



# Mechanisms of Host Plant Resistance in Chickpea (*Cicer arietinum* L.) Against Adzuki Bean Beetle (*Callosobruchus chinensis* L.) Infestation: A Review

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**Abstract:** Plants and insects have been living together for more than 350 million years. In co- evolution, both have evolved strategies to avoid each other's defense systems. The enhancement of insect and disease resistance in chickpea can increase its yield potential by as much as three times. The breeding of chickpea genotypes resistance to the adzuki bean beetle could, therefore, prove one of the possible approaches both for cost effectiveness, agricultural sustainability and food safety. Thus, the objective of this study was to review mechanisms of host plant resistance in chickpea against Adzuki bean beetle infestation. Resistance processes involve morphological, physiological and/or biochemical mechanisms which range from simply minimizing the effect of insect attack to total death of insect pest. In general, the inherent ability of crop plants or varieties to restrict, retard or overcome pest infestations, which provides a potential and sustainable option to be utilized in insect pest management.

**Keywords:** Adzuki bean beetle, Chickpea, Insect, Resistance

## 1. INTRODUCTION

South-Eastern Turkey, and neighboring areas of Syria were considered as the center of origin for cultivated chickpea (Van der Maesen, 1972; Singh, 1997). Chickpea is cultivated mainly in the Indian sub-continent, West Asia, North Africa, the Mediterranean and Ethiopia, but recently introduced to America and Australia. The existence of the wild relatives in Ethiopia, particularly *Cicer cuneatum*, indicated that Ethiopia is the secondary center of diversity for chickpea (Van der Maesen, 1972). It is a diploid ( $2n = 2x = 16$ ) crop which belongs to the family leguminosae, subfamily papilionacea and genus cicer (Van der Maesen, 1987).

There are two main chickpea botanical subtypes grown globally, namely Kabuli and Desi, representing two diverse gene pools. The Desi chickpeas are characterized by small angular seed shape, dark seed coat, pink flowers, anthocyanin pigmentation of stem, rough seed surface, and either semi-erect or semi-spreading growth habit. The Desi types account for about 85% of world production. This subtype is the principal type grown in India, Pakistan, Iran, Afghanistan and Ethiopia, whereas the Kabuli types generally have large owl shaped seeds, white flowers, smooth seed surface, lack of anthocyanin pigmentation, semi-spreading growth habit and more suited to the temperate climates (Pundir *et al.*, 1991; Reddy *et al.*, 2007). It is grown mainly in the Middle East, India, Mexico as well as in North America, Australia and Spain. Kabuli types have been recently introduced to Ethiopia but the Desi types are dominating the production (over 80%) in the country in terms of both area coverage and volume of production (Kinfel *et al.*, 2015).

Chickpea is among the most important cool season food legumes grown worldwide (FAO, 2008; Gaur *et al.*, 2010). Among the pulse crops, chickpea has consistently maintained a much more significant status, ranking second in area and production after common bean (*Phaseolus vulgaris* L.) and field pea (*Pisum sativum* L.) (Gaur *et al.*, 2010). It serves as a multipurpose crop (Shiferaw *et al.*, 2007) valuable as an export commodity, as it fixes atmospheric nitrogen (Bejjiga and Daba, 2006) thereby saves fertilizer costs in subsequent crops. It also allows more intensive and productive use of land, particularly in areas where land is scarce and the crop can be grown as a second crop using residual moisture (Gaur *et al.*, 2010). Chickpea is also a good "break" crop to different diseases and pests,

when grown in rotation with cereals (Kirkegaard *et al.*, 2008). Moreover, it reduces malnutrition and improves human health, especially for the poor who cannot afford livestock products, and increases livestock productivity as the residue is rich in digestible crude protein content compared to residue from cereals (Wood and Grusak, 2007).

