duration was longest on LD 327 and shortest on F 846 with a duration of 25.66 and 19.03 days respectively. Duration on LHH 144 and LHH 1556 was 21.62 and 20.27 days. The shortest larval development period 12.0 days was observed on castor and the longest larval period of 16.0 days on jatropha (Thodsare and Srivastava 2012). Shahout et al(2011) reported the larval duration of 15.55 days on cabbage, 15.73 days on cotton, 17.09 days on soybean, 19.55 days on cowpea, 15.82 days on sweet potato and 20.18 days on alligator weed. A larval period of 20 ± 00 days on castor, 18.75 ± 0.08 days on cabbage and 16.50 ± 0.08 days on cauliflower was reported by Chand and Tripathi (2008). A larval duration of 16.02 ± 1.09 days was found on Banana cv Grand Naine with a period of 3.10 ± 0.54 days for 1st instar, 3.14 ± 0.28 days for 2nd instar, 4.21 ± 0.59 days for 3rd instar, 2.34 ± 0.33 days for 4th instar, 3.22 ± 0.38 days or 5th instar (Shukla and Patel 2011). At ambient CO2 concentration, larval duration of 18.00 days was noticed on peanut. During day time the larvae usually hide under the clods at the base of the plant, they climb the plants after dusk and feed in the night and early hours of dawn (Saini and Verkya, 1985). They migrate in large numbers in search of new crops or other host plants, when there is a shortage of food. Continuous cropping of summer crops and vegetables provides food for the larvae and the pupae do not aestivate in extreme temperatures (Rao*et al* 1989). Although groundnut variety C-501 fulfilled the nutritional requirements of *S. litura* more effectively than dwarf mutant variety, it was less suitable as food plant, possibly on account of texture of its leaves and for the presence of a growth regulator. The suitability food plants in the order of wheat, chickpea, pea and lentil was reported by Pachori and Gargav (1997). In a study on biology of *S. litura* on *Colocasia esculenta*, genotype KCA– 1 was found to be most preferred and the genotype PanchMukhi to be the least preferred one (Suraj et al., 2006). Fast development of *S. litura* on weed hosts shows a high potential of the insect as a pest in the

agroecosystem (Kumar and Ray 2007). Among the sunflower cultivators LS–II was most suitable for the development of *S. litura* followed by KBSH–1, Morden and LS–35 (Thomas and Bilapate 2007). Ahmad *et al* (2013) reported the major host plants on which it thrived for maximum period to be *Gossypium hirsutum, Ricinus communis, Brassica oleraceavar botrytis, Colocasia esculenta, Trianthemaportu lacastrum*and *Sesbania sesban*. Singh and Byas (1975) reported the survival percentages to be 84.4, 79.9 and 35.6 percent on tobacco, cauliflower and cotton respectively. Larval survival or pupation rate of 100% was found on *Ricinus communis* (Patel *et al* 1987). Bhalani (1989) found that the larvae showed 91.15 and 80.70 per cent survival on castor and cotton respectively which was higher than those reared on groundnut (78.15%), cowpea (62.5%), sorghum (59.15%), green gram (58.35%) and maize (49.18%). Singh et al(1989) reported that the survival of larvae was the lowest (31.8%) during August and highest (92%) in September when reared on sesame. According to Sudhakar et al(1993), per cent pupation was the highest on castor 92.50 per cent and lowest on groundnut 75.66 per cent while on green gram it was 88.40 per cent. Arora (1993) reported larval survival of 92 per cent on cotton variety F 414. According to Kumar *et al* (1993), larval survival varied from 84 per cent in July to 80 per cent in October on cotton. Kumar (1996) reported the larval survival from 46.66 to 96.66 per cent on different hybrids of sunflower. A maximum survival of 93.33 per cent was observed on cotton genotype F 846 followed by a survival of 79.99 per cent on LH 1556, 69.99 per cent on LHH 144 and a minimum survival of 23.33 per cent on LD 327. Bae and Park (1999) found that the pupation rates were positively correlated with high temperature, 30.0, 33.3 and 38.5 per cent on sweet potato, perilla and soybean respectively at 24°C and 57.5, 80.0 and 87.5 per cent at 32°C on same host plants, respectively. A larval pupal transformation of 95.72 per cent was reported on LS-11 cultivar of Sunflower (Thomas and Bilapate 2007). Xue*et al* (2010) reported that the larval survival was lowest on tobacco (49.0%) followed by sweet potato (66.2%), Chinese cabbage (75.4%) and highest on cowpea (81.7%).

Figure 12 Larval stage of *S. litura*

Pupal stage

According to Navarajan et al., (1979) the 8th abdominal segment of female pupae was smaller than that of male. Male slit like genital opening was provided on ventro meson of 9th segment. The female aperture has 2 slits on 8th and on 9th segment. The spiracles are present on the same segment that bear genital opening (Shaikh et al., 1994). As reported by Kumar (1996), the male and female pupae could be easily differentiated on the basis of certain morphological features. In male, the genital openings were situated on the ventral side of 9th abdominal segment with two tubercles one on either side. Further, abdominal spiracles were not located on the same segment on which genital openings were present. Female pupae possessed genital openings on the sternum of 8th abdominal segment and tubercles were absent. Pupal weight varied on different host plants. It was 0.40, 0.34, 0.34 and 0.20 g on castor, green gram, moong and cotton respectively (Sudhakar*et al* 1993). Zhou *et al* (1994) found that there was a decrease in pupal weight with the growth of cabbage leaves. Bae and Park (1999) found that pupal weight tended to be 3-13% lower with increasing temperature from 24°C to 28°C, then to 32°C. Soon Do (1999) reported the pupal weight to range from 0.23 g to 0.43 g for female and 0.24 g to 0.35 g for male. Per cent change of pupal weight was lowest (11%) on soyabeancvGeomjeongkong–1 and highest (16%) on soyabean cv Bukwangkong. The weight was found to be 0.28g on sweet potato,

