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A Review of Pesticides for the Control of Some Cotton Pests

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Introduction

Cotton (Gossypium hirsutum L.) is one of the most important fibre cash crops grown for fibre in over 83 countries with tropical and subtropical climatic conditions. The incidence of cotton pests is a significant factor that affects cotton production. The production is severely affected by insect pests, resulting in poor yields despite the growing demand for the commodity. Pests and diseases are estimated to cause 60% losses in cotton production throughout the world [107]. 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 control, which involves the use of pesticides [21].

Pesticides are mainly used on cotton to control insect pests rapidly [10], and farmers opt for pesticides as the first line of defense [54]. Since the development of pesticides after World War II, they have been extensively used in agriculture due to their efficiency in pest control and crop yield increment [68]. Cotton has been reported to receive more chemical control than most other arable crops [66]. Cotton uses up to 60% of all commercialized agrochemicals globally [116]. In Africa, about 50% of pesticides are used on cotton [46], and South Africa has been one of the largest importers of chemical pesticides in sub-Saharan Africa (Quinn et al., 2011). Various insect pests and beneficial insects coexist in a cotton ecosystem; however, pesticides have reduced the impact of beneficial insects [35]. Pesticides, as one of the management tools for pests, can be used as part of integrated pest management to promote sustainable pest control methods [20]. When pesticides such as organophosphates (1960s), carbamates (1970s), and pyrethroids (1980s) were introduced, they had an impact on agricultural pest control and resulted in high yields [5]. In Africa, the use of pesticides has been reported to be low compared to the rest of the world due to economic and social constraints. Most pesticides are applied mostly against pests of commercial crops such as cotton [1]. The use of pesticides in Africa is reported to be more than 1.2 kg.ha-1, a fraction of what is used in Latin America (7.17 kg.ha-1) [95].

Although chemical control remains a key method to control targeted pests, a controversy has surfaced regarding the use and abuse of pesticides [5]. The diversity of pests found in cotton requires serious control, mostly with pesticides, which negatively impact natural enemies and the environment [61]. The continuous use of synthetic chemicals to protect crops may also result in pesticide resistance in pest populations [54]. Combining selective chemical and biological controls is important for integrated pest management; however, this has not been entirely explored due to, among others, insufficient information on the pesticide tolerance or resistance of natural enemies [81]. Developing integrated pest management strategies is required to reduce pesticide use and maximize the impact of natural enemies. However, there is still a need to address the complexity of insect pests in cotton where control needs may conflict [22]. This paper provides an overview of the use of some pesticides to control cotton pests and their challenges.

Pyrethroid – Lambda-Cyhalothrin

Pyrethroids are non-systemic pesticides with contact and stomach action [12]. Pyrethroids are pesticides that are mainly used to control insects that are leaf-eaters [105]. In Africa, py-

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rethroids are the most commonly used pesticides for cotton [47]. They are synthetic derivatives of pyrethrins produced by chrysanthemum flowers [62]. Pyrethroids differ in their vulnerability to sunlight, characterized by their ability to dissolve in water with persistent compounds [59]. This group of pesticides includes cypermethrin, deltamethrin, fenvalerate, lambda-cyhalothrin, and permethrin, among others. Lambda-cyhalothrin, known as Karate®, is a non-selective pesticide commonly used to control agricultural insect pests [61]. It is frequently used on cotton and other crops to control insects, including lepidopterans and coleopterans [15]. The pesticide has low vapour pressure and is relatively stable in water at a pH of less than eight (He et al., 2008).

