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Lifecycle, Hosts and Importance of Some of the Major Cotton Insect Pests in South Africa: A Review

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) is an essential fibre crop cultivated worldwide for centuries. The crop is a cash crop that is grown as raw material for textile industries in over 80 countries with tropical and subtropical climatic conditions. In Sub-Saharan Africa, cotton is a key export crop for global cotton lint exports. In South Africa, cotton is mostly grown by smallholder farmers in five provinces. However, several factors affect production, including low yields, high input costs and pest and weed infestations. The incidence of pests is a significant influence that affects cotton production, resulting in low yields and poor quality. The importance of cotton insect pests lies in their ability to cause significant economic losses by damaging cotton crops. Some are serious pests that require control measures such as synthetic pesticides to warrant a viable yield. A successful control strategy requires integrated pest management that prevents or suppresses damaging populations of insect pests by applying the comprehensive and coordinated integration of multiple and compatible control tactics, including chemical, cultural and biological methodologies. The lifecycles of insect pests can vary depending on factors such as environmental conditions, host availability and pest species. Understanding these lifecycles is crucial for implementing effective pest management strategies at different stages of development to minimize their impact on cotton crops. This paper seeks to review and examine the lifecycle, hosts and importance of *Helicoverpa armigera*, *Aphis gossypii*, *Bemisia tabaci*, *Thrips tabaci*, *Jacobiella facialis*, *Tetranychus urticae* and *Dysdercus* species as major key insect pests in cotton production.

KEYWORDS

Cotton, insect life cycle, aphid, bollworm, whitefly, thrip, leafhopper, spider mite, cotton stainer

INTRODUCTION

Although insects are the largest animal group and have a significant role in the ecosystem, some can be serious crop pests, including cotton[1]. The incidence of pests in cotton significantly affects production, resulting in low yields and poor quality[2]. Sub Saharan Africa has climate conditions suitable for various pests, which attack cotton and result in yield losses[3]. Tay *et al.*[4] reported that an average of 30% of seed

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cotton is lost due to pests. Some insects are casual or random pests, but others may be economically important to cotton as they cause damage and reduce the yield. Insect pests such as the African bollworms[5], aphids[6], thrips[7], whiteflies[8] and leafhoppers[9] are serious crop pests in South Africa. Pesticides are commonly used to control these pests; however, controlling one species can have an impact on the occurrence and population of other species.

All insects undergo their unique life cycles through complete or incomplete metamorphosis. A complete metamorphosis consists of four developmental stages, namely egg, larva, pupa and adult. While complete metamorphosis involves a pupal stage[10], insects undergo incomplete metamorphosis from nymphs to adults without the pupal stage[11]. Some insects have larvae and adults that are different in appearance from each other[12] and often live in various habitats. Because an insect's host, behaviour and development can all drastically alter throughout its life cycle, depending on the type of life cycle, insect life cycles are essential for managing pests. Therefore, this review describes the key insect pest of cotton in South Africa.

Pest lifecycle, host and damage

African bollworm: The African bollworm, *Helicoverpa armigera* Hübner (Lepidoptera, Noctuidae), is the most significant pest of agriculture commonly found in Africa, Asia, Oceania, Europe[13] and recently in South America[14]. In Africa, the pest is regarded as an indigenous species contributing to the reduction of crop production[15]. It is the only heliothine species of major economic importance[16]. In East Africa, *H. armigera* attacks various crops, including cotton, legumes, maize, sorghum, sunflower, tobacco and tomato[17]. In South Africa, cotton is one of the main crops attacked by the pest. It has been regarded as a serious pest due to feeding on a wide range of host crops[4], high fecundity[18], multivoltine life cycle[19], great potential mobility[20], damage to fruiting parts[21] and its resistance to chemical insecticides[22]. van Hamburg and Guest[23] listed 35 host crops of *H. armigera* plus 25 wild host plants in eastern and Southern Africa, while Krinski and Godoy[24] documented over 67 host families worldwide.

The *H. armigera* developmental cycle goes through four stages: Egg, larval, pupa and adult[25]. There can be up to five generations of bollworm per year[5] and each generation can take about four to six weeks[26]. *The H. armigera* females prefer laying eggs on host flowers, squares and fruit[27] during winter or spring[13]. The eggs are laid over two to three days and oviposition may last up to eight days[13]. In South Africa, it can take up to 23 days for oviposition to occur[5]. Eggs are cream to white, changing to brown before hatching[5] and up to 0.6 mm in diameter[13]. A single female may lay up to 1500 eggs[27]. In South Africa, a single female moth can lay an average of 730 eggs[5]. Larval colour and size vary depending on the larval instar. The larvae range in colour from yellow to brown with a cylinder-shaped body and longitudinal stripes occur on the dorsal side[28]. At the later stage, the larvae have white or yellow lines and white spiracles with black rims[29].