0.40g on perilla and cowpea (Bae and Park 1999, Qin *et al* 2004). Pupal weights differed significantly depending on the host plants on which the larvae were fed and differed significantly between females and males when they were fed on the same host plants or on different host plants. The pupal weights in a study ranged from 0.32 to 0.36 g (Xue*et al* 2010). Pupal weights were not found to be significantly different among different temperature regimes (Seema et al., 2002). Rao*et al* (2012) reported a pupal weight of 0.30 g on peanut. Highest pupal weight of 3.54 g was registered on control (castor) while significantly lowest pupal weight was recorded on jatropha (0.59g) and china rose (0.74g) (Thodsare and Srivastava 2012). The most suitable soil for pupation was with a moisture content of 20 per cent. (Nasar et al., 1960). The pupation per cent was highest on cauliflower (93.00 ± 0.08%) followed by cabbage (91.00 ± 0.06%) and castor (80.50 ± 0.05%) (Chand and Tripathi 2008). The per cent larval survival of 86.31±3.73% was found on Banana cv Grand Naine (Shukla and Patel 2011). According to Patel and Chari (1987) pupation took place on an average 2.83 cm deep in river sand and 3.78 cm deep in sandy loam and 2.42 cm in heavy black soil. The full grown larva before pupation became sluggish, ceased feeding and decreased in size (Kumar 1996). Balasubramanian *et al* (1984) observed the duration to be 10.9 and 11.6 days on sunflower and cotton respectively. Bhalani (1989) observed a shortest pupal period (8.05 and 8.38 days) on castor and green gram and the longest (9.05 days) on cotton. The pupal period was longest on slender pigweed (9 days), followed by that on groundnut (8 days) (Ahuja and Noor 1991). Kumar (1992) observed the variation in pupal period from 7.47 to 9.74 days on *arvi*, 7.49 to 12.26 days on sunflower, 7.84 to 13.6 days on cotton and 7.18 to 25.56 days on cauliflower during different periods of crop growth. The period was found out to be 7-10 days on cotton (Patel *et al* 1986, Bhalani 1989) and 6-9 days on sesame (Singh *et al* 1989). Arora (1993) reported the pupal period on cotton variety F 414 as 8.06 ± 0.63 days. The pupal period on different cotton cultivars varied from 6.80 ± 0.37 to 8.50 ± 0.50 days during July- August (Kumar 1996). The duration of pupal period was also influenced by the season. Kumar *et al* (1993) observed the pupal period to vary from 8.58 days in July to

13.6 days in October on cotton. On cotton, the pupal period ranged between 7.73 and 10.86 days from June to September and 22.66 days in October due to sudden fall in temperature (Mann *et al* 1995). Gahukar (1992) reported the pupal period to be 7-10 days on groundnut. The pupal period varied from 9 to 12 days in case of male and 7 to 10 days in case of female on different cotton cultivars (Kaur 1999). On different leguminous plant varieties and cultivars pupal duration varied from 8.7 to 9.5 days depending upon different diets and duration of female pupa (8.3 – 9.1 days) was about 1 day shorter than that of males (9.4 – 10.1 days) (Soon Do 1999). Chand and Tripathi (2008) reported the pupal period to follow on order of (13.00 ± 0.08 days) on castor, (12.25 ± 0.10 days) on cabbage and (11.0 ± 0.09 days) on cauliflower. Pupal period on Chinese cabbage (10.9 days), cowpea (10.1 days) and sweet potato (10.9 days) were not significantly different and were longer than on cowpea (9.5 d) (Xue*et al* 2010). A pupal period of 10.42 ± 0.85 days on Banana cv Grand Naine was noticed (Shukla and Patel 2011). A pupal period of 7.54 days on cabbage, 8.00 days on cotton, 8.43 days on soybean, 8.71 days on cowpea, 8.08 days on sweet potato and 9.13 days on alligator weed was observed (Shahout*et al* 2011). The pupal period was shortest on castor (6.16 day) and longest on jatropha (10.0 days) (Thodsare and Srivastava 2012). According to Balasubramanian *et al* (1984) the pupal survival was 77.4 per cent on cotton and 70.4 per cent on sunflower. Bhalani (1989) reported the pupal survival of 89.11 per cent on cotton. Kumar (1992) recorded pupal survival of 81.82, 86.36, 80.95 and 91.30 per cent on *arvi*, sunflower, cotton and cauliflower respectively. He also observed the survival of pupae as 80.95 per cent in July and 75 per cent in October on cotton. Kumar (1996) observed that the pupal survival varied from 67.20 to 90.00 per cent on sunflower. A survival of 98 percent was observed by Arora (1993) on Hirsutum variety of cotton. A maximum survival of 94 per cent was observed on F 846 followed by 86 per cent on LH 1556, 80 per cent on LHH 144 and 66 per cent on LD 327 (Kaur 1999).

Figure 13 Pupal stage of *S. litura*

Bae and Park (1999) found that only 31.4 per cent of pupae developed to adults at 24°C and 88.6 per cent at 30°C and their emergence rate increased 1.1 to 2.8 fold with temperature increase from 24°C to 32°C. Xue*et al* (2010) reported that more than 91 per cent of *S. litura* pupae successfully developed to adults. Shukla and Patel (2011) found the per cent pupal survival of 95.18±2.32 on Banana cv Grand Naine. Pupal survival varied when rearing was done at different temperatures and relative humidity conditions. According to Jarcyzk and Hartle (1959) the pupae took minimum time at 27-29°C and maximum at 19.5-21.5°C. They noticed that relative humidity had a profound effect on the emergence of moths and the per cent emergence from pupae ranged from 40 per cent at 10 per cent RH to 80 per cent at 80 per cent RH. Female and male pupae took 7.5 days and 8.2 days respectively to become adults at 30°C (Patel et al., 1986). Rao*et al* (1989) reported that the pupal stage required 155 days degree above 10°C threshold. Patil*et al* (1991) observed a pupal period of 9 to 11 days at 29.5 ± 2°C and 80 ± 5 per cent RH on rice variety Jaya. Matsura and Naito (1992) observed that pupae placed in the soil in an unheated green house survived till mid-February but failed to emerge normally. Threshold temperature for pupae of *S. litura* was 7.9°C and sum of effective temperatures was 172.4 day degrees. An adult emergence of

89.11 and 95.49 per cent was found on cotton and castor respectively (Bhalani 1989). The per cent adult emergence was found maximum on cauliflower (92.0 ± 0.06%) followed by cabbage (88.00 ± 0.05%) and castor (81.75 ± 0.08%). The maximum adult emergence and survival was recorded on castor (93.33%) and it was significantly lowest on jatropha (50 and 20% respectively) (Thodsare and Srivastava 2012).

Adult stage

Emergence of adults generally occurred during night time. Adults were dark brownish with numerous spots on the forewing having light coloured lines. The males were smaller than females. They were nocturnal and hence mating occurred in the dark. The moths were stout, dark coloured with wavy white margins having brown colour. Hind wings were whitish and narrowly bordered with brown colour on entire margin (Kumar *et al* 1992). Shaikh*et al* (1994) observed that the male adults were of light brown with bluish markings on the forewings while the female moths had dark brown forewings with yellow margins. As noticed by Soni *et al* (2001), cauliflower recorded the highest wing span and body length of adult female (34.41 and 17.32 mm) and male (32.18 and 15.55 mm) from amongst castor and cabbage.

