



Available Online at EScience Press

Plant Protection

ISSN: 2617-1287 (Online), 2617-1279 (Print)
http://esciencepress.net/journals/PP

Review Article

Current Status, Ecology, and Epidemiology of Cotton Pests and Pathogens in SAARC Nations

^aMd. Rejaul Islam, ^bEshrat Zahan Eshita, ^bShimul Das, ^bMd. Mostofa Kamal

^a Plant Pathology, Agrotechnology Discipline, Life Science School, Khulna University, Khulna 9208, Bangladesh.

^b Entomology and Virology, Agrotechnology Discipline, Life Science School, Khulna University, Khulna 9208, Bangladesh.

ARTICLE INFO

Article history

Received: 24th November, 2025

Revised: 26th April, 2026

Accepted: 27th April, 2026

Keywords

Cotton

SAARC

Insect pests

Pathogens

Integrated pest and
disease management

IPDM

ABSTRACT

Cotton is one of the most economically important fiber crops worldwide, underpinning the textile industry and contributing significantly to global trade while linking agricultural production with the garment sector and everyday human needs. It is cultivated in more than 80 countries across diverse agro-climatic regions, primarily in tropical and subtropical zones. In the SAARC region, cotton is a cornerstone of the economy and apparel industry, with major producers such as India and Pakistan supporting the livelihoods of millions of farmers and industrial workers. In addition to fiber, cottonseed is an important source of edible oil and livestock feed, further enhancing its economic value. However, cotton production is continually threatened by a wide range of insect pests and pathogens, resulting in substantial losses in yield and fiber quality. Major insect pests include bollworms, whiteflies, jassids, and mealybugs, while key pathogens comprise bacterial blight, grey mildew, *Fusarium* wilt, and cotton leaf curl virus. These biotic stresses are strongly influenced by climatic factors such as temperature fluctuations, high humidity, and irregular rainfall patterns. Furthermore, heavy reliance on chemical pesticides, water-intensive cultivation practices, and the growing impacts of climate change pose serious challenges to sustainable cotton production. Although agrochemicals remain widely used, concerns over resistance development and environmental risks have intensified the need for alternative approaches. Consequently, there is increasing emphasis on Integrated Pest and Disease Management (IPDM). This review highlights the need for region-specific resistant varieties, improved farmer awareness, and coordinated regional strategies to ensure sustainable cotton production in SAARC countries.

Corresponding Author: Shimul Das

Email: shimul@at.ku.ac.bd

Introduction

Cotton, a major textile fiber, is obtained from *Gossypium* species belonging to the family Malvaceae. The fibers develop as soft, fluffy structures surrounding the seeds and are composed primarily of cellulose. Cotton is a shrub that thrives in tropical and subtropical regions (Nag,

2017). Global cotton production for 2024-25 is projected to reach 117.4 million bales, driven by increased output in India, Argentina, and the USA (TT, 2025). For the 2024-25 marketing year, global production is forecast to increase by 9.2% compared with the previous year (Looney, 2024). India's cotton area for MY 2025-26 is estimated at 11.4

million hectares (THBL, 2025). Cotton exports from India were valued at US\$ 6.78 billion in FY 2023-24 and Rs. 73,233 crore (equivalent to US\$ 8.48 billion) in FY 2024-25 up to December 2024 (IBEF, 2024). In contrast, the Pakistan Cotton Ginners Association reported a decline in cotton arrivals from 8.35 million bales in 2023-24 to 5.51 million bales in 2024-25 (PCCC, 2025). Pakistan's cotton consumption is projected at 2.1 million tons, contributing approximately 55% to export earnings and 0.8% to GDP, with a 14% share in global cloth exports (ICAC, 2020; Looney, 2024). In MY 2024-25, Bangladesh's cotton area and production are expected to decline to 45,000 hectares and 153,000 bales, respectively, due to sowing disruptions caused by heavy rainfall (USDA, 2024). Bangladesh meets only about 2% of its annual cotton demand domestically and imports over 8 million bales annually at an estimated cost of Tk 35,000 crore equivalents to \$2.86 billion US (Hussain, 2022).

However, cotton productivity across South Asian countries is increasingly threatened by the rising prevalence of insect pests and diseases, which adversely affect both yield and fiber quality. Major insect pests include bollworms, aphids, and whiteflies, while significant diseases comprise wilt, root rot, and seedling blights. The warm, humid subtropical climate of the region further facilitates pest survival, reproduction, and outbreak severity. In response, farmers often rely on indiscriminate use of synthetic pesticides, leading to the development of pesticide resistance and environmental degradation. These concerns necessitate the identification and adoption of region-specific, eco-friendly bio-based alternatives to ensure sustainable cotton production and environmental safety. Although numerous studies have examined the influence of biotic and abiotic factors on cotton productivity and management strategies for pest and disease control, a consolidated and comprehensive synthesis of this information remains lacking. Therefore, this review aims to compile and analyze the status of major insect pests and pathogens affecting cotton in SAARC countries, highlighting their distribution, environmental drivers, emerging challenges, and existing management approaches.

Cotton cultivation in SAARC countries

Major cotton-producing countries in SAARC region

The cotton yarn market has expanded significantly, exhibiting a compound annual growth rate (CAGR) of 6.9%, increasing from \$73.46 billion in 2024 to a projected \$78.52 billion in 2025 (TBRC, 2024). The

leading cotton-producing countries include China, the United States, and India (Wright, 2020). India accounted for approximately 12.5% of global cotton exports during 2023-2024, supplying 5.6 million metric tons valued at \$6.5 billion (Filipenco, 2025). With an annual production of about 5,770 thousand metric tons, India ranks as the world's leading cotton producer (Wright, 2020). Moreover, contributing around 15% of global exports, India is the second-largest exporter of raw cotton (Nag, 2017). Its cotton production is projected to reach 7.2 million tons by 2030 (Mandi, 2024; Table 1).

Pakistan produced approximately 1.5 million metric tons of cotton in 2023-2024, with exports valued at \$3.1 billion (Filipenco, 2025). The genetically modified cotton sector employs about 1.7 million people and accounts for more than 95% of national production (Wright, 2020; Table 1). Globally, Bangladesh is the largest importer and the second-largest consumer of raw cotton (Mortuza, 2021). Domestic production in Bangladesh remains limited, at approximately 200,000 bales, only 2-3% of its annual demand of 8.5 million bales, making it the world's second-largest cotton importer (Table 1). With an investment of approximately \$15 billion in the textile sector, Bangladesh is also the fourth-largest cotton consumer (USDA-FAS, 2022). Cotton production in Bangladesh has improved due to the efforts of the Cotton Development Board (CDB). During 2020-2021, American upland cotton achieved a yield of 1,090 kg ha⁻¹ across 27,005 hectares. The CDB aims to increase yields to 1,400 kg ha⁻¹ by 2025 and 1,800 kg ha⁻¹ by 2030 through the adoption of improved seed varieties and advanced agronomic practices (Mortuza, 2021).

India recorded the highest cotton production from 2023 to 2025, exhibiting a relatively stable trend, whereas Pakistan showed significantly lower output with pronounced inter-annual variability. In contrast, Bangladesh's cotton production remained minimal and largely static over the same period.

Climate and soil favoring cotton cultivation

Cotton cultivation is favored by well-drained soils with good aeration and moderate fertility. Suitable soil types include alluvial, loamy, black, and red sandy loam soils, with optimum performance observed in sandy loam to sandy clay loam soils, particularly on medium to high land. Deep ploughing and thorough soil pulverization are essential, as cotton possesses a deep taproot system that penetrates extensively into the soil profile.

Land preparation typically involves two harrowings in opposite directions, followed by disc ploughing and chiseling at 0.5 m intervals to break hardpans (Sathya, 2022). The optimal soil pH ranges from 6.5 to 7.5; soil amendments such as lime are applied to raise low pH, whereas gypsum or elemental sulfur is used to reduce high pH (Sharma et al., 2014).

Cotton requires a minimum temperature of approximately

16°C for germination, while optimal vegetative growth occurs between 21°C and 27°C. Fruiting is best supported at temperatures ranging from 27°C to 32°C, particularly under relatively cooler night conditions. The crop is predominantly grown during the tropical monsoon season. Although moderately tolerant to salinity, cotton is highly sensitive to waterlogging, frost, and chilling stress (Ahmed et al., 2016).

Table 1. Cotton production, cultivated area, and average yield in India, Pakistan, and Bangladesh (2023-2025).

Country	Year (MY)	Production (Million Bales)	Area (Million Hectares)	Yield (kg/ha)
India	2023/24	25.7-32.50	12.38-12.68	436-441
	2024/25	24.5-30.20	11.2-11.5	454-464
	2025/26	24.5-34	11.2	463-467
Pakistan	2023/24	7-10.22	2-2.40	635
	2024/25	5-5.52	1.95-2.10	544
	2025/26	4.8	2	523-558
Bangladesh	2023/24	0.155	0.045	734
	2024/25	0.153	0.045	740
	2025/26	0.153	0.045	740

*MY = Marketing Years (Ahmed, 2025; Farooq, 2025; Sood, 2025).

Cotton varieties grown in SAARC nations

Cotton production in the SAARC region is predominantly based on *Gossypium hirsutum*. Traditional Asiatic cotton species, *G. arboreum* and *G. herbaceum*, are confined to specific regions and are gradually declining due to their relatively lower yield potential. *Gossypium barbadense* is cultivated on a limited scale owing to its superior fiber quality but comparatively lower productivity. The widespread adoption of Bt cotton hybrids has further reduced varietal diversity across the region.