The effect of lambda-cyhalothrin on cotton pests and beneficial insects has been widely reported around the globe. Cole et al. (1997) investigated the efficacy of lambda-cyhalothrin (Karate®) in Bt cotton and reported that lambda-cyhalothrin had no major disruption of beneficial insects but significantly increased yield. Gayi et al. (2017) evaluated the efficacy of bio and pesticides against H. armigera and its natural enemies on cotton. They reported that under laboratory conditions, lambda-cyhalothrin combined with Thiamethoxam showed 100% mortality of third instar larvae of H. armigera after 96 hours, while under field conditions, lambda-cyhalothrin combined with profenofos showed 100% mortality after 96 hours. Furthermore, it was observed that pesticides significantly reduced natural enemy populations. This aligns with the findings of Ruberson and Tillman (1999) and Riley et al. (2001), who recorded a reduction in the number of natural enemies after applying Karate. Lambda-cyhalothrin has been reported to have the quickest and best control against cotton leafhopper nymphs after the first spray [63]. In a study comparing the efficacy of some conventional and neonicotinoid pesticides against whiteflies, leafhoppers, and thrips, Asif et al. (2016) observed that Karate®, when sprayed twice, had a significant reduction of the pests from one to seven days after application. Lambda-cyhalothrin showed a 57.93% reduction against leafhopper seven days after application. Zidan et al. (2012) found that lambda-cyhalothrin was the most efficient pesticide against bollworms and aphids, with an average reduction of 71.91% in pink bollworms and 81.61% in spiny bollworms. However, the data also revealed that this pesticide had a weak to moderate effect against leafhoppers and whiteflies and was more toxic against predators. Javaid et al. (1999) recommended that including insect growth regulators in managing cotton insect pests could eliminate the continuous use of pyrethroids.

Organophosphate – Chlorpyrifos

Organophosphates are one of the major pesticide classes that became prominent in the mid-1940s [27]. They are the large chemical class used in agriculture [49]. Over the years, there has been a significant decline in the use of organophosphates in developed countries, but this has been offset by an increase in developing countries [36]. Organophosphates are highly toxic and impact both target insect pests and non-target species and mammals, including humans [29]. Chlorpyrifos is a heterocyclic organophosphate that belongs to organophosphorus pesticides and has been widely used in agriculture [101]. Chlorpyrifos is a non-systemic pesticide that disrupts the production of certain important nervous system enzymes [110]. It is a frequently used pesticide on a wide range of crops, including cotton [79], and various formulations have been developed to control important insect and arthropod pests [48]. Chlorpyrifos is known to be persistent and toxic to non-target organisms; however, it may exhibit low persistence in the field [55]. Chlorpyrifos is among the most effective and cheaper pesticides than alternative products [101]. However, in South Africa, chlorpyrifos was banned for residential use in 2010 and is only used in the agricultural sector.

A mixture of chlorpyrifos and alphacypermethrin was tested against cotton bollworms and compared to chlorpyrifos alone [100]. The mixture was more effective in controlling the cotton bollworm complex and resulted in the highest seed cotton yield. Similar results were observed by Vojoudi et al. (2011), who reported that chlorpyrifos controlled the third larval instars of cotton bollworms and reduced the longevity and fecundity of adults. Chlorpyrifos has been found to significantly affect the control of cotton stainers in a laboratory experiment [87]. Chlorpyrifos has also been recorded to control J. facialis [54]. Zidan et al. (2012) evaluated the efficacy of different pesticides against cotton bollworms and sucking insects and their associated natural enemies. It was evident from the results that chlorpyrifos was efficient against cotton bollworms and aphids but had a weak to moderate effect against whiteflies and leafhoppers. Martin et al. (2003) studied the synergism of pyrethroids by organophosphorus pesticides on cotton using the combination index method. They revealed that the organophosphorus pesticides significantly reduced the resistance of H. armigera against pyrethroids and increased the toxicity of the pyrethroids.