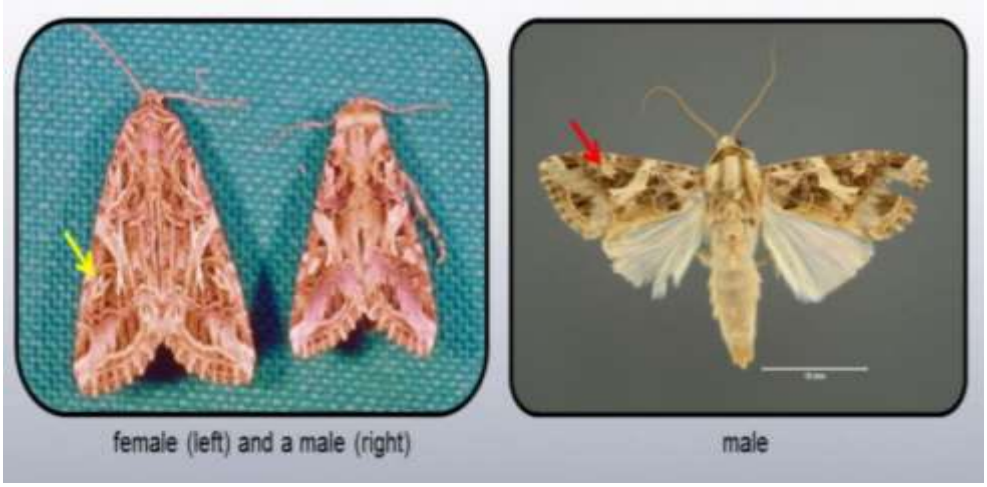

Figure 14 Male & female adults of *S. litura*

The pre-oviposition period was 2.3 days in July and 2.4 days in August and September on cotton (Kumar *et al* 1993). The period varied on different host plants, it was 1-2.8 days on sugar beet varieties (Singh and Sachan. 1982), 3.8 days on sunflower (Balasubramanian *et al.,* 1984), 1.6 days on cotton (Patel *et al* 1986), 2-4 days on sesame (Singh *et al* 1989) and 1.83 ± 0.22 days to 2.16 ± 0.18 days on sunflower hybrids (Kumar 1996). The difference in pre-oviposition period on different cotton cultivars *viz.* F 846, LH 1556, LHH 144 and LD 327 were non significant ranging from 1.2 to 1.7 days (Kaur. 1999). *S. litura* females generally oviposited from the second day and the eggs generally took 5-6 days for hatching (Suryakala et al., 1995). Singh and Sachan (1982) reported that the oviposition period differences were not evident when rearing of moths was done on different sugarbeet varieties. The oviposition period was observed as 7.6 days by Patel *et al* (1986) on cotton, 1-2 days on sesame (Singh *et al.,* 1989) and 1.33 ± 0.188 to 2.41 ± 0.29 days on sunflower hybrids (Kumar 1996). According to Chu and Yang (1991) multiple mating did not influence the female life span but it promoted oviposition. Yang and Chu (1991) found that the time taken to deposit one egg mass averaged about 58 minutes. Duration of oviposition averaged about 50-60 minutes and was postponed by delayed mating. There were two peaks of oviposition occurring from 24:00 to 01:0h and from 03:00 to 04:00h, when one female was paired with three males. For the case of 3 females:1 male combination, the major peak of oviposition occurred at 23:00 to 24:00 h and the minor peaks were noticed at 01:00 to 02:00 h (Chen et al., 2002). Oviposition period varied from 1.4 to 2.4 days on *arvi*, 1.4 to 2.8 days on sunflower, 1.3 to 2.6 days on cotton and 2.3 to 3.6 days on cauliflower during different months of the year (Kumar 1992). He also observed the oviposition period to vary from 1.4 days in July to 1.5 days in August. The differences were non-significant among the cotton cultivars, F 846, LH 1556, LHH 144, LD 327 and it ranged from 1.3 to 1.5 days (Kaur 1999). The biological development of *S. litura* on the leaves of sunflower cultivars revealed a shortest oviposition period on LS–35 (6.80 days) and longest on KBSH–1 (9.40 days) (Thomas and Bilapate 2007). The post-oviposition period was reported to be 3.1 days on cotton (Patel *et al* 1986), 1-2

days on sesame (Singh *et al* 1989) and 1.41 to 2.87 days on sunflower (Kumar 1996). The period was prolonged during the cooler months and was not affected much by different type of food plants. The post-oviposition period varied from 0.9 days in June to 2.2 days in July on *arvi*, 1.5 days in June to 2.6 days in November on sunflower and 1.6 days in July to 1.7 days in September on cotton (Kumar 1992). The post-oviposition period ranged from 2.7 ± 0.15 days on LD 327 to 2.9 ± 0.23 days on F 846 (Kaur 1999). The average adult longevity varied from 10.1 to 14.4 days and it did not differ on different sugar beet varieties (Singh and Sachan 1982). Patel *et al* (1986) reported male and female longevity to be 6.3 and 12.3 days on cotton. According to Srivastava (1987), the adult life span varied from 4-24 days and the total number of eggs laid by female from 500-3000. Patil *et al* (1991) found it to be 3-10 and 8-14 days on rice. On different sunflower hybrids, the mated males lived for 5.40 to 6.00 days while the mated females lived for 5.94 to 6.03 days (Kumar 1992). Kharub *et al* (1993) reported it to be 8.8 and 9.7 days on groundnut. Male longevity was found to vary between 3.9 and 5.9 and female longevity between 5.4 and 7.7 days on cotton during September and November, respectively (Kumar *et al* 1993). Arora (1993) reported the mean adult longevity to be 5.66 ± 0.87 days. Kumar (1996) observed the longevity in male adult to vary from 3.7 to 6.96 days and in female adult from 5.46 to 5.84 days on sunflower. The longevity in case of mated adults ranged from 4.6 to 5.9 days on different cotton cultivars. The females lived relatively longer than males (Kaur 1999). Adult longevity ranged from 7.8 days on cowpea cvDongbu to 11.2 days on Bukwangkong and tended to become slightly longer in females than in males (Soon Do 1999). A maximum longevity of female and male moth was noticed on cabbage 8.20 and 7.0 days respectively whereas a minimum of 6.09 and 5.60 days was observed on castor (Soni*et al* 2001). The longevity of both female and male *S. litura* adults was also significantly affected by the host plants on which their larvae were fed. The female longevity of 6.6 ± 0.2, 7.7 ± 0.6, 6.8 ± 0.8, 7.2 ± 0.4 was observed on Chinese cabbage, cowpea, sweet potato and tobacco respectively. The male longevity of 7.4 ± 0.2, 8.8 ± 0.7, 8.8 ± 0.6 and 8.2 ± 0.4 was found on these hosts (Xue*et al* 2010). Shahout *et al* (2011) observed the adult

longevity to range from 5.64 days on cowpea, 5.93 days on alligator weed, 6.07 days on soybean, 6.33 days on cabbage, 6.62 days on cotton and 6.92 days on sweet potato. The adult male and female survived for a period of 8.66 ± 0.60 and 6.89 ± 0.19 days respectively on banana cv Grande Naine (Shukla and Patel 2011).