India is unique in cultivating all four major cotton species: *G. arboreum* and *G. herbaceum* (Asiatic cotton), *G. barbadense* (Egyptian cotton), and *G. hirsutum* (American upland cotton) (Solanki, 2017). Both intraspecific (*G. hirsutum* × *G. hirsutum*) and interspecific (*G. hirsutum* × *G. barbadense*) hybrids are widely grown, whereas diploid hybrids (*G. herbaceum* × *G. arboreum*) have seen limited adoption due to constraints in seed production. Since 2002-2003, transgenic cotton has been extensively cultivated, initially with Bollgard I (Cry1Ac) and subsequently Bollgard II (Cry1Ac + Cry2Ab), predominantly in the form of *G. hirsutum* hybrids, now covering over 90% of the cotton-growing area (Narayanan et al., 2014). During 2020-21, 22 non-Bt and 69 Bt cotton varieties were identified for release across

diverse agro-climatic zones in India (ICAR, 2021).

In Pakistan, *G. arboreum*, derived from ancestral *G. herbaceum*, is cultivated alongside *G. hirsutum* (upland cotton). Approximately 70 or more varieties of *G. hirsutum* and around 12 varieties of *G. arboreum* are grown nationwide (Rahman et al., 2014). More than 30 approved Bt cotton varieties are currently under cultivation (ISAAA, 2009; Abdullah, 2010; ISAAA, 2015; Kashif et al., 2022). Popular Bt cotton varieties include MNH-886, FH-142, IUB-2013, and Cyto-178. Several cultivars, such as Cyto-533, CIM-537, and CIM-775, are recognized for their high yield potential and drought tolerance (ISAAA, 2021; Razzaq et al., 2021; Shahzad et al., 2022).

In Bangladesh, cotton has been cultivated since ancient times. Currently, two main species are grown: American upland cotton (*G. hirsutum*) and hill cotton (*G. arboreum*). American upland cotton is cultivated across 39-42 districts spanning multiple agro-ecological zones (AEZs 1, 2, 3, 4, 7, 8, 9, 11, 12, 13, 25, 26, 27, 28, and 29). The Cotton Development Board has released 18 high-yielding upland varieties (CB-1 to CB-17), three hill cotton varieties, including two high-yielding types, HC-1 and HC-2 (white and khaki, respectively), and one hybrid cotton variety (Islam and Uddin, 2014; Mortuza, 2021;

Akhteruzzaman and Islam, 2022; Tabib, 2023). Moreover, private seed companies have introduced hybrid varieties such as Rupali-1 and DM-1 (developed by Lalteer Seed Company) and Shuravi-1 (ACI) (Islam and Uddin, 2014). The CDB in Bangladesh has also released Bt cotton varieties JKCH 1947 Bt and JKCH 1050 Bt (Hossain, 2022). Furthermore, kapok (*Bombax* spp.), locally known as Simul tula, is widely cultivated in the greater Mymensingh region (Banglapedia, 2021).

Epidemiology and ecology of major insect pests of cotton in SAARC nations

Insect pests pose a major constraint to cotton production worldwide. Approximately 1,326 insect species have been reported globally in association with cotton. In addition, about 17 diseases affect cotton at the global level, although the number of major diseases varies by country; for instance, six have been reported in India, five in Pakistan, and four in Bangladesh. Of the total insect species recorded worldwide, about 130 occur in India. Among these, nearly a dozen species regularly reach economically damaging levels, necessitating effective management interventions. In Bangladesh, 29 pest species have been documented, including 28 insect species and one mite species; of these, 13 insect species are considered major pests due to their consistent and significant field damage, as presented in Table 2 (Ahmed et al., 2016).

These pests cause substantial yield losses and economic damage to cotton crops in the region (Naeem et al., 2020; Fu et al., 2022; Mohapatra and Sisodiya, 2022). The pest complex proliferates under temperatures ranging from 25°C to 35°C and relative humidity levels of 50% to 80%. Both sucking insect pests and bollworms pose serious threats to cotton production. Among the sucking pests, jassids and whiteflies are the most destructive. Thrips damage seedlings by rasping leaf tissues, resulting in a characteristic silvery appearance. Bollworms inflict severe internal damage to developing bolls, while whiteflies contribute significantly to economic losses through the transmission of viral diseases. Collectively, these pests impose considerable economic burdens on cotton farmers in India, Pakistan, and Bangladesh.

Major pathogens affecting cotton in SAARC countries

Cotton is susceptible to several destructive diseases, among which six are considered globally critical: bacterial blight, virulent strains of *Fusarium* and *Verticillium* wilts, Texas root rot, cotton leaf curl disease (CLCuD), and blue disease. In Bangladesh, a total of 13 diseases have been reported, with seedling blight, *Fusarium* wilt, bacterial

blight, and boll rot identified as the major constraints to production (Table 3) (Ahmed et al., 2016).

The epidemiology of cotton diseases varies from moisture-dependent to vector-mediated infection cycles. Fungal and bacterial pathogens primarily rely on hydrochory, requiring high humidity, rainfall splash, and soil moisture for the dispersal of inoculum from infected debris or seeds into host tissues, particularly the vascular system. In contrast, viral pathogens are transmitted by insect vectors, notably whiteflies. Fungi and bacteria proliferate under humid and wet conditions, whereas viral diseases tend to intensify under relatively dry conditions that favor vector multiplication and movement from alternate host reservoirs. Moreover, environmental stressors such as waterlogging, hailstorms, sandblasting, heat stress, and cold shock can predispose plants to infection and adversely affect early crop establishment.

Among these diseases, cotton leaf curl disease (CLCuD) is the most economically devastating due to its systemic nature and rapid spread via whitefly vectors. Bacterial blight ranks second, causing severe yield losses through defoliation and boll rot, particularly under rainy conditions. Although *Fusarium* and *Verticillium* wilts are highly destructive, their occurrence is often restricted to specific soil types and environmental conditions. Consequently, viral and bacterial diseases remain the primary drivers of widespread cotton crop losses in the SAARC region.

Pest and pathogen dynamics across SAARC climates

Cotton, a major commercial crop and a cornerstone of the textile industry, supports large rural populations and contributes substantially to foreign exchange earnings. Globally, approximately 1,326 insect species are associated with cotton, of which about 162 are considered economically important. Significant yield losses are primarily caused by bollworms, including *Helicoverpa armigera*, *Pectinophora gossypiella*, *Earias vittella*, and *Earias insulana* (Jat et al., 2013; Figure 1). In contrast, Over one hundred distinct pathologies have been documented in tropical cotton; however, a mere 10 to 12 of these are considered to be the principal diseases that limit yield. Among these, the prominent conditions include fusarium wilt (*Fusarium oxysporum* f. sp. *vasinfectum*), verticillium wilt (*Verticillium dahliae*), bacterial blight (*Xanthomonas citri* pv. *malvacearum*), and the root-rot complex (*Rhizoctonia solani* and *Macrophomina phaseolina*) (Cotton Disease Council, 2022; Figure 1).

Table 2. Major insect pests of cotton with signature symptoms, economic threshold and damage percentage at their congenial temperature and humidity.

Damaging stage of pest	ETL	% Damage	Pest Biology and Status	Symptoms	Temperature	Humidity
Nymph of Thrips (<i>Thrips tabaci</i>)	8-10 per leaf	30 to 50 %	Egg (3 - 5 days) - Nymph (7 - 10 days) -Adult (15 - 25 days). Persistent major at seedling phase (25-35 DAS)	Silver spots on lower surface of leaves	23-34°C.	70-90%.
Nymph of Aphids (<i>Aphis gossypii</i>)	10/leaf or on visible damage	30 to 40%	Asexual reproduction (3-10 nymphs/ day/ female) - Nymph (7-10 days) - adult (12-20 days). Non persistent major at early vegetative phase (20 DAS)	Curling and crinkling of leaves and stunted growth. Excrete honeydew which leads to the growth of sooty mould and contamination of the lint which inhibits photosynthesis and gives the plant a dark appearance.	28-30°C	> 80%
Nymph of Jassid (<i>Amrasca biguttula</i>)	1 adult/nymph per leaf	20 to 40% or upto 55%	Egg (4 – 10 days) – Nymph (7 – 21 days) –Adult (15 – 20 days). Persistent major at seedling (15-20 DAS) to early flowering stage (45-75 DAS)	Yellow blotches, downward curling and reddening/bronzing of the leaf edges and tips (turning brick red in severe cases) which leads to brittleness, premature leaf drop, and stunted growth	25-34°C	76.6%
Nymph of Whitefly (<i>Bemisia tabaci</i>)	5 adult/nymph per leaf	Upto 50% in severe infestation	Egg (3 – 5 days) – Nymph (9 – 14 days) -Adult (10 – 20 days). Persistent major at vegetative phase (30-45 DAS)	Chlorotic spots on the leaves due to sap sucking. Leaves become reddish and brittle, and they may curl upward. Transmit Cotton Leaf Curl Virus (CLCV).	28-38°C	80 to 90 %
Larvae of Spotted bollworm (<i>Earias vitella</i>)	3 larvae/plant	20 % yield loss but can cause upto 50% damage in susceptible varieties	Egg (3-4 Days) - Larva (10-14 Days)-Pupa (7-10 Days)-Adult (8-12 Days). Major at pre flowering (30 DAS) to boll formation phase (65-80 DAS)	Clear-cut, circular bore hole in the bolls accompanied by granular faecal pellets near the bore hole. Larvae feed inside the squares, flowers, and bolls and form a characteristic "rosette flower" or "double flower".	20-30°C	60-80%
Larvae of Pink bollworm (<i>Pectinophora gossypiella</i>)	Damage to 5% of boll or presence of larvae	20 to 90% loss of yield and 48% damage of green bolls	Egg (4-5 Days) - Larva (15-20 Days)-Pupa (7-10 Days)-Adult (10-15 Days). Major at flowering to boll formation phase (50 DAS)			60-80%
Larvae of American bollworm (<i>Helicoverpa armigera</i>)	5 brown eggs or 3 larvae per plant	10 to 70%	Egg (3-5 Days) - Larva (15-25 Days)-Pupa (10-15 Days)-Adult (10-12 Days). Major at flowering and fruiting stage (from 60 DAS onwards)			50–70%

*DAS = Days after seeding (Chaudhari et al., 1999; Parajulee, 2007; El-Wakeil and Abdallah, 2012; Gopalakrishnan et al., 2012; Ahmed et al., 2016; Safdar, 2018; Murtaza et al., 2019; Patel, 2020; Chandi et al. 2021).