Neonicotinamide – Imidacloprid

Neonicotinoids, such as imidacloprid, are products of synthetic nicotinoids used to control insects and pests of different crops, including cotton [74]. They are a newer class of pesticides developed in the late 1970s with low risk for non-target organisms and selective for insect pests [94]. Neonicotinoids attack the central nervous system, reducing reproduction and insect movement and resulting in their death [17]. Imidacloprid is the first and most-used member of the neonicotinoid family [33]. In the US, over 60% of cotton is planted with seed treated with the neonicotinoids imidacloprid [6]. Imidacloprid belongs to a newer class of chloronicotinyl [99], registered for many agricultural uses [91]. Imidacloprid has been reported as a safer pesticide than the older pesticide classes because, despite its high-water solubility, it has low leaching potential in the soil [72]. However, this depends on soil type, as some soils with low organic matter content may not absorb imidacloprid well [23]. Imidacloprid can be applied directly onto the crops or used as a seed or soil treatment to control different pests, including leafhoppers, aphids, whiteflies, and thrips [60]. Imidacloprid can control aphid infestations of cotton plants [26]. However, the pesticide harms ladybirds [115] and has been found to reduce the fecundity of other natural enemies of aphids [52]. It is, therefore, recommended that imidacloprid be applied only during the initial stages of aphid invasion in cotton fields [115].

Imidacloprid has been widely reported to significantly reduce cotton leafhopper, thrip, and whitefly infestations [9,93]. Asif et al. (2016) tested different pesticides against sucking insect pests of cotton. They reported that imidacloprid exhibited a significant reduction in the populations of leafhoppers (86.92%), whiteflies (74.5%), and thrips (66.30%) and gave the highest seed cotton yield. In a study to determine the production of honeydew by whiteflies, Cameron et al. (2014) documented that when adult whiteflies were placed on pesticide-treated plants, imidacloprid showed a reduction in the honeydew produced by the pest. Similarly, He et al. (2013) reported that imidacloprid reduced feeding, honeydew excretions, and fecundity of adult whiteflies. Afzal et al. (2014) compared different pesticides under field conditions. They reported that imidacloprid reduced the leafhopper population up to seven days after application and gave an average of more than 90% mortality after three days of application.

Challenges of Pesticides

Despite the duration of use of pesticides on agricultural pests, their extensive use has resulted in health hazards, environmental pollution, outbreaks of secondary pests, toxicity to natural enemies, development of resistances, and decreases in biodiversity [29,57,58,75,111].

Health Hazards

Pesticide use in cotton poses a hazard to humans [116]. In developing countries, the use of pesticides has been reported to account for up to 14% of work-related injuries, of which 10% of these injuries led to fatality [14]. In Pakistan, health problems associated with the absence of personal protective equipment were reported in cotton pickers who experienced headaches, stomachaches, fever, and skin and eye problems due to the lack of proper education and training programmes on personal protective measures [67]. In Sudan, human blood samples were analyzed for organochlorine pesticide residues in areas that used pesticides intensively. The levels of organochlorine in blood samples were lower in areas distant from where the heavy application of these pesticides was previously done [32]. In Benin, Agbohessi et al. (2015) conducted a study to determine the impact of agricultural pesticides on the health status of fish found in the water near cotton fields. It was evident that pesticides significantly reduced the health condition of fish living in the Beninese cotton basin.

Toxicity to Natural Enemies

In any area where cotton is grown, insect pests and natural enemies coexist. It is therefore important that while the use of pesticides reduces the pest populations, it must not have a negative impact on natural enemies. Lambda-cyhalothrin has been recorded as toxic to natural enemies of different crop pests [38]. Van Hamburg and Guest (1997) noted that the variety of natural enemies in South Africa plays a vital role in controlling insect pests; however, spraying of pesticides reduces the ability of natural enemies to control cotton pests. Barros et al. (2018) observed that after exposure to different pesticide residues, parasitoids and some of the predator populations were reduced by lambda-cyhalothrin. D'ávila et al. (2018) studied the effects of imidacloprid and lambda-cyhalothrin and reported that the pesticides negatively affected the longevity of adult aphid parasitoids. In contrast, Saner et al. (2014) reported that lambda-cyhalothrin and imidacloprid were eco-friendly towards the ladybird beetle population.