Pupae are round at both ends with a brown colour and are about 14-18 mm long 5. The pupal stage occurs in the soil[25] at a depth of 3-15 cm[13]. When the pest feeds on cotton, the pupal viability increases and the pupal stage lasts about 15 days[27]. The moth is usually brown[30], with a broad thorax and seven to eight blackish spots on the forewings[31]. The hind wings have apical ends with a broad dark-brown border and yellow margins[32]. *Helicoverpa armigera* is a nocturnal pest[33] that can travel long distances due to a separation of feeding and oviposition by unfavourable habitats[13]. Long-range movement can also be attributed to migration, which may have implications for managing pests in the various agricultural landscapes[34]. Daguang *et al.*[35] reported that most moths were distributed within a 720 m range when released in the field.

Helicoverpa armigera damage differs by crop and because of the migratory behaviour, the occurrence of this pest is frequently unpredictable[36]. The pest causes damage of more than US$2 billion to crops every year and this excludes the environmental costs that are related to its control[5]. The damage caused by *H. armigera* depends, to some extent, on the adult population numbers, the number of eggs laid and the survival rate of larvae[37]. Young larvae tend to feed on younger leaves, while the older ones feed on different parts of the plants, preferably the buds, flowers, fruits and pods[38]. Although there may be low numbers in the field, the damage may significantly increase because the larvae tend to feed partly on one cotton ball and then move to another 5. The damaged bolls ultimately drop off the plant[39]. When left untreated, *H. armigera* can cause up to 90% of boll damage in cotton. In Brazil, the pest was reported to reduce cotton yields by up to 80%[4]. In 2014, de Freitas Bueno and Sosa-Gómez[40] reported that Brazil had crop loss estimated at US$ 0.8 billion due to the pest's damage.

Cotton aphid: The cotton aphid, *Aphis gossypii* Glover (Hemiptera, Aphididae), is an important agricultural pest due to its wide host range[41]. Ma *et al.*[42] reported that the pest has over 900 hosts from 116 plant families. Although *A. gossypii* can significantly damage the crop through direct feeding, its main threat is the ability to transmit many plant viruses[43]. *Aphis gossypii* populations are primarily high on cotton from mid to late season[44]. Before genetically modified cotton was introduced, pesticides sprayed against Helicoverpa species-controlled aphids; however, the aphid populations increased thereafter, resulting in resistance to pesticide control[45].

Aphis gossypii is a tiny, soft-bodied insect with a pear-like shape and a pair of black cornicles[46]. They are 1 to 2 mm long with relatively long antennae and legs[47]. Aphids can be distinguished from other pests like mites through slower movement when disturbed[48]. Body colour varies depending on the host plant and the biological state of the individual aphid[49]. The nymphs vary in colour from yellow to green, black or brownish[50]. They often have a dark head and thorax with a dark green abdomen[51]. The first instar has four antennal segments, while the second has five[52]. The third instar can be differentiated from the fourth instar by the absence of setae on the genital plate[46]. The fourth-instar nymphs have developed wings, while adults are primarily wingless[53]. Small yellow or white aphids are observed during unfavourable environmental periods and do not reproduce until conditions are favourable[54]. During favourable conditions, larger green forms are produced[55]. The aphids generally require at least two hosts and the primary host is for sexual reproduction, while the secondary host is for asexual reproduction[56]. Females produce offspring that takes about a week to develop and moult four times to become reproductive adults[57]. The reproductive period covers 20 days and the female can produce up to 80 offspring[58].

Aphids can cause severe loss in cotton production[59]. They cause damage to the undersurface of the leaves and the stems by using sharp mouthparts and sucking the sap from the tissues[60]. The leaves may produce insufficient chlorophyll, initiate curling and die prematurely[61]. Genetically modified cotton has been reported to not affect preference and colonization by aphids[62]. Besides the physical damage to the host, aphids have been widely reported to transmit various virus diseases[63]. Moreover, aphids produce a sugary substance called honeydew that causes stickiness[64], interfering with the plant's photosynthesis[47]. When aphids feed on cotton plants, the honeydew drops onto the bolls, resulting in a sticky deposit on the fibre[65]. Stickiness reduces the lint quality and results in substantial price penalties for the grower[66]. It is a severe challenge during cotton ginning since it causes the lint to stick to machinery[67]. Honeydew also exposes the leaves to sunburn, which results in secondary infections that inhibit the plant's functions[68].