Figure 15 Life cycle of *Spodoptera litura*
(Ramaiah et al., 2018)

Fecundity

The *Spodoptera litura* moths were found primarily active during night and due to its high mobility, female oviposited on a wide range of host plants, which promoted or even ensured its survival over a broad range of environmental conditions (Chelliah 1985). The number of egg masses laid by a single female ranged from 10-16 averaging 12.80, whereas eggs laid numbered 2507-3467 averaging 3032 (Patel *et al* 1986). The number of eggs deposited per female was 2815.61 and 3772.60, that had mated once and thrice respectively (Yang and Chu 1991), while Chu and Yang (1991) recorded that 3609.48, 3782.75 and 5995.00

eggs were laid by females that had mated once, twice and thrice, respectively. A single female laid 400- 1500 eggs on cotton (Bhalani 1989, Sanjrani*et al* 1989), 536-1250 eggs on rice (Patil*et al, 19*91), 1618.8 eggs on groundnut in 12 egg masses (Kharub*et al* 1993) and 938 eggs on cotton (Arora 1993). According to Kumar *et al* (1993) fecundity on cotton in the months of July and November was 417 and 420 respectively. Kumar (1996) reported that the number of eggs laid by single female ranged from 1223 to 1600 in 2.9 to 5.2 egg masses on different hybrids of sunflower. Comparatively lesser number of eggs (1305 ± 40.54) were laid when the larvae were reared on LD 327 as compared to other cultivars i.e. F 846, LHH 144, LH 1556 (1715 - 1718 eggs), the latter three being on par. Arora (1993) found the fecundity per female to be 938 ± 12.2. As reported by Srivastava (1987), the number of eggs laid by a female varied from 500-3000. Adults of *S. litura* laid around 2000 eggs on the abaxial surface of groundnut leaves, in batches of 200-300 each (Gahukar 1992). Oviposition by females varied greatly on different hosts under different environmental conditions (Patel *et al* 1986, Bae and Park 1999). Numbers of eggs laid by a single female ranged from 935 on soybean (Bae and Park 1999) to 3,467 on cotton (Patel *et al* 1986). On wheat and lentil fecundity of 1055 and 714 was reported by Pachori and Gargav (1997). Singh and Prasad (2001) conducted experiments on chili in Manipur and reported the number of eggs per female to vary from 70 to 72 during a 24 hour period. In a study on host biology relation of *S.litura* highest fecundity of female was recorded on cabbage and lowest on cauliflower (557.06 and 397.63 eggs respectively) (Soni*et al* 2001). Kaur (1999) observed significantly less number of eggs (1350 ± 40.54) to be laid when larvae were reared on LD 327 cultivar of cotton. On sunflower cultivars, greatest fecundity of 4586 eggs was found on KBSH–1 and a lowest fecundity of 3163.30 eggs on LS–11 (Thomas and Bilapate 2007). *S. litura* oviposited same numbers of egg masses and eggs per female on cowpea, sweet potato, Chinese cabbage, but less on tobacco than on other three hosts. The number of eggs per egg mass was found to be 283.5 on Chinese cabbage, 282.1 on sweet potato, 224.9 on cowpea, 233.6 on tobacco (Xue *et al* 2010). Shukla and Patel (2011) observed that on an average female moth laid

241.60 ± 41.25 eggs on Banana cv Grand Naine. Rao*et al* (2012) observed 467.35 eggs to be laid per female per day on peanut & found an average of 1930 eggs to be laid by a single female on *Centella asiatica* in Malaysia.

Sex ratio

The females outnumbered males on sugarbeet varieties Ramonskaya 06, R-poly I, Munica and KS-1 while the males dominated on Mezzanopoly-R, KS-3 and Mezzanopoly A. Further, both the sexes emerged in equal number on variety KS 2 II (Singh and Sachan 1982). The sex ratio was found in favour of females on cauliflower (1:1.5), *arvi*(1:1.3), sunflower (1:1.17) and cotton (1:1.4) (Kumar 1992). Sex ratio (M: F) of 1:1.30 and 1:1.14 was observed on wheat and lentil (Pachori and Gargav 1997). The sex ratio was relatively high on F 846 (1:1.8), followed by that on LHH 144 (1:1.5), LD 327 (1:1.3) and LH 1556 (1:1.1) genotypes of cotton (Kaur 1999). It favored males in all cultivars. Sex ratios were found to be biased and more female adults emerged than male adults when their larvae were fed on four host plants. The sex ratio of 1:0.64, 1:0.71, 1:0.75, 1:0.64 was observed on Chinese cabbage, cowpea, sweet potato and tobacco respectively (Xue*et al* 2010). The sex ratio of 1:1.77 on Banana cv Grand Naine was reported by Shukla and Patel (2011).

Total life cycle

The life cycle of 31.7 days on Monorom and Ramonskaya 06, 36.4 days on KSI, 35.8 days on Mezzanopoly-R was observed on sugarbeet genotypes (Singh and Sachan 1982). The total development period of 32.67 days on germinating seeds of soyabeans and 43.72 days on linseed (Sharma 1994). Mann *et al* (1995) reported the generation period to vary from 25 days during August 8 to September 2 to 54 days during October 11 to December 4 on cotton. Kumar (1996) recorded the life cycle of 34.99 days on Jawalamukhi and 42.31 days on PSFH67 hybrid of sunflower. According to Kaur (1999) the insect took 34.42 days on F 846, 37.07

days on LH 1556, 39.13 days on LHH 144, 43.86 days on LD 327. The larvae were polyphagous and pentamoulter having six larval instars and the entire life cycle was completed within 50.57 ± 1.30 days during April to May and 40.02 ± 0.54 days during July to August under laboratory conditions on chili (Singh and Prasad 2001). In a study on response of types of tobacco to *Spodoptera litura*, it was found that the longest duration of life cycle (44 days) was recorded on oriental tobacco followed by chewing (43 days) and FCV tobacco (41 days) (Bharathi *et al* 2008). The biological parameters of *S. litura* were not significantly affected when reared on five different Bt cotton transgenics carrying Cry 1Ac gene in comparison with their non-Bt counter parts (Basavaraja H, 2008). Shukla and Patel (2011) reported the total life cycle from egg laying to adult emergence to be completed in 39.80 ± 1.88 days on Banana cv Grande Naine. Javar*et al* (2013) studied the suitability of *Centella asiatica*as a food source for *S. litura* and found that the caterpillar completed its life cycle in 29 to 35 days.

Morphology

Eggs

Spherical, somewhat flattened, 0.6 mm in diameter, laid in batches and covered with hair scales from the tip of the abdomen of the female moth. Usually pale orange-brown or pink in colour (*S. litura*) or whitish-yellow (*S. littoralis*) (Ramaiah & Maheswari, 2018).