Table 3. Major diseases of cotton with signature symptoms and damage percentage at their congenial temperature and humidity.

Diseases	Pathogen Status	Damage Percentage	Symptoms	Temperature	Humidity
Fusarium wilt (<i>Fusarium oxysporum</i> f. sp. <i>Vasinfestum</i>)	Major, systemic, facultative saprophyte (Necrotroph)	35-60% at seedling phase (40-50 DAS)	Cotyledons with dark veins, chlorosis, and necrosis.	20-30°C	>85%
Verticillium wilt (<i>Verticillium albo-atrum</i>)	Major, systemic, facultative saprophyte (Necrotroph)	Upto 75% damage at flowering and boll-fill stages (80 DAS)	Infected plants show drooping, yellowing, Interveneal chlorosis tiger-striped leaves, stunting, and vascular discoloration	15-20°C	70-80%
Alternaria leaf spot (<i>Alternaria macrospora</i>)	Major, localized, foliar pathogen, facultative saprophyte (Necrotroph)	30 to 50 % damage at flowering and boll formation stages (75 DAS)	Leaves develop brown spots with concentric rings, later turning gray and “shot-holed,” leading to blighting and defoliation.	25-28°C	80-90%
Boll rot (<i>Colletotrichum gossypii</i>)	Major, systemic and localized, facultative saprophyte (Hemibiotroph)	20-30% damage at flowering and boll-fill stage (35 DAS)	Small brown or black dots on bolls enlarge, rotting seeds and lint.	25-30%	>90%
Bacterial blight of cotton (<i>Xanthomonas campestris</i> pv. <i>Malvaearum</i>)	Major, systemic and localized, facultative saprophyte (Necroph)	Upto 60% damage at seedling stage (40-80 DAS)	Small water-soaked lesions on cotyledons, spreading to stem via petiole, causing seedling withering and death.	15-35°C	>85%
Cotton leaf curl disease (CLCuD) (<i>Cotton Leaf Curl Virus</i>)	Major, systemic, obligate	Damage 60% at seedling stage up to the early flowering/boll setting stage (around 40-80	Affected cotton shows thickened, dark veins (SVT) with leaf curling. Some leaves develop enations, and plants remain stunted with reduced internodal length.	25-30°C	70-80%

*DAS = Days after seeding (Kemerait and Price, 2011; Kemerait et al., 2017; Arunkumar et al., 2021; Sain et al., 2023a).

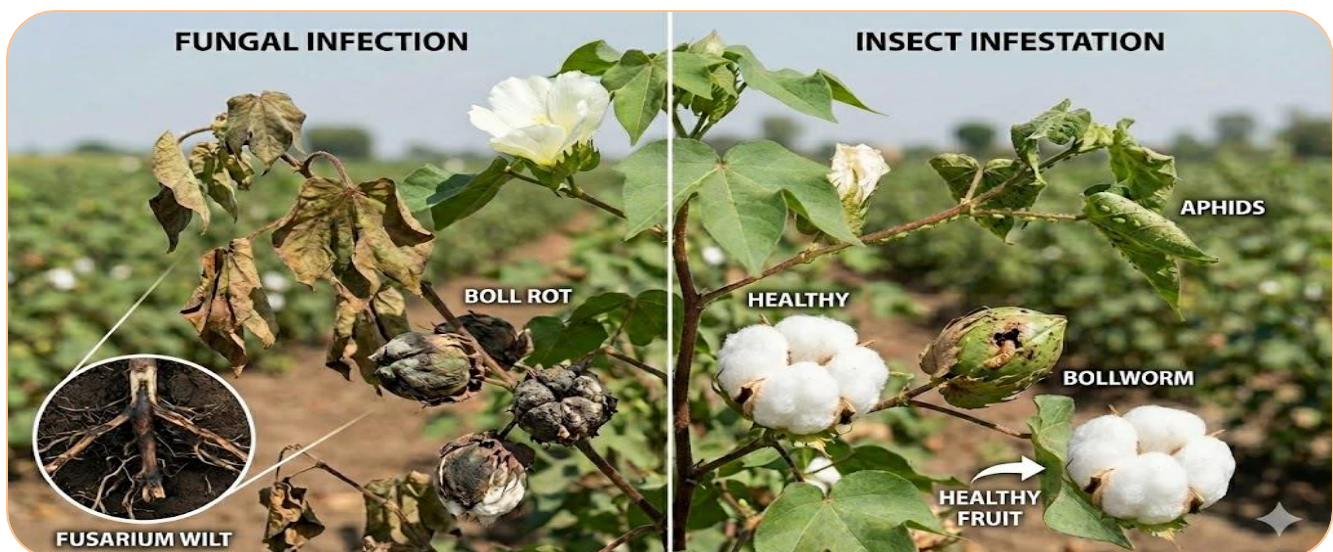


Figure 1. Major pest and disease infestation in cotton under changing climatic conditions.

Regional variation in pest and pathogen distribution

Cotton is cultivated across diverse agro-climatic zones in SAARC countries, resulting in considerable spatial variability in pest and pathogen assemblages. In India, cotton is grown in the North, Central, and South zones (Ahmed et al., 2016), where approximately 166 insect species have been recorded (Dhawan et al., 2009). Major insect pests include termites (*Microtermes obesi*, *Odontotermes obesus*), jassids (*Amrasca biguttula biguttula*), whiteflies (*Bemisia tabaci*), mealybugs (*Phenacoccus solenopsis*), spotted bollworms (*Earias insulana*, *Earias vittella*), pink bollworm (*Pectinophora gossypiella*), American bollworm (*Helicoverpa armigera*), tobacco caterpillar (*Spodoptera litura*), and red cotton bug (*Dysdercus cingulatus*).

Pest incidence and severity vary markedly among regions due to differences in climatic conditions and agronomic practices. For instance, *Thrips tabaci* often causes moderate to severe damage in Central India, whereas in the South zone, stem weevil (*Pempherulus affinis*), *Spodoptera litura*, and *Scirtothrips dorsalis* are predominant. Outbreaks of *Helicoverpa armigera* have been reported across multiple states, including Maharashtra, Gujarat, Andhra Pradesh, Punjab, Haryana, Rajasthan, and Madhya Pradesh. Similarly, *Spodoptera* outbreaks are common in Gujarat, Maharashtra, and Andhra Pradesh, while whitefly infestations have intensified across northern, central, and southern cotton-growing regions (Dhawan, 2016).

In Pakistan, major insect pests include termites, cutworms, thrips, jassids, whiteflies, aphids, leaf-rollers, red cotton bugs, mites, grey weevils, and various bollworms (Ahmed et al., 2016). These pests significantly reduce lint quality and can cause yield losses ranging from 10% to 40%. Recently, the mealybug (*Phenacoccus solenopsis*) has emerged as a serious and polyphagous pest. Major diseases include bacterial blight caused by *Xanthomonas campestris* pv. *malvacearum*, boll rot caused by multiple pathogens, and root rot caused by *Rhizoctonia solani*. Minor diseases comprise seedling rot, anthracnose (*Colletotrichum* spp.), stunting of unknown etiology, cotton leaf curl virus (transmitted by whiteflies), and several foliar diseases such as *Alternaria*, *Cercospora*, and *Myrothecium* leaf spots, as well as *Choanephora* wet rot and nematode-associated disorders (CCRI, 2016).

In Bangladesh, more than 20 insect pests have been reported on cotton, with major species including spotted

bollworm (*Earias vittella*) and American bollworm (*Helicoverpa armigera*). Other pests include pink bollworm, spiny bollworm, cotton jassid, and aphids. Important diseases include Fusarium wilt, bacterial blight, angular leaf spot, damping-off, leaf spots, and anthracnose; however, disease incidence is generally lower than in other cotton-producing countries (Banglapedia, 2021).

In the dry and semi-arid regions of Pakistan and northwestern India, elevated thermal regimes increase whitefly voltinism, making these areas hotspots for Cotton Leaf Curl Virus (CLCuV) epidemics. In contrast, humid tropical regions such as Bangladesh and southern India, characterized by high rainfall and relative humidity, favor moisture-dependent diseases such as bacterial blight and facilitate early-season infestations of sucking pests like jassids. A major regional concern is the widespread breakdown of Bt resistance in pink bollworm populations, driven in part by altered monsoon patterns that extend the cropping season and provide continuous host availability. Overall, pest dynamics in the SAARC region are shifting from dominance by chewing insects to more complex systems involving vector-borne pathogens and moisture-sensitive disease complexes.

Effects of climate change on cotton pests and disease outbreaks

Climate change is exerting a profound influence on cotton agroecosystems by altering pest and pathogen dynamics. Rising temperatures, shifting precipitation patterns, and elevated atmospheric CO₂ concentrations affect pest development, survival, fecundity, and geographic distribution. These changes have led to increased frequency, intensity, and geographic spread of pest infestations, while simultaneously enhancing the emergence, transmission, and severity of plant diseases (Rehman et al., 2020; Iqbal et al., 2022; Tiwari, 2022; Das et al., 2023; Pramanik et al., 2023).

Current integrated pest and disease management (IPDM) approaches

Integrated pest and disease management (IPDM) in cotton prioritizes prevention, regular monitoring, and judicious intervention through the use of resistant cultivars, improved cultural practices, and biological control agents. This approach aims to reduce reliance on chemical pesticides, lower production costs, safeguard environmental health, and ensure sustainable pest suppression. Effective IPDM relies on maintaining crop

vigor, continuous surveillance of pest and beneficial insect populations, application of economic threshold levels, and the selective use of pesticides only when necessary.

Chemical control strategies and their effectiveness

Cotton production is significantly constrained by insect pests

and a range of diseases, with global yield losses reaching up to 60%. Consequently, farmers often depend on chemical pesticides as a primary control strategy (Table 4). Since the mid-20th century, particularly after World War II, pesticides have been extensively used in agriculture due to their rapid effectiveness in pest suppression and yield enhancement.