Whitefly: Whiteflies, *Bemisia tabaci*, Gennadius (Hemiptera, Aleyrodidae) are one of the most important agricultural and horticulture pests worldwide[69]. Whiteflies are regulated quarantine species in Australia, Africa, China, the EU and the USA[70]. Currently, 39 species differ in their host-plant range[71] and they have more than 600 host-plant species[72]. This species reportedly transmits over 100 plant viruses[73].

Whiteflies undergo six developmental stages: Egg, four larval instars and adults[74]. The average developmental stage in cotton takes approximately 17 to 29 days to complete. Perring *et al*.[69] reported that at a lower temperature of 15°C, the complete development could take up to 105 days compared to 14 days at 30°C. The eggs are approximately 0.2 mm long and elongated with a pale brown colour[75]. They are laid singly or in group circles on the undersides of the leaf surface[69]. Each female can lay between 60 and 300 eggs[76], which takes about five to nine days to hatch, depending on the host species and humidity[77]. Of the four larval stages, the first and second larval instars are up to 0.6 mm long and the first larval instar is the only mobile larval stage[74]. The fourth instar, known as the pupa, is 0.7 mm long, oval and lasts about six days[78].

The adult emerges from the pupal case and expands its wings before powdering itself with wax from glands on the abdomen[79]. Adults are about 1 to 2 mm long with wings covered in white powder wax[80]. Their body is white to slightly yellowish with seven segmented antennae and one sensorial cone on the third, sixth and seventh segments[81,82]. The wings are kept above the body in a tent-like position[83] and up to 15 generations can occur annually[77]. Onstad[84] stated that mating occurs several times from 12 hrs after emergence and the female may live up to 60 days while the male lives for a shorter period. Whitefly nymphs and adults can be easily identified in the crop[83].

Whiteflies can cause damage through phloem-feeding, excretion of honeydew and transmitting viruses such as cotton leaf curl virus[85]. Whiteflies suck phloem-sap and cause damage to a wide range of crops, including cassava[86], cotton[87] and tomato[88]. With their piercing-sucking mouthparts, they insert their stylets into the plant to feed on the phloem[89]. While feeding on the plant, immature and adult stages excrete honeydew onto the leaf surface and fruit[83], causing discolouration of leaves and fruit deformations[90]. Whiteflies have developed resistance due to the overuse of insecticides[91].

Thrips: Thrips, *Thrips tabaci*, Lindeman (Thysanoptera, Thripidae) is a serious early-season pest of seedling cotton[92] and vegetable crops[93] throughout the world. They are commonly one of the first insects found on cotton[94]. Hull[95] reported that thrips feed on a wide host range, including 140 species from over 40 families of plants, while Varela and Fail[96] and Cook *et al*.[97] reported that there are several hundred host plants. Thrips may be found on weeds and flowers growing near cotton and migrating onto cotton plants[92].

The life cycle of thrips has six stages: Egg, two larval stages, two pronymph stages and an adult stage[81]. The life cycle can take between 10 and over 30 days to complete, depending on the climate and the host plant[98]. Reproduction is both asexual and sexual[99], producing both males and females from unfertilized eggs[100] and females from fertilized eggs[99]. The eggs are small, shiny white[101], 0.2 mm long and 0.08 mm wide[102]. They are laid individually inside the leaf tissues[99]. A female can lay up to 100 eggs, which take up to six days to hatch[103]. The first instar is semi-transparent and white, while the second instar is yellow[93]. The larvae undergo two instar stages, which last up to 10 days[104]. The pupae do not feed[105] and the pupal stage takes about four days to complete[81]. Adult females are about 1.2 mm long, while males are smaller than 0.7 mm long[93]. The body colour varies from yellow to brown depending on temperature[106]. Adults are very active with fringed and pale wings[107]. The antennae have seven segments and the eyes are grey[108]. Adults live up to 35 days[92] and several generations can develop annually[109].