Figure 16 Egg mass of *S. litura*

Larva

Attains 2.3-32 mm in length; hairless, variable in colour (blackish-grey to dark-green, becoming reddish-brown or whitish-yellow); sides of body with dark and light longitudinal bands; dorsal side with two dark semilunar spots laterally on each segment, except for the prothorax; spots on the first and eighth abdominal segments larger than others, interrupting the lateral lines on the first segment. Though the markings are variable, a bright-yellow stripe along the length of the dorsal surface is characteristic of *S. litura* larvae (Ramaiah & Maheswari, 2018).

Pupa

15-20 m long, red-brown; tip of abdomen with two small spines (Ramaiah & Maheswari, 2018).

Figure 17 Spines at the posterior end of pupal stage in *S. litura*

Adult

Moth, with grey-brown body, 15-20 mm long; wingspan 30-38 mm. The forewings are grey to reddish-brown with a strongly variegated pattern and paler lines along the veins (in males, bluish areas occur on the wing base and tip); the hindwings are greyish-white with grey margins, often with dark veins in *S. litura* but without in *S. littoralis*. The variability and similarity of the two species often make it difficult to distinguish them visually. On dissection of the genitalia, ductus and ostiumbursae are the same length in female *littoralis*, different lengths in *litura*. The shape of the juxta in males is very characteristic, and the ornamentation of the aedengusvesica is also diagnostic Schmutterer, (1974), Cayrol, (1972), Brown and Dewhurst, (1975).

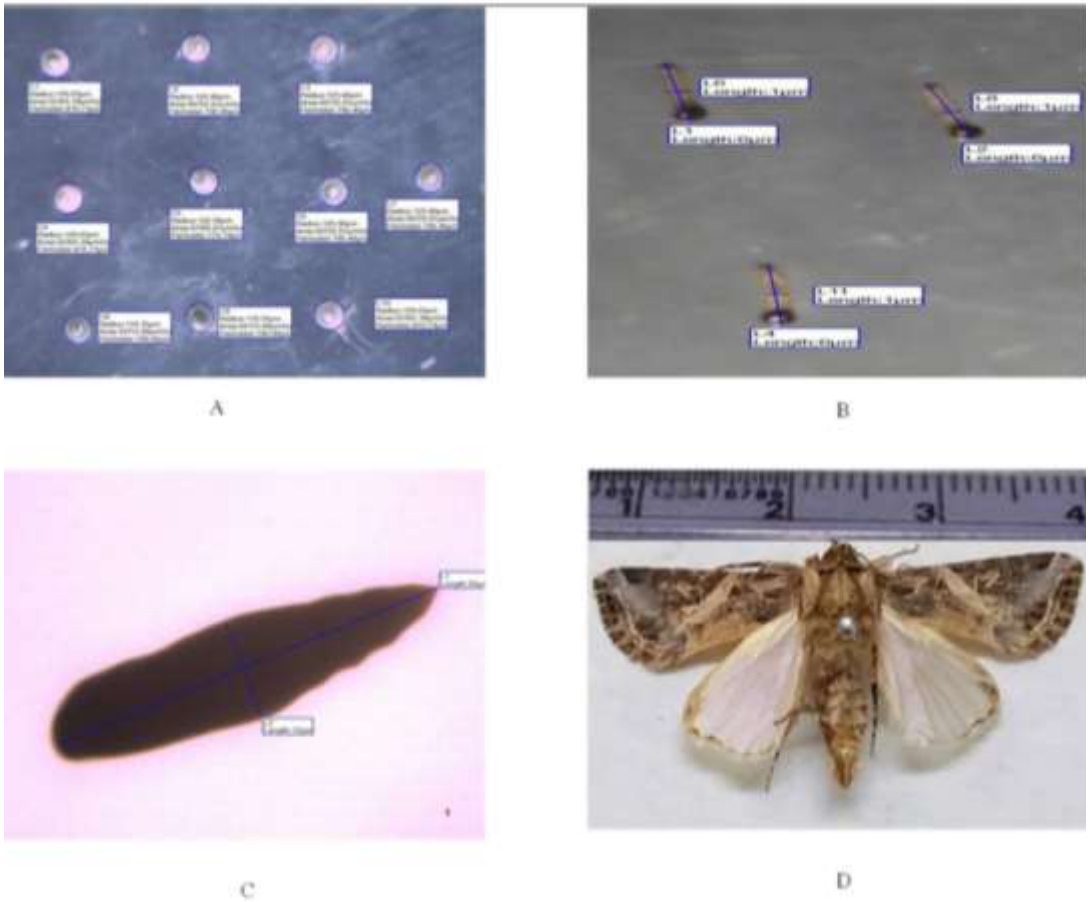

Figure 18Morphometrics of *S. litura*

(Ramaiah & Maheswari, 2018)

1.12 Influence of biotic and abiotic factors on *S. litura*

Abiotic factors such as temperature, humidity, light, and soil can influence a species' ability to survive. Every species is able to survive within a range of each of these factors. This range is called the species' tolerance range. Near the upper and lower limits of the tolerance range, individuals experience stress. This will reduce their health and their rate of growth and reproduction. Within a species' tolerance range is an optimal range, within which the species is best adapted. The largest and healthiest populations of a species will occur when conditions are within the optimal range. Each species has a tolerance range for every abiotic factor. Some species have wide tolerance ranges, while others have much narrower ranges. Species with broad tolerance ranges will tend to be widely

distributed and may easily invade other ecosystems. For example, buckthorn, a small tree native to Europe, has become widespread over much of southern and central Ontario due to its broad tolerance range. Conversely, the showy lady's-slipper orchid has a narrow tolerance range. It is found only in specific types of wetlands (Fand et al., 2012).

Anthropogenic and natural environmental variations are voraciously affecting the arthropods with the passage of time. Certain factors like thermal affect is changing the status of pest by suppressing or stimulating genetic potential, rate of fecundity and mortality and range of hosts (Finlay-Doney M et al., 2012). Variable wavelength of white light specifically for red and far red light when absorbed by photosynthetic system as an unambiguous signal of proximity of hearers causing a good developmental responses like shade avoidance responses (Ruberti et al., 2012). Survival rate of young ones of *Cnaphalocrosis medinalis* (Rice leaf folder) was affected at 35 ℃ even adults emerging from these pupae could not laid eggs. In some biological control agents particularly *C. lividipennis*(egg predator) showed a positive response to predation and decrease the handling time (Holland JM et al., 2014).

Helicoverpa armigera on pigeon pea is at decreasing tendency from year to year and causing less injury to crop. During last four years (2011 to 2014) there was a lot of change in prevalence of abiotic factors viz., rainfall, temperature and relative humidity in this region might have unpleasant the pest buildup from year to year at decreasing tendency and near future if this type of change continued with abiotic factor particularly rainfall, maximum temperature and relative humidity will play a major role to reduce to this pest status (Jakhar et al., 2016).