Similarly, Ahmed et al. (2014) conducted a study to evaluate the impact of neonicotinoids and traditional pesticides against cotton pests and their natural enemies. From the outcome of the study, it was evident that imidacloprid controlled sucking pests while it did not have an impact on the natural enemies. Tillman and Mulrooney (2009) recorded that, after spraying cotton with lambda-cyhalothrin, the number of predators of cotton aphids was found to increase as the number of cotton aphids increased, indicating that lambda-cyhalothrin did not have an impact on the predator population. Saeed et al. (2016) evaluated the efficacy of imidacloprid against the cotton leafhopper and its predators. They documented that when imidacloprid is applied at the manufacturer-recommended dose, there are fewer negative effects on the abundance of natural enemies [70]. Chlorpyrifos has been reported to cause high mortality among the natural enemies of whiteflies [77], aphids [34], and spider mites [7] as well as the larvae of green lacewing and spiders (Dhawan, 2000). Natural enemies also reduce cotton bollworm eggs and larvae without pesticide application [109]. Despite all the positive and negative impacts of pesticides, cases of natural enemies showing resistance to pesticides have also been recorded in some studies [11]. It is recommended that selective pesticides be encouraged to control cotton pests, maintaining the natural enemies' population [61].

Environmental Pollution

The excessive use of hazardous pesticides greatly impacts the environment, water, and soil fertility in many countries [98]. Over 4.6 million pesticides are applied to the environment [8]. Most pesticides are resilient to degradation, so they remain in the environment for a prolonged period [37]. Environmental impact due to repeated use of pesticides is categorized by different environmental compartments such as air, soil, land, and groundwater [73]. The soil is regarded as the main source of pollutants and contaminants in surface water, groundwater, and air [118]. Pesticides can be transported from the soil through contaminated surface water and leach into groundwater, resulting in damage to non-target organisms and pollution of the soil [119]. The use of neonicotinoid pesticides in agriculture has been reported to contaminate the soil while their residues are transferred to the aquatic environment and reduce the abundance of aquatic insects [85]. Sumon et al. (2018) stated that imidacloprid might pollute aquatic ecosystems through spray drift, surface runoff, and groundwater leaching. They further conducted a study to assess the effects of imidacloprid on Bangladesh's freshwater and sub-tropical ecosystems. It was recorded that imidacloprid negatively affected sub-tropical ecosystems compared to temperate regions. Lambda-cyhalothrin has also been widely used in agriculture, and its residues in runoff waters are toxic to humans and aquatic organisms [25].

Imidacloprid and chlorpyrifos residues contaminate most soils [78]. A study was done in fruit orchards in the Western Cape province of South Africa to determine the effect of organophosphorus and endosulfan pesticides as a potential source of contamination in farm streams [90]. It was found that the level of pesticide deposition on the ground declined with increasing distance from the sprayed plants. In India, a study was conducted to determine the level of organophosphorus pesticide residues along the 85 km stretch of a river that flows near cotton plantations [102]. Chlorpyrifos was one of the organophosphorus pesticides detected in the water samples above the permissible limit.

Secondary Pest Outbreaks

The effect of broad-spectrum pesticides on targeted pests may reduce natural enemies and cause outbreaks of secondary pests [40]. The outbreak of secondary pests may occur after effective control of primary pests when the two pest species feed on the same plant part [31]. However, secondary pest outbreaks are occasionally difficult to document as they may be due to factors other than the applied pesticides [40]. With the introduction of Bt cotton, there has been a reduction in pesticide use for bollworms. However, this led to outbreaks of secondary pests, necessitating the continuous use of pesticides [117]. This continued use of pesticides may also cause the resistance of the target pests. Harris et al. (1998) have demonstrated that over-spraying Karate (λ-cyhalothrin) combined with proper habitat management can control secondary pests on Bt cotton and reduce resistance development. Pesticides are highly toxic to insect predators of pink bollworms, and they are alleged to encourage the outbreaks of other cotton pests [96].

While lambda-cyhalothrin has been highly poisonous to spider mites and their natural enemies, imidacloprid has been recorded to have minimal harm to this pest but is highly poisonous to the natural enemies [89].