Table 4. Agrochemicals commonly used to control cotton diseases.

Disease name	Pathogen	Chemical control measure
Fungal diseases		
Fusarium wilt (Any stage of crop growth)	<i>Fusarium oxysporum f. sp. Vasinfectum</i>	Treating seed with Thiram 75% WS 2g/kg seed Or Apply Chlorothalonil @ 4 g/kg to acid-delinted seeds. For spot treatment, use Carbendazim 50% WP at 1 gm/L of water
Boll rot	<i>Ascochyta gossypii</i> , <i>Colletotrichum gossypii</i> <i>Fusarium spp.</i> , <i>Diplodia gossypina</i> <i>Phytophthora spp.</i> , <i>Rhizoctonia solani</i>	Spray Carbendazim 50%WP 2 g/L water
Verticillium wilt	<i>Verticillium albo-atrum</i>	Spray Mancozeb 75% WP @ 2 – 2.5 gm/lit water or soil application of Metalaxyl 4% + Mancozeb 64% @ 1 – 1.5 gm/lit water
Anthraxnose	<i>Colletotrichum gossypii (anamorph)</i> . <i>Glomerella gossypii</i>	Drench with Carbendazim 12 % + Mancozeb 63 % WP @ 1.8 – 2.5 gm/lit water
Root rot	<i>Rhizoctonia solani</i>	Spot drench with 0.1% Carbendazim
Bacteria diseases		
Bacterial blight of cotton	<i>Xanthomonas campestris pv. malvacearum</i>	Foliar application of Cupravit 50 WP (0.2%), Indofil M-45 (0.2%), and Streptomycin sulphate (150 ppm) either individually or in combination
Nematodal diseases		
Root-knot nematode	<i>Meloidogyne incognita</i>	Seed treatment with Tioxazafen (Nemastrike) and fumigation with 1,3-Dichloropropene
Viral diseases		
Leaf curl	<i>Cotton leaf curl virus (CLCuV)</i>	For early vector control treat seeds with Hombre Excel 372.5 FS (Imidacloprid + Tebuconazole) at 10 ml/kg, providing protection for up to 60 days
Insect	Chemical control measure	
	Chemical insecticide	Classes of insecticide
Thrips (<i>Thrips tabaci</i>)	Imidacloprid, Spinosad, Spirotetramat, Chlorfenapyr, Acephate, Lambda-cyhalothrin, Acetamiprid, Abamectin	Neonicotinoids, Spinosyns, Tetramic Acid Derivatives, Pyrroles, Organophosphates, Pyrethroids, Avermectins
Aphids (<i>Aphis gossypii</i>)	Clothianidin, Diafenthiuron, Thiamethoxam, Imidacloprid, Acetamiprid, Flonicamid, Pymetrozine, Buprofezin	Neonicotinoids, Thioureas, Pyridine Azomethines, Neonicotinoids, Diamides/Pyridine Azomethines, Insect Growth Regulators (IGR)
Jassid (<i>Amrasca biguttula</i>)	Imidacloprid, Thiamethoxam, Acetamiprid, Dinotefuran, Flonicamid, Pymetrozine, Fipronil	Neonicotinoids, Pyridine Azomethines, Phenylpyrazoles
Whitefly (<i>Bemisia tabaci</i>)	Buprofezin (for nymphs), Acetamiprid (for adults), Diafenthiuron, Imidacloprid, Thiamethoxam, Lambda-cyhalothrin, Pyriproxyfen, Cyantraniliprole	Insect Growth Regulators (IGR), Neonicotinoids, Thioureas, Pyrethroids, Juvenile Hormone Mimics, Diamides
Bollworm (<i>Earias vitelli</i> , <i>Pectinophora gossypiella</i> , <i>Helicoverpa armigera</i>)	Emamectin Benzoate, Spinosad, Abamectin, Indoxacarb, Chlorantraniliprole, Flubendiamide, Pyrethroids (e.g., Cypermethrin, Deltamethrin)	Avermectins, Spinosyns, Oxadiazines, Diamides, Pyrethroids

(Sarker, 2013; Faske, 2021; Rubayet, 2021; Khan and Riaz, 2022; Deepika, 2023).

However, intensive and indiscriminate pesticide use in cotton has led to a “pesticide treadmill,” characterized by diminishing returns and the rapid evolution of pest resistance. Systemic insecticides such as imidacloprid, acetamiprid, and fipronil are widely used against sucking pests, yet their efficacy is increasingly compromised by resistant populations of whiteflies. Similarly, broad-spectrum insecticides, including cypermethrin, deltamethrin, and chlorpyrifos, often disrupt natural enemy complexes, leading to secondary pest outbreaks. In addition, contact insecticides such as profenofos are ineffective against endophytic or concealed larval stages within cotton bolls.

As a result, countries in the SAARC region are progressively transitioning from unsustainable, pesticide-intensive practices toward Integrated Resistance Management (IRM), which emphasizes resistance mitigation, ecological balance, and the long-term sustainability of pest control strategies.

Biological control agents and their role in pest suppression

Biological control is an ecologically based approach to pest suppression that utilizes living organisms, predators, parasitoids, and entomopathogens, along with biostimulants to reduce pest populations to economically acceptable thresholds (Table 5). In cotton agroecosystems, biological control operates as a multi-trophic system in which these agents employ distinct yet complementary mechanisms to regulate pest densities.

Predators such as *Chrysoperla carnea* (green lacewing) and *Coccinella septempunctata* (ladybird beetle) are voracious, mandibulate feeders that rapidly suppress populations of aphids and whiteflies across multiple life stages. Parasitoids, including *Trichogramma* spp. (egg parasitoids) and *Encarsia formosa* (nymphal parasitoid), oviposit within or on host insects; subsequent larval development leads to host mortality. Entomopathogens such as *Beauveria bassiana* and *Bacillus thuringiensis* (Bt) infect and kill pests through diverse modes of action, including cuticular penetration, toxin production, septicemia, and gut paralysis following ingestion.

In addition, induced systemic resistance (ISR) enhances plant defense capacity by modulating secondary metabolite pathways, thereby reducing herbivory. Biostimulants, including humic substances and plant growth-promoting rhizobacteria (PGPR), contribute indirectly to pest suppression by strengthening plant

resilience. Overall, predators and parasitoids are most effective for rapid, real-time population suppression in the field, whereas entomopathogens provide a robust and environmentally compatible alternative to chemical control, particularly under high-humidity conditions favorable for pathogen activity.

Biological control also encompasses the use of biopesticides and botanical extracts as integral components of sustainable pest management. These agents are generally effective against a wide range of pests, exhibit low toxicity to non-target organisms, and are readily incorporated into integrated pest management (IPM) programs (Lengai et al., 2019). Biopesticides are derived from natural sources, including microorganisms (bacteria, fungi, viruses), plants, and certain minerals (Hegde and Vijaykumar, 2022; Mawcha et al., 2024; Tyagi et al., 2024), and are broadly classified into microbial, biochemical, and plant-incorporated protectants. Their mechanisms of action include toxin production, pathogen-mediated mortality, enhancement of plant immunity, and competitive exclusion of harmful organisms.

Botanical pesticides, derived from plant materials or extracts, represent another important category. Common examples include neem, pyrethrum, and eucalyptus oil, which act through multiple mechanisms such as direct toxicity, repellency, antifeedant effects, and disruption of pest growth and reproduction (Lengai et al., 2019). Together, these biologically derived inputs offer environmentally sound and sustainable alternatives for pest management within modern agricultural systems.

Cultural practices for reducing pest and disease incidence

In cotton cultivation, where pest and disease pressure, particularly from bollworms, whiteflies, and viral diseases such as CLCuV, is high, cultural practices constitute a fundamental component of IPM (Table 6). These strategies involve the systematic manipulation of agronomic practices and the crop environment to disrupt pest and pathogen survival, reproduction, and spread, while promoting the development of a vigorous and resilient crop capable of tolerating or escaping damage. Adoption of practices such as crop rotation, field sanitation, and optimal planting time and density can significantly reduce reliance on chemical control, thereby enhancing sustainability, lowering production costs, and minimizing environmental risks.

Table 5. Commonly used bioagents (parasitoids, predators and entomopathogens) of cotton insect pests.

Biocontrol using parasitoids				
Parasitoids	Type	Pest as Host	Parasitization	Period of activity
<i>Trichogramma spp.</i>	Egg	Pink bollworm (<i>Pectinophora gossypiella</i>), American bollworm (<i>Helicoverpa armigera</i>), spotted bollworm (<i>Erias spp.</i>)	48-73 %	September-October
<i>Bracon spp.</i>	Larva	Boll weevil	40 to 60%	September-November
Biocontrol using predators				
Predators		Pest as prey	Pest stage attacked	Period of Activity
<i>Chrysoperla carnea</i>		Aphid (<i>Aphis gossypii</i>)	Nymph	Throughout the season
<i>Scymnus nubilis</i> , <i>Ceolophora bissellata</i> , <i>Pullus xeramphelinus</i> , <i>Sphaerophoria javana</i> , <i>Ischiodon scutellaris</i>			Nymph	Throughout the season
<i>Chrysoperla cymbela</i> , <i>Geocoris bicolor</i> , <i>Orius sp.</i> , <i>Mallada boninensis</i> ,			Egg, Nymph	Throughout the season
<i>Encarsia sp</i> , <i>Brumus saturalis</i> , <i>Cheilomenes sexmaculatus</i>			Nymph	Throughout the season
<i>Geocoris Ochropterus</i>		<i>Pectinophora gossypiella</i>	Egg, larva, imago	Throughout the season
Biocontrol using entomopathogens				
Entomopathogens		Pest	Pest stage attacked	
<i>Nomuraea rileyi</i>		American bollworm	Larva	
<i>Aspergillus spp.</i>		Whitefly	Nymph	
<i>Bacillus thuringiensis</i>		Bollworms	Larva	
<i>Beauveria bassiana</i>		Bollworms	Larva	
NPV (Nuclear Polyhedrosis Virus)		<i>Helicoverpa armigera</i> and <i>Spodoptera spp.</i>	Larva	
Nematodes		Bollworm	Larva	
<i>Steinernema siamkayai</i> , <i>S. carpocapsa</i>		<i>S. litura</i>	Larva	
Biocontrol using biostimulants				
Biostimulants		Pathogens	Disease	
<i>Trichoderma harzianum</i> (Th)		<i>Fusarium oxysporum</i> , <i>Rhizoctonia solani</i>	Fusarium wilt, Rhizoctonia induced damping-off	
<i>Pseudomonas fluorescens</i> (Ps)		<i>Pythium spp.</i> , <i>Fusarium spp.</i> , <i>Verticillium dahliae</i>	Pythium root rot, Fusarium wilt, Verticillium wilt	
Arbuscular Mycorrhizal Fungi (AMF)		<i>Verticillium dahliae</i> , <i>Fusarium oxysporum</i>	Verticillium wilt, Fusarium wilt	

(Vennila et al., 2007; Malaquias et al., 2011; Dhawan, 2016; Dhawan et al., 2009; Burana et al., 2022; Eroglu, 2022; Kumara et al., 2022; Kumawat and Meena, 2023; Sain et al., 2023b; Vaishnavi, 2024).