Insects Responses to High Temperature

In multi climatic factors particularly temperature can extend or reduce the life cycle of insects (Régnière J et al., 2012). High thermal thresh hold influence the insects cycle stage, growth or some internal metabolic activities. For example in case of *Helicoverpa armigera* egg period was observed 7.9 days at 28 ℃ but extended 10.4 days at 25 ℃. Degree days for hatching are negatively correlated

with rise in temperature from 10-27 ℃. Generation time of *L. acuta* was supposed to be increased 1-3 days with the raise to 3 ℃ (Harrison J et al., 2006). In costal environment fitness and survival of terrestrial insects was greatly affected due to a-biotic factors especially in case of soil salinity. In the case study of rice insect pests under influence of global warming and meteorological factors was analyzed in Korea in 1992-2008. Experiment was conducted on eight regions classifying the samples into clustures (I, II, III, IV). The first two and last two clusters were collected before 2000, respectively. Population of *S. litura* was less two clusters (I, II) as compared to *L. oryzophilus* having high density in cluster III and IV (Kwon Y-S et al., 2012). In another case study of European forest including herbivore insects against climatic change like global warming. Ectothermic organisms had a great response against dispersal, fecundity, mortality, reproduction or multiplication and resistance through community interactions. *Thaumetopoea Pityocampa* was monitored had a great effect on altitudinal and latitudinal dispersion intensity checked by thermal effect or global warming modification (Netherer S, 2010). Population dynamic of biological control agent is also affected due to thermal effect or drought conditions. Eggs of Asian lady beetle (*Harmonia axyridis*) were placed under stress or 41, 39, 37 ℃ and control (25 ℃) in ascending order respectively. These eggs were exposed for 1 hour then shifting to normal condition (25 ℃) up to their hatching. Larvae were not emerged in the eggs which are exposed to 41 ℃. While for weight, survival, longevity, development and reproduction of Asian lady beetle exhibited significant differences against thermal effect. Overall reproduction, oviposition period and longevity of insect were reduced while pre-oviposition period was positively affected to increase in temperature (Overgaard J et al., 2008). The response of insects varies against a series of temperatures as 9-55 ℃ enhancing individual insect mortality. Insects flourish up to 10 ℃ but below 6 ℃ mortality of certain insects like coleopterons species goes up to > 99 ℃ after 9 months at 45% R.H. storage conditions. Many psocopteran and coleopterons species were dead almost 99% at 50 ℃ within 2.5 h (Beckett SJ, 2011). Some sucking insects like blood sucking bug (*Rhodnius prolixus*) when use their proboscis for feeding

they extend it. This proboscis action response (PER) varies due to the temperature of an object itself or thermal effect in the environment. In *Rhodnius prolixus* triggering response of PER was highest at 30 and 35 °C where temperature of thermal background was below 35 °C. It was concluded that bugs prefers optimal temperatures as present in most of the mammal for maximum proboscis extension response (Franzle O, 2003). In case of insect pest management population fluctuation, various physiological process and different environmental temperatures showed a significant linkage. When two flies which medfly (*Ceratitis capitata*) and natal fruit fly (*C. crosa*) was exposed to radiation expressing as sensitive to temperature used in the sterile insect technique. In the field experiments these mutated species showed greater longevity under as compared to others, so helpful in male sterile insect technique (Nyamukondiwa C et al., 2013). Tropical species of insects considered to be the high risk of microclimatic variation and behavioral optimization than the temperate regions. Ants (*Iridomyrmex purpureus*) forage for short period of time even when soil temperature is 45.8±1.3 higher than their thermal limit. Ants could not elevate higher thermal effect tolerance utilizing plastic responses (Nigel RA et al., 2013).

Insect Responses Low Temperature

Cooling and freezing have a great effect to disturb the physiological, mechanical and behavioral of the various insects (Karl I et al., 2011). It can change the chemical ingredients and causing dehydration of the cells or maintaining body fluids keeping liquids below melting point (Sinclair BJ et al., 2003). In scientific literature considerable research has been made to check the physiological behavioral response of insect against a-biotic factors (Sinclair BJ et al., 2003). In this regard experiment was performed to check out the thermal effect on reproduction, development and survival rate of insects. They noted that insects could not bear the challenge against high and low thresh hold temperatures. High mortality was observed and somewhat developmental rate was affected. They also performed the successful insect modeling that can aid to analyze the insect population response and behavior against climatic change (Karl I et al., 2011). In

some beetles (*Alphitobius diaperinus*) bear oxidative damage against cooled thermal stress but antioxidant system is switch on to recover this cooled induce damage (Lalouette L et al., 2011). Life cycle gene expression of yellow meal worm beetle was (*Tenebrio molitor*) observed under constant (18±1°C) and variable temperatures (mean=18°C and variance of 6.8°C). Insects were more cool tolerant against variable thermal affect with maximum gene expression (*Hsp70*) (Arias MB et al., 2011). In various insects species fecundity and survival enhance due to fluctuating regimes (FTR) contain cycles between both benign and stressful low temperatures. Results also revealed that at larval stage body water (BWCo) and lipids (BLC) do not change with reaction FTR and show long term fitness consequences (Boardman L, 1977). Pine beetle flourish and disperse with better survival rate at warm winter as compared to lethal (-16 °C) which reduce drastically. Aphids can produce 1-5 generation more with an increase a 2°C in a temperature. In response to minute change in temperature also affect the pre-oviposition period, oviposition and survival of insects is strongly affected. *Nilapavatalugens*(Brown plant hopper) showed no affect on survival ability between 25-35°C but reduced at 40°C. In a similar way female oviposited in higher rate at 35 and 40°C as compared to 25 and 30°C. In contrast to survival and oviposition, pre-oviposition period was decreased at high temperatures (Yamamura K et al., 1998). It was observed that *N. cincticeps* population fluctuate from 3-4 with change in thermal effect. Both of *N. cincticeps* and *C. suppressalis* greatly affect to global warming. Their population boost up due to winter temperature, significantly can be related the number of generation per year. In winter season death rate of adults of *Nezara viridula* and *Halyomorphahalys* was supposed to be decreased 15% by each increase of 1°C temperature. On the other hand number of generation per year of *C. suppressalis* decrease after 2°C warming. Degree day ariation in sucking insect (mustard aphid) can alter its infestation. In a similar way in *Leptocorisa acuta* (rice ear head bug) increase or decrease in population is affected with each raise of 3°C (Reji G et al., 2008). Various insects respond to a-biotic factors like humidity, thermal affect, light and food etc. in different ways. These a-biotic factors not only affect the behavior of

insects but also disturb the physiological mechanism (Overgaard J et al., 2008). When variation in a-biotic environment likes humidity, heat light and diet give a stress to host in return the host produce immune responses. Immune responses can be assessed by observation of the rate of change rather than describing direct change in a specific physiological reaction (Franzle O et al., 2003). These factors can the mortality, fecundity, generation time, multiplication rate, sex ratio and somewhat mutation. For instance, with the range of temperature speed of development can be enhance but production of deformities and larval mortality will also increased (Chown SL et al., 2011). Species richness and insect activity varies due to temperature and water availability. Certain receptors like thermo trp's may act as primary integers, source of sensory information (such as environmental moisture and temperatures) which react to a wide range of stimuli. Sub elytra chamber and cuticular hydrocarbons in integument also play a vital role in water conservation and prevention during drought environmental conditions (Chown SL et al., 2011).