The host plant, temperature and humidity play a role in the development of thrips[110]. Adults may hibernate in field crops[106] and overwinter in the soil[111]. Adults can fly long distances from immediate plant hosts[112] and flight occurs during daylight at low wind speeds[113]. Thrips found in nearby weeds migrate onto cotton plants[114] and adults are attracted to white, blue and yellow colours[115]. It is sometimes impossible to control thrips with pesticides since the eggs are laid under leaf tissues[116], the pupae are found in the soil or between the leaves[109] and some adults may avoid control by hiding in the inner leaf spaces[104].

During the seedling stage, cotton growth is slow, resulting in an attack by early-season insect pests such as thrips[117]. When feeding, thrips move from the lower to the upper parts of the cotton plant as the plants increase in size[118]. The feeding preference may be due to the pest trying to access younger leaves with thinner epidermis on the lower surface[119]. Thrips feed on leaves, young leaves and flower buds[120], causing the silvering of leaves due to the loss of chlorophyll[93]. The silvery appearance occurs after the fluids in the cell are replaced by air[97]. Both adults and larvae feed on plant epidermal cells' contents, causing damage that results in 30-50% of lint yield[97]. Damaged cells wrinkle and the leaves do not develop well, causing them to twist[97]. The damage caused by thrips can also allow secondary infection by plant pathogens[121]. Attique and Ahmad[122] reported that thrips and cotton leafhoppers cause almost 40% loss in seed cotton yield. Scouting for thrips is difficult; a lens may be required[104] and the population level can be determined by observing leaf damage[121]. Wardle and Simpson[123] reported no evidence of toxicity from the thrips salivary secretion. Thrips are also reported to be vectors of plant viruses[124]. Hull[95] stated that 17 species are reported to transmit viruses from four plant virus groups, most feeding on the plant's vegetative parts and pollen.

Leafhopper: Leafhoppers, *Jacobiella facialis* Jacobi (Hemiptera: Cicadellidae), commonly known as jassids, are one of the major cotton pests in Africa[125]. The pest has a synonym called *Empoasca facialis* and it was described in Dutch East Africa in 1912. Leafhoppers are commonly found in the tropics and subtropics[126]. Numerous species of leafhoppers are found on cotton[127] and can feed throughout the crop cycle despite pesticide application[125].

Leafhoppers reproduce sexually and the egg hatches to a nymph[126]. The nymphs look like adults but are smaller with a pale yellow-green colour[75]. Leafhoppers undergo five nymphal instars[75] and they are multivoltine with several generations every year[128]. Eggs are laid on the underside of leaves and they can hatch in about ten days[129]. They are elongated and range from 0.8 to 10 mm[130]. Leafhopper species are almost similar in shape but vary in colour from green to yellowish-brown[131]. They overwinter as egg, adult, or immature forms and pass through several moults before becoming an adults[132]. Leafhoppers are generally found low in the canopy[129] and when disturbed, they hop fast[75]. The nymphs and adults may feed on the aerial parts of the same plant[133] and the attack occurs throughout the crop production cycle[134]. Both the nymphs and the adult suck the sap from the xylem and phloem tissues of the plant and young leaves from the lower surfaces[135]. The damage caused by the leafhoppers is called "hopper burn" because of the brownish appearance of plants and it is a non-contagious disease[136]. Hopper burn causes the edges of the leaves to curl downwards and change to yellow and then red before drying out and falling off the stem[137].

Premature reddening has been reported to be a characteristic reaction of the plant rather than the attack[127]. Hopper burn occurs when there is an interaction between insect-feeding stimuli and plant responses[138]. Heavy infestations can damage the canopy and impair cotton growth, causing a 40 to 100% reduction in the number of bolls[139]. Prolonged feeding also results in the shedding of leaves, squares and young bolls, leading to significant yield losses[140]. The pest damage levels vary under different climatic conditions and lower rainfall significantly increases the pest population[141].

Spider mite: Spider mites, *Tetranychus urticae* Koch (Trombidiformes: Tetranychidae), are important cotton pests[142]. There are many controversial reports on the taxonomic placement of the two-spotted spider mite, with about 65 synonyms included under this species[143]. While numerous spider mite species attack cotton worldwide[144], the two-spotted mite is one of the most common and important species[145]. This species is an early-season pest that causes significant yield losses in cotton[146]. The growth stages of spider mites differ from one species to another[147]. However, their life cycle is short, with high fecundity and haploid-diploid sexes[148]. Depending on temperature, spider mite development occurs in five to twenty

days and may have overlapping generations every year[149]. The optimal reproduction usually occurs in seven days at a temperature above 30°C[150]. Gunning and Easton[151] reported average development periods of 27 days at 16°C, six days at 29°C for females and a slightly shorter time for males. The complete life cycle consists of the egg, larva, two nymphal or pupal stages and the adult[73]. Females lay male eggs during asexual reproduction and in sexual reproduction, both female and male eggs are laid[152]. Female spider mites can lay over 100 eggs over 12 days[142] and under optimal conditions, several hundred eggs are laid by each female[147]. The eggs are oval, shiny, colourless, 0.08 mm long and 0.13 mm in diameter[142].