Table 6. Cultural practices for pest and disease management in cotton.

Cultural practices	Target pest	Mode of action
Weeding	Mealy bug, Whitefly and CLCuV	Minimizes residual pest population.
Soil sterilization by deep ploughing for sun exposure before sowing and after harvest	American bollworm, tobacco caterpillar	Birds and other factors feed on pupa of the insects and increase pupal mortality.
Maintenance of proper spacing and optimum plant population	Sucking pest, bollworms and foliage feeders	Reduces pest infestations
Growing barrier crops e.g. maize, sorghum	Mealy bug	Acts as a physical barrier for crops.
Growing non Bt around Bt cotton field	Bollworm complex	Delays resistance development process in insect against Bt technology.
Early harvesting	Bollworms	Reduces the spread of pests.
Removal of infested terminal shoots	Spotted bollworm	Reduces infestation.
Avoid cotton as a ratoon crop	Pink bollworms	Reduces carryover.
Judicious use of nitrogen fertilizer	Jassids, whitefly and bollworms	Overdose increases diseases incidence.
Avoid discarding uprooted infested weeds in cotton fields, irrigation channels, or public areas.	Mealy bug	Check further infestation.
Crop rotation	Grey mildew	Break pest and disease cycle.
Drainage	Verticillium wilt	Reduces disease incidence.

(Dhawan, 2016; Mohan et al., 2014).

Use of trap crops and companion planting

Trap cropping involves the strategic use of plants that are highly attractive to specific insect pests, thereby diverting them from the main crop. In cotton-based systems, field pea and grain sorghum can function as effective trap crops by attracting *Helicoverpa* spp., thus reducing pest pressure on cotton (Tillman and Mullinix, 2004). Similarly, small onion has been reported to attract thrips and can be utilized as a trap crop (Amutha et al., 2022). Companion planting further enhances pest management; for example, marigold is widely used in cotton fields to attract beneficial insects and repel certain pests (Amutha et al., 2022; Azcarraga, 2025). In addition, aromatic plants such as basil, cilantro, mint, dill, and sage contribute to natural pest deterrence through the release of volatile compounds (Devenish, 2022).

Resistant cotton varieties and their performance

Resistant cotton varieties are developed to withstand major biotic and abiotic stresses, including insect pests (e.g., bollworms), diseases (e.g., *Fusarium* wilt), and environmental constraints such as drought (Table 7). These varieties incorporate inherent genetic resistance or engineered traits. For instance, Bt cotton expresses

insecticidal proteins derived from *B. thuringiensis*, providing effective control against key lepidopteran pests. Moreover, conventional and modern breeding approaches have produced varieties with enhanced resistance to diseases and improved tolerance to environmental stresses, thereby contributing to stable yield and sustainable cotton production.

Adoption of IPDM practices in SAARC nations

The adoption of IPDM across SAARC countries remains limited. Although some farmers demonstrate moderate to high uptake, large-scale implementation is constrained by inadequate technical knowledge, limited access to quality inputs and extension services, and insufficient capacity-building initiatives (Shrestha et al., 2024). Nevertheless, the increasing incidence of pest resistance and rising production costs are stimulating renewed interest in IPDM-based approaches.

Challenges in cotton pest and disease management

Cotton production in the SAARC region is increasingly challenged by a complex biosecurity and policy landscape. Porous borders and reduced intra-regional trade hinder coordinated efforts to manage transboundary pest outbreaks. Pest dynamics have shifted from simple infestations to broader ecological

imbalances. The widespread cultivation of Bt cotton, coupled with poor compliance with refuge strategies (i.e., planting non-Bt crops), has contributed to the resurgence of secondary pests such as the pink bollworm, which has developed substantial resistance.

In addition, regulatory frameworks have not kept pace with emerging challenges. Despite the prevalence of high-voltinism pests, the approval and deployment of biopesticides and advanced technologies such as CRISPR-based solutions remain constrained by outdated regulations that impose similar requirements on biological and synthetic products. Consequently, pest management has transitioned from an “insecticide treadmill” to a broader technological treadmill. Rapid

evolution of pathogens such as CLCuV, along with the emergence of climate-resilient vectors, continues to outpace the development of new control strategies, forcing farmers into a cycle of increasing input use merely to sustain, rather than enhance, productivity.

Pesticide resistance development in major pests

The development of pesticide resistance in major cotton pests is driven by several interrelated factors, including excessive and indiscriminate use of chemical pesticides, limited adoption of integrated pest management practices, and inadequate resistance monitoring systems (Table 8). Monoculture cropping systems and the inherent genetic adaptability of pest populations further accelerate the evolution of resistance.

Table 7. Current status of resistant cotton varieties against pest and pathogens with their KPI (key performance indicators).

Varieties	Performance of resistant varieties
India	
LRA 5166, Shresth (CSHH 198), Kalyan (CSHH), Simran (CSHH)	Variety shows resistance against CLCuV.
Anjali (LRK 516), KIRAN (CNH 36), CCH 2623, Suchitra, CICR-H Cotton 47 (CNH 1111), CICR-H Cotton 48 (CNH 1128), CAN 1028	Tolerant to jassids.
ICAR-CICR PKV 081 Bt, ICAR-CICR Rajat Bt, ICAR-CICR Suraj Bt, ICAR-CICR GJHV-374 Bt, ICAR-CICR 23 Bt,	The presence of the cry1Ac gene provides resistance against <i>Helicoverpa armigera</i> and major diseases. Certain varieties also exhibit resistance to drought conditions.
Pakistan	
Badar-3(C-II), YBG-2222(C-II), Rustam-Beej-11(C-II), TJ-king (C-II), Suncrop (C-II), Tahafuz-12 (C-II), Weal-AG-201(C-II), Diamond - 2	Contains <i>Cry1Ac</i> + <i>Cry2A</i> gene and resistant to bollworms.
Tahafuz-2, Suncrop-3, Half-3(CKC), Ghauri-2(CKC), CEMD-Klean-Cotton-3, CEMD-Klean-Cotton-4, CEMD-Klean-Cotton-5, CEMD-Klean-Cotton-6, Sahara-Klean-5	Have <i>Cry1Ac+Cry2A+GTG</i> genes and tolerant to bollworms.
Bangladesh	
CDB Tula 1	High-yielding, drought-tolerant, disease-resistant variety
CB-5 and CB-9	These varieties have some tolerance to jassids
CB-13	Resistant to chewing insects like bollworm and Spodoptera
CB-14	Resistant to diseases, and Jassids and aphids.
CB-18	This newly evolved variety is moderately tolerant to Jassid
JKCH 1947 Bt	Resistant to Lepidopteran pests and antibiotics and bollworms
JKCH 105 Bt	Resistant to bollworms

(Mondol, 2008; IAEA, 2021; Faruque, 2021; Murtaza, 2021; Akhteruzzaman and Islam, 2022; Hossain, 2022; Shahzad et al., 2022; Manickam and Sabesh, 2023; CDB, 2025).

Table 8. Current scenario of pesticide resistance of some major cotton pests.

Pest	Resistant to synthetic insecticides
<i>Helicoverpa armigera</i>	This pest has shown resistance to various insecticides like triazophos, cypermethrin, and fenvalerate.
<i>Spodoptera litura</i>	This species has developed resistance to endosulfan, cypermethrin, fenvalerate, and monocrotophos.
<i>Pectinophora gossypiella</i>	High levels of resistance to endosulfan have been observed in some regions, and pyrethroids have also seen reduced efficacy.
<i>Bemisia tabaci</i>	This pest has been moderate to high resistant to cypermethrin.

(Foreign, 2002; Radhika and Subbaratnam, 2006; Nagaraj et al., 2024).

Limited access to biological control agents and IPM technologies

In many SAARC countries, inadequate availability of biological control agents and low adoption of IPM compel cotton farmers to depend heavily on synthetic pesticides. This overreliance accelerates the development of pest resistance and disrupts natural enemy-mediated pest regulation. Furthermore, biological control is inherently a gradual process that requires sound technical knowledge for effective implementation. However, limited training opportunities and insufficient farmer capacity-building programs constrain its practical application and wider adoption.

Policy and institutional constraints in pest management implementation

Policy and institutional limitations significantly impede the implementation of sustainable cotton pest management strategies. Preferential policies supporting synthetic pesticide use, inadequate dissemination of IPM knowledge, weak agricultural extension systems, and poor coordination among relevant institutions collectively restrict the adoption and scaling of science-based pest management approaches (Togbé et al., 2012).