Insect responses to humidity

Tendency of occurrence of *Spodoptera litura* and *Pieris brassicae* on cabbage in relation to maximum and minimum humidity on different dates of observations is showed in figure 2. Larval population of *S. litura* ranged from 0.56 to1.57 larvae/plant during 8 January to 12 February 2014 crop season. The highest observation was on 5 February 2014 (1.57 larvae/plant) at 96% and 38% relative humidity of both maximum and minimum categories. In case of *Pieris brassicae*, larval population ranged from 0.58 to 1.98 larvae/ plant and more or less alike tendency of population fluctuation was observed on various dates of observations. Likewise, the highest observation of *P. brassicae* was on 5 February at alike conditions of humidity. Maximum and minimum humidity had negative impact on population growth of both species. As occurrence of pest depends on host suitability and climatic condition, therefore, occurrence and highest infestation of pest differ from variety to variety and due to variation of management practices in cabbage field (Khan & Talukder., 2017).

Different host plants as a biotic factor

S. litura is totally polyphagous(Holloway, 1989). The host range of each species covers over 40 families, among the main crop species attacked by *S. litura* in the tropics are *Colocasiae sculenta*, cotton, flax, groundnuts, jute, lucerne, maize, rice, soyabeans, tea, tobacco, vegetables (aubergines, *Brassica*, *Capsicum*, cucurbit vegetables, *Phaseolus*, potatoes, sweet potatoes, *Vigna*etc.). Other hosts include ornamentals, wild plants, weeds and shade trees (e.g. *Leucaenaleuco cephala*, the shade tree of cocoa plantations in Indonesia). In most of the EPPO region, outdoor crops are not likely to be attacked, so the principal potential hosts are ornamentals under glass.

Tomato

The tomato is the edible, often red, berry of the plant *Solanumly copersicum*, commonly known as a tomato plant. The species originated in western south America and central America. The Nahuatl (Aztec language) word tomato gave rise to the Spanish word tomate, from which the English word tomato derived (Peralta et al., 2001). Its domestication and use as a cultivated food may have originated with the indigenous peoples of Mexico. The Aztecs used tomatoes in their cooking at the time of the Spanish conquest of the Aztec Empire, and after the Spanish encountered the tomato for the first time after their contact with the Aztecs, they brought the plant to Europe. From there, the tomato was introduced to other parts of the European-colonized world during the 16th century (Jacobsen et al., 1994).

Tomatoes are a significant source of umami/pleasant flavor. The tomato is consumed in diverse ways, raw or cooked, in many dishes, sauces, salads, and drinks. While tomatoes are fruits—botanically classified as berries—they are commonly used as a vegetable ingredient or side dish. Numerous varieties of the tomato plant are widely grown in temperate climates across the world, with greenhouses allowing for the production of tomatoes throughout all seasons of the year. Tomato plants typically grow to 1–3 meters (3–10 ft) in height. They

are vines that have a weak stem that sprawls and typically needs support (Jacobsen et al., 1994). Indeterminate tomato plants are perennials in their native habitat, but are cultivated as annuals. Determinate, or bush, plants are annuals that stop growing at a certain height and produce a crop all at once. The size of the tomato varies according to the cultivar, with a range of 0.5–4 inches (1.3–10.2 cm) in width (Jacobsen et al., 1994).

Figure 19 Tomato plant

Botanically, a tomato is a fruit—a berry, consisting of the ovary, together with its seeds, of a flowering plant. However, the tomato is considered a "culinary vegetable" because it has a much lower sugar content than culinary fruits; it is typically served as part of a salad or main course of a meal, rather than as a dessert. Tomatoes are not the only food source with this ambiguity; bell peppers, cucumbers, bean, eggplants, avocados, and squashes of all kinds (such as zucchini and pumpkins) are all botanically fruit, yet cooked as vegetables. This has led to legal dispute in the United States. In 1887, U.S. tariff laws that imposed a duty on vegetables, but not on fruit, caused the tomato's status to become a matter of legal importance. The U.S. Supreme Court settled this controversy on May 10, 1893, by declaring that the tomato is a vegetable, based on the popular

definition that classifies vegetables by use—they are generally served with dinner and not dessert (Nix v. Hedden (149 U.S. 304)). The holding of this case applies only to the interpretation of the Tariff of 1883, and the court did not purport to reclassify the tomato for botanical or other purposes.

Tomatoes that have been modified using genetic engineering have been developed, and although none are commercially available now, they have been in the past. The first commercially available genetically modified food was a variety of tomato named the FlavrSavr, which was engineered to have a longer shelf life (Sato et al., 2012). Scientists are continuing to develop tomatoes with new traits not found in natural crops, such as increased resistance to pests or environmental stresses. Other projects aim to enrich tomatoes with substances that may offer health benefits or provide better nutrition. An international consortium of researchers from 10 countries, among them researchers from the Boyce Thompson Institute for Plant Research, began sequencing the tomato genome in 2004, and is creating a database of genomic sequences and information on the tomato and related plants (Powell AL et al., 2012). A pre release version of the genome was made available in December 2009. The genomes of its mitochondria and chloroplasts are also being sequenced as part of the project. The complete genome for the cultivar Heinz 1706 was published on 31 May 2012 in Nature. Since many other fruits, like strawberries, apples, melons, and bananas share the same characteristics and genes, researchers stated the published genome could help to improve food quality, food security and reduce costs of all of these fruits (Sato et al., 2012).

The world dedicated 4.8 million hectares in 2012 for tomato cultivation and the total production was about 161.8 million tones. The average world farm yield for tomato was 33.6 tones per hectare, in 2012 (Hooks et al., 2010).

Tomato farms in the Netherlands were the most productive in 2012, with a nationwide average of 476 tones per hectare, followed by Belgium (463 tones per hectare) and Iceland (429 tones per hectare) (Stassen et al., 1997).

Cabbage

Cabbage (comprising several cultivars of *Brassica oleracea*) is a leafy green, red (purple), or white (pale green) biennial plant grown as an annual vegetable crop for its dense-leaved heads (Chen et al., 2011).