The eggs are attached to a silk web[153] and their presence can be used to confirm when the plant damage is due to spider mites[154]. The eggs hatch in three days into larvae that are 0.1 mm long[147] with a pale green colour and three pairs of legs[149]. The larval stages are mainly dormant and only become active after the moulting to the nymphal stage[155]. The larvae move slowly and develop into the nymphal stage within three days[156]. The two nymphs are known as protonymph and deutonymph and they have darker markings and eight legs[157]. Initially, the nymph is pale yellow-green and later turns darker green[142]. Adult females are 0.2-0.6 mm long, elongated with long hairs on the dorsal side of the body and translucent pale greenish-yellow to brown[158]. Adult females live for about two to four weeks[159], while males can live up to nine days 149. The overwintering females are orange to orange-red[160].

Spider mites feed on the undersurface of the leaves[161], where they remove the sap[73]. Spider mites are mesophyll feeders because they pierce the leaf epidermis and feed mostly on mesophyll cells, affecting photosynthesis in the leaves of host plants[162]. The damaged leaves become grey or yellow and damage to the open flower results in brown colour and withering of the petals[163]. Complete defoliation may occur when the pest is not controlled at higher population densities[164]. Crop development is reduced in cotton by high infestation during the early developmental stage[161]. The spider mites also transmit several viruses, including potato virus Y, tobacco mosaic virus and tobacco ringspot virus[163].

Cotton stainer: Cotton stainers, *Dysdercus* species (Hemiptera: Pyrrhocoridae), are serious cotton pests[165]. The Pyrrhocoridae is a small family comprising 33 genera and approximately 360 species worldwide[166]. Eleven pest species are found in Africa[167], with four species occurring in South Africa. The *Davus fasciatus*, *Danio nigrofasciatus* and *Dipturus intermedius* are important in Africa cotton[168]. Cotton stainers have a wide range of alternative hosts, including wild plants and various hibiscus species[169].

The cotton stainers have several generations a year and the complete life cycle may take one to three months, depending on temperature[170]. Over 100 small pale eggs are laid and incubation can take up to two weeks[170]. The female lays eggs in the soil or plant debris[171]. The emerging nymphs are initially red and after five moults, they have the same colours as adults but lack wings[172]. The last stages of nymphs and adults have long mouthparts used when feeding on the cotton seeds inside the bolls, while younger nymphs only feed on slightly opened bolls[173]. Nymphs and adults are usually found in larger groups[165]. The cotton stainers resemble assassin bugs; however, adult females are bigger than males[170]. Adults are up to 2 cm long[168] with colours that vary from a red to an orange body and black stripe on the wings[172]. Adults are active during the daytime and can travel long distances[170].

Both adults and nymphs suck the sap from the seeds with piercing mouth parts causing physical damage and shedding of young bolls[167]. While feeding on cotton, the pest also damages the fibres and affects the development of the bolls[174]. The feeding on developing and mature cotton seeds negatively affects the quality of the seed and oil content[175]. Cotton stainers attack cotton throughout the fruiting stage and transmit a fungus disease known as boll disease, resulting in hard bolls and stained lint[172]. Adults are found on cotton as early as when the first bolls open and can remain inside the boll until harvesting[170].

SIGNIFICANCE STATEMENT

Insect pests cause severe losses in cotton production in South Africa. A successful control strategy requires integrated pest management that prevents or suppresses damaging populations of insect pests by applying the comprehensive and coordinated integration of multiple and compatible control tactics. Understanding the biology and damage caused by these significant cotton insect pests is crucial to minimize their impact on cotton production. This paper provides an overview of the lifecycle, hosts and importance of *Helicoverpa armigera*, *Aphis gossypii*, *Bemisia tabaci*, *Thrips tabaci*, *Jacobiella facialis*, *Tetranychus urticae* and *Dysdercus* species as major key insect pests in cotton production. In conclusion, the future of understanding and managing cotton insect pests lies in integrating advanced scientific research with practical, sustainable agricultural practices.

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