Advances in cotton protection technologies

Bt cotton and genetically modified (GM) varieties in SAARC countries

Bt cotton cultivation was introduced in India in 2002 and in Pakistan in 2005. In Bangladesh, after extensive multi-year field evaluations, Bt cotton cultivation was officially initiated in 2022 with the objective of enhancing productivity and reducing dependency on cotton imports (Economy, 2023). India predominantly cultivates Bollgard I and Bollgard II technologies. MECH 162 Bt, MECH 184 Bt, and MECH 12 Bt were among the first Bt cotton varieties approved in India, developed by MAHYCO using transgenic events from Monsanto, USA (Shah, 2012). In Pakistan, FH-142, IUB-13, BS-15, and FH-Lalazar are

widely cultivated Bt cotton varieties (Shahzad et al., 2024). In Bangladesh, JKCH 1947 Bt and JKCH 1050 Bt are the officially released Bt cotton varieties.

Nanotechnology and precision pest management

Recent advances in cotton pest management include the application of nanotechnology-based pesticides. Nanopesticides such as silica nanoparticles (SiO_2) have been reported to suppress pests like thrips by forming a physical barrier on plant surfaces and enhancing plant defense responses. Metal-based nanoparticles, including silver, iron oxide, and zinc oxide, have shown significant efficacy against sucking pests such as thrips and whiteflies. Botanical nanoformulations derived from plant extracts, particularly neem, provide an environmentally friendly alternative for pest control. In addition, nano-chitosan enhances the stability, bioavailability, and efficacy of insecticidal nanoemulsions, effectively targeting pests such as the Egyptian cotton leafworm (*Spodoptera littoralis*) (Darwesh et al., 2024; Jayapradha et al., 2025; Luneja and Mkindi, 2025).

Role of artificial intelligence (AI) and remote sensing in pest detection

Cotton pest and disease monitoring increasingly relies on image-based data acquisition from field sources and online databases to evaluate crop health and pest incidence. These datasets are pre-processed and cleaned to ensure high-quality inputs for analytical modeling. Extracted data are then used to generate predictive understandings for improved pest management strategies in cotton. Machine learning and artificial intelligence approaches such as Naïve Bayes (NB), K-Nearest Neighbors (KNN), Decision Trees (DT), Random Forest (RF), Stochastic Gradient Descent (SGD), Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Logistic Regression (LR) are commonly employed for classification and prediction tasks in crop protection (Kurra and Rajkumar, 2022).

RNA interference (RNAi) technology in pest and disease management

RNA interference (RNAi) represents a highly specific and environmentally sustainable approach for managing cotton pests and diseases by silencing essential genes in target organisms. Techniques such as Host-Induced Gene Silencing (HIGS) and Spray-Induced Gene Silencing (SIGS) deliver double-stranded RNA (dsRNA) into pests or pathogens. These molecules are processed into small interfering RNAs (siRNAs), which bind to complementary messenger RNA (mRNA), thereby inhibiting the synthesis of vital proteins and ultimately suppressing pest development or disease progression (Agarwal et al., 2011; Saxena et al., 2021; Halder et al., 2022; Zhan et al., 2025).

Policy interventions and research gaps

Governmental policies on pest and disease management

Governmental policies across SAARC nations regarding cotton pest and disease management generally emphasize IPM approaches, aiming to reduce dependence on chemical pesticides and promote sustainable pest control practices. Several countries in the region are also participating in “Seeds Without Borders” initiatives to facilitate the exchange of improved cotton germplasm and varieties, thereby enhancing regional crop productivity and resilience (Khoury and Makkouk, 2010; Gurung and Azad, 2013; Gauchan and Joshi, 2019).

Research and development initiatives in SAARC nations

The SAARC Agriculture Centre (SAC) has conducted regional consultations, training programs, and workshops to strengthen collaboration and knowledge sharing among member countries in cotton research and development (Ahmed et al., 2016). In parallel, the International Institute for Sustainable Development (IISD) has supported the implementation of voluntary sustainability standards in the cotton sectors of Bangladesh, India, Pakistan, and Sri Lanka (Voora et al., 2023). These initiatives collectively aim to facilitate the exchange of knowledge, technologies, and best practices to improve cotton production, processing, and sustainability across the region (Ahmed et al., 2016).

Need for regional collaboration in cotton protection

Regional collaboration in cotton protection within SAARC countries is essential for efficient resource utilization, coordinated research efforts, and effective management of transboundary pest and disease threats. Institutions such as the SAARC Agriculture Centre and the SAARC Seed

Bank play a critical role in promoting joint breeding programs, pest surveillance systems, and seed exchange networks, thereby accelerating innovation and enhancing crop resilience. Furthermore, harmonization of policies related to pesticide regulation, seed certification, and sustainability standards can strengthen regional trade and support environmentally sustainable cotton production systems. Strengthening these collaborative frameworks is therefore vital for improving productivity, pest management efficiency, and long-term sustainability in South Asian cotton systems (CUTSI, 2013; Voora et al., 2023; Asif et al., 2024).

Conclusion and future prospects

Summary of key findings

Cotton remains a cornerstone of economies, livelihoods, and agro-industries across the SAARC region; however, its production is persistently challenged by insect pests, diseases, and climatic variability. Excessive reliance on chemical pesticides has contributed to resistance development, environmental degradation, and ecological imbalance. Although sustainable alternatives such as IPM, IPDM, and resistant varieties are available, their adoption remains limited. Strengthening farmer capacity, promoting regional cooperation, and tailoring management strategies to local agro-ecological conditions are critical for ensuring resilient and sustainable cotton production systems in the future.

Recommendations for sustainable cotton protection

To enhance sustainable cotton protection in South Asia, greater emphasis should be placed on the adoption of Voluntary Sustainability Standards (VSS), improved farmer training programs, and the development of robust traceability systems. Policymakers need to update regulatory frameworks and actively promote regional collaboration to support sustainable cotton value chains (Voora et al., 2023; Dristy et al., 2024). Modern precision agriculture technologies can significantly improve input efficiency and sustainability. Tools such as GPS, GIS, and remote sensing facilitate precise crop management, while transgenic cotton varieties reduce pesticide dependency, and unmanned aerial vehicles (UAVs) enable targeted application of fertilizers and pesticides. Integrated approaches such as IPM, integrated weed management (IWM), and integrated nutrient management (INM) help reduce production costs and environmental emissions, while mechanization further enhances productivity and contributes to global fiber

and oil security (Ghaffar et al., 2020).

For soil health management, crop rotation involving legumes, forage, or cereal crops (e.g., alfalfa and wheat), or the use of fallow periods, can restore soil fertility, enhance microbial diversity, and reduce soil-borne pathogens and nematode populations. Conservation agriculture practices such as reduced tillage, cover cropping, and the application of organic amendments improve soil organic matter, enhance biological activity, minimize erosion, and strengthen system resilience (Liang, 2025).

Effective pest management strategies should emphasize regular monitoring, strict implementation of IPM principles, and conservation of natural enemies. Avoiding unnecessary or early pesticide applications, practicing judicious rotation of chemical modes of action, and integrating biological control methods or transgenic cotton varieties can significantly reduce production costs, delay resistance development, and minimize environmental risks.

Author's contributions

SD conceptualized the study and contributed to reviewing and editing the manuscript. MRI and EZE conducted the literature review, prepared the initial draft, and contributed to writing, editing, and refining the manuscript. MMK performed cross-checking and provided editorial input to improve the overall quality of the manuscript. All authors reviewed, revised, and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Research Funding

This research did not receive any grant from funding agencies.

Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger

SDG 12: Responsible Consumption and Production

Goal 13: Climate Action

Policy Addressed

1. Regional Integrated Pest and Disease Management (IPDM) Policy

2. Climate-Resilient Cotton Production Policy

References

- Abdullah, A., 2010. An analysis of Bt cotton cultivation in Punjab, Pakistan using the Agriculture Decision Support System (ADSS). *AgBioForum*, 13(3), 274–287.
- Agarwal, S., Mohan, M., Mangrauthia, S.K., 2011. RNAi: Machinery and role in pest and Disease Management. In *Springer eBooks* (pp. 447–469). https://doi.org/10.1007/978-94-007-2220-0_13
- Ahmed, H.U., Latif, M.A., Huq, M.F., Mia, A.T., Latif, M.A., Ahmed, S., Awal, M.R., 2016. Pest risk analysis (PRA) of cotton in Bangladesh (Draft Report). Center for Resource Development Studies Ltd. Submitted to the Department of Agricultural Extension (DAE), Strengthening Phytosanitary Capacity in Bangladesh Project.
- Ahmed, T., 2025. Cotton and products update: Bangladesh (Report No. BG2025-0013). USDA Foreign Agricultural Service.
- Akhteruzzaman, M., Islam, M.K., 2022. Bangladesh country report: Cotton research and development status and future prospects. Cotton Development Board. https://icac.org/Content/EventDocuments/PdfFile/s2d78aea9_6051_43ec_8690_9788523a1243/Bangladesh%20Country%20Report_final2022.pdf
- Amutha, M., Sankaranarayanan, K., Anisha, V., 2022. Performance assessment of intercrops as trap crop for the management of thrips in cotton (*Gossypium hirsutum* L.). *Proceedings of the National Academy of Sciences India Section B Biological Sciences*, 92(4), 897-905.
- Arunkumar, R., Vignesh, K., Suthin Raj, T., 2021. Major Diseases of Cotton. *Just Agriculture* 1(9), 1-5.
- Asif, M., Khakwani, K., Hasnain, M., Ilahi, F., Babar, M.H., Chuhan, S.M., Farooq, J., Abbas, H.G., Parveen, I., Sarwar, G., Ahmad, S., Hussnain, H., 2024. Evaluation of cotton genotypes for agromorphological traits and resistance to insect pests in Faisalabad, Pakistan. *Sarhad Journal of Agriculture* 40(2), 386-394.
- Azcarraga, L., 2025. Zinnia Companion Plants: Enhancing Biodiversity- *Meadowlark Journal*. *Meadowlark Journal*.
- Banglapedia, 2021. Cotton. In *Banglapedia: National Encyclopedia of Bangladesh*. <http://en.banglapedia.org/index.php/Cotton>
- Burana, K., Ehlers, R.-U., Nimkingrat, P., 2022. Entomopathogenic nematodes for control of the