Figure 20 Cabbage plant

Cabbage weights generally range from 0.5 to 4 kilograms (1 to 9 lb). Smooth-leafed, firm-headed green cabbages are the most common. Smooth-leafed purple cabbages and crinkle-leafed savoy cabbages of both colours are rarer. It is a multi-layered vegetable. Under conditions of long sunny days, such as those found at high northern latitudes in summer, cabbages can grow quite large. As of 2012, the heaviest cabbage was 62.71 kilograms (138.25 lb). Cabbage was most likely domesticated somewhere in Europe before 1000 BC, although savoys were not developed until the 16th century AD. By the middle Ages, cabbage had become a prominent part of European cuisine. Cabbage heads are generally picked during the first year of the plant's life cycle, but plants intended for seed are allowed to grow a second year and must be kept separate from other cole crops to prevent cross-pollination. Cabbage is prone to several nutrient deficiencies, as

well as to multiple pests, and bacterial and fungal diseases. Cabbages are prepared many different ways for eating; they can be pickled, fermented, steamed, stewed, sautéed, braised, or eaten raw. Cabbage is a good source of vitamin K, vitamin C and dietary fiber. World production of cabbage and other brassicas for 2017 was 71 million tones, with China accounting for 47% of the world total. Cabbage consumption varies widely around the world: Russia has the highest annual per capita consumption at 20 kilograms (44 lb), followed by Belgium at 4.7 kilograms (10 lb), the Netherlands at 4.0 kilograms (8.8 lb), and Spain at 1.9 kilograms (4.2 lb). Americans consume 3.9 kilograms (8.6 lb) annually per capita (Wright, 2001).

Chili

The Chili pepper is the fruit of plants from the genus Capsicum which are members of the nightshade family, Solanaceae. Chili peppers are widely used in many cuisines as a spice to add heat to dishes. The substances that give Chili peppers their intensity when ingested or applied topically are capsaicin and related compounds known as capsaicinoids. Chili peppers originated in Mexico (Kraft et al., 2013).

After the Columbian Exchange, many cultivars of Chili pepper spread across the world, used for both food and traditional medicine. Capsicum fruits have been a part of human diets since about 7,500 BC, and are one of the oldest cultivated crops in the Americas, as origins of cultivating Chili peppers are traced to northeastern Mexico some 6,000 years ago. They were one of the first self-pollinating crops cultivated in Mexico, Central America, and parts of South America (Kraft et al., 2013).

Figure 21 Chili plant

Peru is considered the country with the highest cultivated capsicum diversity because it is a center of diversification where varieties of all five domesticate were introduced, grown, and consumed in pre-Columbian times. Bolivia is considered to be the country where the largest diversity of wild Capsicum peppers is consumed. Worldwide in 2016, 34.5 million tons of green Chili peppers and 3.9 million tons of dried Chili peppers were produced. China was the world's largest producer of green Chili, providing half of the global total. Global production of dried Chili peppers was about one ninth of fresh production, led by India with 36% of the world total (Tewksbury et al., 2008).

There are five domesticated species of Chili peppers. *Capsicum annuum* includes many common varieties such as bell peppers, wax, cayenne, jalapenos, chiltepin and all forms of New Mexico Chili. Capsicum frutescens includes malagueta, Tabasco and thai peppers, piripiri and Malawian Kambuzi. Capsicum Chinese includes the hottest peppers such as the naga, habanero, Datil and Scothch bonnet.

Capsicum pubescens includes the south American rocoto peppers. Capsicum baccatum includes the south American aji peppers (O'Neill et al., 2012).

The substances that give Chili peppers their pungency (spicy heat) when ingested or applied topically are capsaicin (8-methyl-N-vanillyl-6-nonenamide) and several related chemicals, collectively called capsaicinoids. The quantity of capsaicin varies by variety, and on growing conditions. Water stressed peppers usually produce stronger pods. When a plant is stressed, by absorbing low water for example, the concentration of capsaicin increases in some parts of the fruit (Tewksbury et al., 2008).

When peppers are consumed by mammals such as humans, capsaicin binds with pain receptors in the mouth and throat, potentially evoking pain via spinal relays to the brainstem and thalamus where heat and discomfort are perceived. The intensity of the "heat" of Chili peppers is commonly reported in scoville heat units (SHU). Historically, it was a measure of the dilution of an amount of Chili extract added to sugar syrup before its heat becomes undetectable to a panel of tasters; the more it has to be diluted to be undetectable, the more powerful the variety, and therefore the higher the rating. The modern method is a quantitative analysis of SHU using high-performance liquid chromatography (HPLC) to directly measure the capsaicinoid content of a Chili pepper variety. Pure capsaicin is a hydrophobic, colorless, odorless, and crystalline-to-waxy solid at room temperature, and measures 16,000,000 SHU. Capsaicin extracted from Chilies is used in manufacturing pepper spray and tear gas as chemical irritants, forms of less-lethal weapons for control of unruly individuals or crowds. Such products have considerable potential for misuse, and may cause injury or death (Haar et al., 2017).

Cotton

Cotton is a soft, fluffy staple fiber that grows in a boll, or protective case, around the seeds of the cotton plants of the genus Gossypium in the mallow family Malvaceae. The fiber is almost pure cellulose. Under natural conditions, the cotton bolls will increase the dispersal of the seeds. The plant is a shrub native

to tropical and subtropical regions around the world, including the Americas, Africa, Egypt and India. The greatest diversity of wild cotton species is found in Mexico, followed by Australia and Africa (Moulherat et al., 2002).

Cotton was independently domesticated in the Old and New Worlds. The fiber is most often spun into yarn or thread and used to make a soft, breathable textile. The use of cotton for fabric is known to date to prehistoric times; fragments of cotton fabric dated to the fifth millennium BC have been found in the Indus Valley Civilization, as well as fabric remnants dated back to 6000 BC in Peru. Although cultivated since antiquity, it was the invention of the cotton gin that lowered the cost of production that led to its widespread use, and it is the most widely used natural fiber cloth in clothing today. Current estimates for world production are about 25 million tones or 110 million bales annually, accounting for 2.5% of the world's arable land. India is the world's largest producer of cotton. The United States has been the largest exporter for many years. In the United States, cotton is usually measured in bales, which measure approximately 0.48 cubic meters (17 cubic feet) and weigh 226.8 kilograms (500 pounds) (Hughs et al., 2008).

Genetically modified (GM) cotton was developed to reduce the heavy reliance on pesticides. The bacterium *Bacillus thuringiensis* (Bt) naturally produces a chemical harmful only to a small fraction of insects, most notably the larvae of moths and butterflies, beetles, and flies, and harmless to other forms of life. The gene coding for Bt toxin has been inserted into cotton, causing cotton, called Bt cotton, to produce this natural insecticide in its tissues. In many regions, the main pests in commercial cotton are lepidopteran larvae, which are killed by the Bt protein in the transgenic cotton they eat.

Figure 22 Cotton plant

This eliminates the need to use large amounts of broad-spectrum insecticides to kill lepidopteran pests (some of which have developed pyrethroid resistance). This spares natural insect predators in the farm ecology and further contributes to non-insecticide pest management (Lu y et al., 2012).