This may be because spider mites are initially susceptible to the pesticide and develop resistance faster than their natural enemies. In Australia, the application of organophosphates has been observed to disrupt beneficial insects, which may result in outbreaks of secondary pests [45]. Wilson et al. (1998) studied the effect of pesticides on cotton red spider mites and their predators, and they reported an outbreak of spider mites when pesticides significantly suppressed the predator. In South Africa, red spider mites were also recorded as a primary pest on cotton after predator suppression caused by the negative effect of pesticides [109].

Pest Resistance to Pesticides

The resistance of pests to different pesticides, such as pyrethroids, neonicotinoids, and biopesticides, has been extensively studied worldwide [84]. Insects can develop resistance to pesticides through various mechanisms such as behavioural, morphological, and physiological adaptations [51]. Cotton bollworms and whiteflies have shown resistance to organophosphates, organochlorines, pyrethroids, and carbamates [69]. The development of resistance in whiteflies on cotton has been recorded for over 40 active ingredients of pesticides in several countries [69]. Pittendrigh et al. (2008) have observed resistance mechanisms of whiteflies to imidacloprid. The resistance of whiteflies to different pesticides can be reduced by alternating the pesticides with products such as biological agents [19]. Using pesticides to control H. armigera has led to widespread resistance [106].

Ochou and Martin (2002) studied pyrethroid resistance management using several non-pyrethroid pesticides to control H. armigera on cotton in West Africa. They found that alternating pyrethroids with endosulfan or profenofos at the vegetative stage of cotton significantly controlled H. armigera and increased yields. In Côte d'Ivoire, Martin et al. (2000) noted that the continuous application of pyrethroids resulted in resistance of H. armigera populations. This led to the development of resistance management of the pest that was intended to reduce the reliance on pyrethroid by using alternative pesticides (Djihinto et al., 2016). Although the resistance management strategy to control the H. armigera populations is effective, this often significantly increases secondary pests on cotton plants [16].

Pest resistance to pyrethroids has been noticed in cotton-producing regions around the world. In Australia, cotton bollworm resistance to pyrethroids was first identified in 1983 [50], while countries such as Thailand, Egypt, and Zimbabwe reported resistance by 1985 [8]. In South Africa, pesticide restrictions were introduced in the late 1970s to avoid over-reliance on synthetic chemicals [42]. Cotton aphids have developed resistance against neonicotinoid pesticides despite using high rates [108]. Herron and Wilson (2017) revealed that although aphids were effectively controlled by pesticides sprayed against cotton bollworms, they showed resistance to organophosphates targeted against bollworms after some time.

Similarly, Wu and Guo (2003) reported significant resistance of cotton aphids to pyrethroid and organophosphate pesticides used to control cotton bollworms. Furthermore, Ulusoy et al. (2018) revealed that aphids had developed resistance to imidacloprid. Thrips have also developed resistance to pyrethroids [104] and organophosphates (Nazemi et al., 2016). Pests with high fertility and a short life cycle can easily infest their hosts and develop pesticide resistance [30]. The spider mites can quickly develop resistance to pesticides due to their short life cycle and abundant reproduction (van Leeuwen et al., 2010). Although cotton stainers continue to be susceptible to pyrethroids, including lambda-cyhalothrin, they may develop resistance to these pesticides [84].

With the rising concern among different stakeholders regarding the negative impact of pesticide application on the control of crop pests [53], biopesticides can be alternated with pesticides to avoid insect resistance [56]. The increasing pest status of H. armigera in South Africa has prompted renewed interest in using biopesticides, especially as resistance is suspected to develop against commonly used chemical control measures. However, nearly 30 insect species have been reportedly resistant to B. thuringiensis toxins [92]. The insect-resistant varieties have been used as a method of insect control; however, due to Bt resistance by non-target pests, cotton farmers are spending more money on pesticides than before the introduction of Bt cotton [56].

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