- cotton cutworm (*Spodoptera litura*) in marigolds. *Journal of Applied Entomology* 146(1-2), 128-135.
- CCRI, 2016. Central Cotton Research Institute., Pathology section. <https://ccri.gov.pk/pathology.html>
- CDB (Cotton Development Board, Bangladesh), 2025. Varieties and technologies developed in the last 5 years. <https://cdb.gov.bd/site/page/03b1dbe9-54e7-4b42-b7fb-52c121d6e27b/>
- Chandi, R.S., Kataria, S.K., Fand, B.B., 2021. Effect of temperature on biological parameters of cotton whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae). *International Journal of Tropical Insect Science* 41, 1823-1833.
- Chaudhari, G.B., Bharpoda, T.M., Patel, J.J., Patel, K.L., Patel, J.R. 1999. Effect of weather on activity of cotton bollworms in middle Gujarat. *Journal of Agrometeorology* 1(2), 137-142.
- Cotton Disease Council, 2022. Global review of cotton diseases and their management. In: *World Organic Science Journal* 3(4), 100 diseases in cotton worldwide, pp. 70-74.
- CUTSI, 2013. Consumer Unity and Trust Society International., The SAARC regional seed bank: A case study for India. Jaipur: CUTS International. <https://www.cuts-international.org>
- Darwesh, O.M., Abdelmaksoud, N.M., El-Bakry, A.M., 2024. Nano-chitosan as a bio-enhancer for improving insecticide formulations: A study on indoxacarb and methomyl against cotton leafworm. *International Journal of Biological Macromolecules* 282, 137465.
- Das, A., Chakraborty, S., Nath, H., Pathak, B.B., 2023. Impact of climate change-induced pest and disease attack on crop production. *Climate Smart Approaches Toward Sustainable Crop Production*; Vital Biotech Publication: Kota, India, pp.1-23.
- Dhawan, A.K., 2016. Integrated pest management in cotton. *Integrated Pest Management in the Tropics*, 499575(20), 16.
- Dhawan, A.K., Singh, S., Kumar, S., 2009. Integrated Pest Management (IPM) helps reduce pesticide load in cotton. *Journal of Agricultural Science and Technology* 11(5), 599–611.
- Dristy, S.A., Dhar, A.R., Uddin, M.T., 2024. Sustainable practices for cotton production in Bangladesh: economic and environmental perspectives. *Discover Agriculture* 2(1).
- Economy., 2023. GM cotton cultivation kicks off. *The Daily Star*.
- El-Wakeil, N., Abdallah, A., 2012. Cotton pests and the actual strategies for their management control. *Agric. Res. Updates*, 7, pp.161-218.
- Eroglu, G.B. 2022. Pest insects and their biological control. IntechOpen. <https://doi.org/10.5772/intechopen.101980>
- Farooq, W. 2025. Cotton and products update: Pakistan (Report No. PK2025-0016). USDA Foreign Agricultural Service.
- Faruque, M.K., Ali, M.M., Mondol, M.A.H., Hossain, M.S., 2021. Performance assessment of three cotton varieties under the coastal region of Bangladesh. *Journal of Agroforestry and Environment* 15(1), 53-58.
- Faske, T.R., 2021. An overview of root-knot nematodes. *Crop Protection Network*. <https://doi.org/10.31274/cpn-20210820-2>
- Filipenco, D., 2025. From fields to fabric: the leading cotton producing countries around the world. *DevelopmentAid*.
- Foreign, C.D.O., 2002. Insecticide resistance in five major insect pests of cotton in India. *GOV.UK*.
- Gauchan, D., Joshi, B.K., 2019. Seeds without borders initiative for enhanced food and nutrition security in South Asia. *Seeds Without Borders Initiative in South Asia Current Status and Future Directions*. SAARC Agricultural Centre (SAC) and International Rice Research Institute, Dhaka, Bangladesh p, 203.
- Ghaffar, A., Rahman, M.H.U., Ali, H.R., Haider, G., Ahmad, S., Fahad, S., Ahmad, S., 2020. Modern concepts and techniques for better cotton production. In *Springer eBooks* (pp. 589–628). https://doi.org/10.1007/978-981-15-1472-2_29
- Gopalakrishnan, N., Chinniah, C., Mohanraj, P., Karuppuchamy, P., 2012. Influence of weather factors on thrips incidence in cotton. In *Proceedings of the National Seminar on Agrometeorological Aspects of Climate Change in Indian Agriculture* (pp. 52-57). Tamil Nadu Agricultural University.
- Gurung, T.R., Azad, A.K. (Eds.). 2013. Extent and potential use of bio-pesticides for crop protection in SAARC Countries. SAARC Agriculture Centre (SAC).
- Halder, K., Chaudhuri, A., Abdin, M.Z., Majee, M., Datta, A., 2022. RNA interference for improving disease resistance in plants and its relevance in this

- clustered regularly interspaced short palindromic repeats-dominated era in terms of dsrna-based biopesticides. *Frontiers in Plant Science* 13, 885128.
- Hegde, G.M., Vijaykumar, K.N., 2022. Formulation, Application and Commercialization of Biopesticides in India. *Asia Pacific Biofertilizer and Biopesticide Information Platform* 306, 1-20.
- Hossain, T., 2022. Agricultural biotechnology annual: Bangladesh (Report No. BG2022-0026). United States Department of Agriculture, Foreign Agricultural Service.
- Hussain, N., 2022. Cotton imports cost Tk 35,000 crore annually. *Jagonews24*.
- IAEA, 2021. Nuclear techniques help Bangladeshi experts develop improved cotton varieties in record time. International Atomic Energy Agency (IAEA) News Centre. Devenish, T., 2022. Organic Cotton | Companion Planting. *Reer Endz Underwear*.
- IBEF, 2024. India Brand Equity Foundation., Cotton industry in India.
- ICAC, 2020. International Cotton Advisory Committee., Country report of Pakistan.
- ICAR, 2021. Indian Council of Agricultural Research., ICAR - AICRP (Cotton) Annual Report. ICAR - All India Coordinated Research Project on Cotton Coimbatore, Tamil Nadu
- Iqbal, A., Iqbal, M., Alamzeb, M., Qiang, D., Xiangru, W., Ahmad, I., Khan, M.A., Farooq, M., Shahzad, B., Saud, S., Adnan, M., Fahad, S., 2022. Climate change and cotton production. In: Fahad, S., Adnan, M., Saud, S. (Eds.), *Improvement of Plant Production in the Era of Climate Change*. CRC Press, Taylor & Francis Group, UK, pp. 95–112.
- ISAAA, 2009. International Service for the Acquisition of Agri-biotech Applications., Bt cotton varieties approved in Pakistan. Technology Networks.
- ISAAA, 2015. International Service for the Acquisition of Agri-biotech Applications., Country facts and trends: Pakistan. International Service for the Acquisition of Agri-biotech Applications.
- ISAAA, 2021. International Service for the Acquisition of Agri-biotech Applications., Punjab issues schedule for sowing of registered Bt cotton varieties.
- Islam, M.K., Uddin, M.F. 2014. Cotton biodiversity in Bangladesh. Paper presented at the 9th Biennial Conference of the Plant Breeding and Genetics Society of Bangladesh, Dhaka, Bangladesh.
- Jat, B.L., Rolaniya, K., Yadav, S.S., 2013. Insects and pests management in cotton crop. *Krishisewa*.
- Jayapradha, J., Suganthi, M., Murugan, M., Rajkishore, S.K., Jeya, D.S.S., Janaki, P., 2025. Potential nano strategies in insect pest management: synthesis, applications and plant interactions. *Plant Science Today* 12(3), 1-14.
- Kashif, S., Iqra, M., Meng, Z., Xuexian, Z., Jianyong, W., Chaozhu, X., 2022. Progress and perspective on cotton breeding in Pakistan. *Journal of Cotton Research* 5(1), 29.
- Kemerait, B., Allen, T., Lu, S., Rothrock, C., Faske, T., Kelly, H., Nichols, R., Lawrence, K., Hagan, A., Price, P., Mehl, H., Dufault, N., Bart, R., Phillips, A., Woodward, J., Wheeler, T., Isakeit, T., 2017. Identification and management of bacterial blight of cotton. *Cotton Incorporated*.
- Kemerait, R.C., Price, B.W., 2011. A review of cotton diseases and their management. In: *Cotton Disease Loss Estimates and Management*. Association of Applied Insect and Disease Specialists, pp. 1–15.
- Khan, Y.S., Riaz, M., 2022. Cotton Leaf Curl Virus-Pakistan: CLCV. *PlantwisePlus Knowledge Bank*.
- Khoury El, W., Makkouk, K., 2010. Integrated plant disease management in developing countries. *Journal of Plant Pathology* 92(4, Supplement), S4.35-S4.42.
- Kumara, G.T., Navik, O., Venkatesan, T., Hosamani, A., Patil, J., Mohan, M., Jalali, S.K., 2022. Performance and field efficacy of indigenous egg parasitoid *Trichogrammatoidea bactrae* (Hymenoptera: Trichogrammatidae) against the cotton pink bollworm (*Pectinophora gossypiella*) (Saunders) (Lepidoptera: Gelechiidae) in transgenic Bt cotton. *Biological Control* 170, 104902.
- Kumawat, S., Meena, S.K., 2023. Biological control of insect pests in cotton ecosystem. In *Doctoral Seminar*.
- Kurra, S.S., Rajkumar, R., 2022. Pests and Diseases Detection of Cotton Farm Using Artificial Intelligence Technologies: A review.
- Lengai, G.M., Muthomi, J.W., Mbega, E.R., 2019. Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. *Scientific African* 7, e00239.
- Liang K.W., 2025. Best practices for sustainable cotton farming systems, *Cotton Genomics and Genetics* 16(2), 80-94.

- Looney, M., 2024. Market report on the global and regional cotton sectors for 2023/2024. In L. Ruiz and M. McCue (Eds.), Cotton: Review of the World Situation (Vol. 77, No. 4). International Cotton Advisory Committee.
- Luneja, R.L., Mkindi, A.G., 2025. Advances in botanical-based nanoformulations for sustainable cotton insect pest management in developing countries. *Frontiers in Agronomy*, 7, 1558395.
- Malaquias, J.B., Fernandes, F.S., Nascimento, A.R.B., Zanuncio, J.C., 2011. Effect of temperature on the reproduction of *Bracon vulgaris* Ashmead (Hymenoptera: Braconidae), a parasitoid of the cotton boll weevil. *Anais da Academia Brasileira de Ciências* 83(3), 795-804.
- Mandi, T., 2024. India's cotton industry to hit \$30 billion by 2027: Know its impact.
- Manickam, S., Sabesh, M., 2023. CICR varieties and hybrids. Central Institute for Cotton Research.
- Mawcha, K.T., Kinyanjui, G., Simiyu, S.W., Babalola, O.O., Ndolo, D.O., 2024. Biopesticides for Sustainable Agriculture: A review of their role in Integrated Pest Management. IntechOpen eBooks.
- Mohan, S., Monga, D., Kumar, R., Nagraire, V., Gokte-Narkhedkar, N., Vennila, S., Tanwar, R.K., Sharma, O. P., Bhagat, S., Agarwal, M., Chattopadhyay, C., Kumar, R., Birah, A., Amaresan, N., Singh, A., Sushil, S.N., Asre, R., Kapoor, K.S., Jeyakumar, P., Satyagopal, K., 2014. Integrated pest management package for cotton (p. 84).
- Mohapatra, A.R., Sisodiya, D., 2022. Emerging Insect-Pests of Agricultural Crops and its Management.
- Mondol, M., 2008. Status of cotton in Bangladesh. International Cotton Advisory Committee (ICAC), Washington, DC.
- Mortuza, M.G.G., 2021. Country report on research, development of cotton production in Bangladesh. International Cotton Advisory Committee, Atkinson, North Carolina, USA. Naeem, U., Ramzan, M., Bokhari, S.H.M., Saleem, A., Qayyum, M.A., Iqbal, N., Rahman, M.H.U., Fahad, S., Saeed, S., 2020. Insect pests of cotton crop and management under climate change scenarios. In Springer eBooks (pp. 367-396).
- Murtaza, G., Ramzan, M., Ghani, M.U., Munawar, N., Majeed, M., Perveen, A., 2019. Effectiveness of different traps for monitoring sucking and chewing insect pests of crops. *Journal of Agricultural and Biological Sciences* 14(3), 1-10.
- Nag, O., 2017. The leading cotton exporting countries in the world. WorldAtlas.
- Nagaraj, S., Rajasekaran, R., Palaniappan, J., Rangasamy, S., Narayanasamy, C., Narayanan, M.B., 2024. Emerging technological developments to address pest resistance in Bt cotton. *Journal of Cotton Research* 7(1).
- Narayanan, S.S., Vidyasagar, P., Srinivasu Babu, K., 2014. World cotton germplasm resources. In I.Y. Abdurakhmonov (Ed.), World cotton germplasm resources (pp. 58622). InTech.
- Parajulee, M.N., 2007. Influence of constant temperatures on life history parameters of the cotton aphid, *Aphis gossypii*, infesting cotton. *Environmental Entomology* 36(4), 666-672.
- Patel, Y., 2020. Effect of weather parameter on the population of pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera-Gelechiidae) in cotton. *International Journal of Current Microbiology and Applied Sciences* 9(4), 1476-1481.
- PCCC., 2025. Pakistan Central Cotton Committee., Monthly cotton review. Directorate of Marketing & Economic Research.
- Pramanik, K., Layek, A., Debnath, P., 2023. Pest outbreak and climate change.
- Radhika, P., Subbaratnam, G.V., 2006. Insecticide resistance management in cotton: Indian scenario - A review. *Agricultural Reviews* 27(3), 157-169.
- Rahman M., Rahmat, Z., Mahmood, A., Abdullah, K., Zafar, Y., 2014. Cotton germplasm of Pakistan. In M. Caliskan (Ed.), Genetic diversity in plants (pp. 135-155). InTech.
- Razzaq, A., Zafar, M.M., Ali, A., Hafeez, A., Batool, W., Shi, Y., Gong, W., Yuan, Y., 2021. Cotton germplasm improvement and progress in Pakistan. *Journal of Cotton Research* 4(1), 1.
- Rubayet, M.T., 2021. Diseases of cotton. Department of Plant Pathology, Bangabandhu Sheikh Mujibur Rahman Agricultural University.
- Safdar, M.Z., 2018. Effect of abiotic factors on population dynamics of whitefly and jassid on BT cotton. *Current Investigations in Agriculture and Current Research* 6(1).
- Sain, S.K., Dewasi, H., Singh, A., 2023b. Combined application of effective *Trichoderma*, *Pseudomonas* and arbuscular mycorrhiza spp. reduced soil-borne diseases and boosted growth

- in cotton. *Egyptian Journal of Biological Pest Control* 33(1), 94.
- Sain, S.K., Monga, D., Sabesh, M., Prasad, Y.G., Prakash, A.H., Singh, R.K., 2023a. Diseases and disorders of cotton: A field guide for symptom-based identification and management. ICAR-AICRP on Cotton, ICAR-CICR, Regional Station, Coimbatore, Tamil Nadu.
- Sarker, S., 2013. Management of bacterial blight of cotton by using some selected chemicals (Master's thesis, Sher-e-Bangla Agricultural University). Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka.
- Sathya, G., 2022. Field preparations for cotton crop. *Kisanvedika*.
- Saxena, S., Yogindran, S., Arya, M., Sharma, Y., Singh, C.P., 2021. RNAI-Mediated control of lepidopteran pests of important crop plants. In *IntechOpen eBooks*.
- Shah, D., 2012. Bt cotton in India: A review of adoption, government interventions and investment initiatives. *Indian Journal of Agricultural Economics* 67(3), 265-283.
- Shahzad, K., Mubeen, I., Zhang, M., Li, Y., Zhou, Z., Xing, C., 2022. Progress and perspective on cotton breeding in Pakistan. *Journal of Cotton Research* 5(1), Article 1.
- Shahzad, R., Jamil, S., Chaudhry, U.F., Rahman, S.U., Iqbal, M.Z., 2024. In-depth analysis of Bt cotton adoption: farmers' opinions, genetic landscape, and varied perspectives-a case study from Pakistan. *Journal of Cotton Research* 7(1).
- Sharma, A.K., Singh, R., Yadav, D.S., 2014. Fertilizer management and soil fertility in cotton (*Gossypium hirsutum* L.). *Indian Journal of Agronomy* 59(2), 152-158.
- Shrestha, S., Amgain, L.P., Pandey, P., Bhandari, T., Khatiwada, S., 2024. Adoption status of Integrated Pest Management (IPM) practices among vegetable growers of Lamjung district of Nepal. *Heliyon* 10(18), e37999.
- Solanki, B.G., 2017. Cotton in India. 7th Meeting of the Asian Cotton Research and Development Network, Nagpur, India.
- Sood, D., 2025. Cotton and products update: India (Report No. IN2025-0071). USDA, Foreign Agricultural Service.
- Tabib, M.F.A.I., 2023. Ecology and economics of cotton in Bangladesh. *Textile Today*.
- TBRC, 2024. The Business Research Company., Cotton yarn global market report 2025.
- THBL, 2025. The Hindu Business Line., India's cotton area may see a dip in 2025-26 as farmers seen shifting to pulses, oilseeds. The Hindu Business Line.
- Tillman, P.G., Mullinix, B.G., 2004. Grain sorghum as a trap crop for corn earworm (Lepidoptera: noctuidae) in cotton. *Environmental Entomology* 33(5), 1371-1380.
- Tiwari, A.K., 2022. Impacts of climate change on insect pests and crop protection strategies. *Chemical Engineering* 3(2), 1-5.
- Togbé, C., Zannou, E., Vodouhê, S., Haagsma, R., Gbèhounou, G., Kossou, D., Van Huis, A., 2012. Technical and institutional constraints of a cotton pest management strategy in Benin. *NJAS-Wageningen Journal of Life Sciences* 60-63(1), 67-78.
- TT, 2025. Textile Today., Global cotton production set to rise by 1.2mn bales in 2024-25. *Textile Today*.
- Tyagi, A., Tamang, T.L., Kashtoh, H., Mir, R.A., Mir, Z.A., Manzoor, S., Manzar, N., Gani, G., Vishwakarma, S.K., Almalki, M.A., Ali, S., 2024. A Review on biocontrol agents as sustainable approach for crop disease management: applications, production, and future perspectives. *Horticulturae* 10(8), 805.
- USDA, 2024. United States Department of Agriculture, USDA Foreign Agricultural Service. Bangladesh: Cotton and products update.
- USDA-FAS, 2022. United States Department of Agriculture, Foreign Agricultural Service, Cotton: World Markets and Trade. Washington, DC: U.S. Department of Agriculture, Foreign Agricultural Service.
- Vaishnavi, H.N., 2024. Spotted bollworm: A threat to cotton farming. *AgriApp*.
- Vennila, S., Biradar, V.K., Sabesh, M., Bambawale, O.M., Khadi, B.M., Chakrabarty, M., 2007. Know your native natural enemies of cotton insect pests! Central Institute for Cotton Research, Division of Crop Protection (Nagpur & Coimbatore), & National Centre for Integrated Pest Management, New Delhi.
- Voora, V.A., Elder, S.D., Sarmiento, F., 2023. Voluntary Sustainability Standards in South Asia: A focus on the cotton sector in Bangladesh, India.
- Wright, S., 2020. Top Cotton Producing Countries in The

World. WorldAtlas.

Zhan, C., Jiao, B., Xu, L., Peng, Y., Zhao, Y., 2025. Topical RNA interference induces mortality in the

cotton-melon aphid *Aphis gossypii* with no adverse effect on the predator *Propylea japonica*. Insects 16(3), 276.

Publisher's note: EScience Press remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access: This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.