Chickpea production faces a number of challenges, some of the problems are partly due to abiotic factors such as moisture stress, extreme temperatures, drought, and alkalinity. Heat and salinity problems are relatively important following drought and cold stresses (Singh, 1997). Moreover, chickpea is also attacked by various biotic constraints such as fusarium wilt, collar rot and dry root rot, aschochyta blight, botrytis grey mold diseases and insect pests. The most important pests of stored grain legume seeds are *C. chinensis* L., *Callosobruchus maculatus* Fabricius, *Callosobruchus analis* Fabricius, *Acanthoscelides obtectus* Say, and *Bruchus incarnates* (Desroches, *et al.*, 1995). Reports indicate that from 25 to 40% of the grain crops are lost in stores annually due to infestations by insect pests in the sub-Saharan Africa (Mulungu *et al.*, 2007; Kimatu, *et al.*, 2012; Ahmad *et al.*, 2015). Even low initial infestation rates can cause tremendous damage because of the polycyclic nature, high fertility and short generation times of bruchid beetles (Southgate, 1979).

Among the bruchid beetles, adzuki bean beetle is one of the most devastating storage pest throughout the world causing substantial loss during storage (Gowda *et al.*, 1982; Sing *et al.*, 1994; Desroches *et al.*, 1995; Gemechu *et al.*, 2012). Reports indicate that adzuki bean beetle in chickpea may cause losses of up to 50% in Ethiopia and 28% in Eritrea (Kemal and Tibebu, 1994; Haile, 2006). It is widely agreed that food losses after harvest can be substantial and are important in terms of quantity, quality, and nutritional and economic values (Homan and Yubak, 2011).

Adzuki bean beetle render quality loss, which is more frequently based on subjective judgment and locally accepted quality standards. It may include the presence of contaminants, such as uric acid and other nitrogenous wastes, the presence of adult beetle inside the seed, exit holes, glued eggs to the seeds, coastal larval skin, species of insect chitin and changes in appearance, and texture and taste, making it unfit for human consumption. Commercial grain buyers usually reject or refuse to accept delivery of insect contaminated grain or may pay very low price for it (Hill, 1990; Espinal, 1993; Nichimbi-Mosolla and Miswangu, 2001).

The enhancement of insect and disease resistance in chickpea can increase its yield potential by as much as three times (ICRISAT, 1992). Which is an effective, feasible, economical and environmentally safe pest management approach (Pedigo, 1996; Gemechu *et al.*, 2012). Dobie (1984) suggested that the use of improved grain cultivars with resistance to storage pests could provide a key element in integrated pest management for stored grains.

The breeding of chickpea genotypes resistance to the adzuki bean beetle could, therefore, prove one of the possible approaches both for cost effectiveness, agricultural sustainability and food safety (Somta *et al.*, 2008). Thus, the objective of this study was to review mechanisms of host plant resistance in chickpea against Adzuki bean beetle infestation.

## **2. INSECT HOST PLANT INTERACTION**

Plants and insects have been living together for more than 350 million years. In co- evolution, both have evolved strategies to avoid each other's defense systems. This evolutionary arms race between plants and insects has resulted in the development of an elegant defense system in plants that has the ability to recognize the non self molecules or signals from damaged cells, much like the animals, and activates the plant immune response against the herbivores (Hare, 2011). Ecologically, in insect-plant interaction, interrelationship between two is important for the survival of both. Insects always look for a true and healthy host plant that can provide them proper food and could be suitable for mating, oviposition and also provides food for the offsprings. The nutritional requirements of insects are similar to other animals, and any imbalance in digestion and utilization of plant proteins by the insects' results in drastic effects on insect physiology. Furthermore, research on plant-insect interactions should be focused not only to genetic effects, but also toward the epigenetic regulation of plant defense pathways and insect responses, because a substantial body of evidence has been demonstrated for mobile siRNA signals and inheritance of DNA methylation based changes in gene expression (War *et al.*, 2012).

The interactions between bruchids and legumes are highly specific, as one insect species feeds on a very few seed species (Somta *et al.*, 2007). In this arms race, legumes have produced many toxic compounds to kill or deter bruchids. Although the biochemical defenses utilized by legumes against bruchids are effective, bruchids have developed counter-adaptations to most of these toxic chemicals (Chi *et al.*, 2009). Also the bruchids, in turn, have developed adaptive strategies to combat the effect of these toxic compounds.

The counter-adaptations in bruchid toward mung bean defensive traits have not been studied in detail, however, the adaptations of these pests to the defensive traits of the closely related legumes such as cowpea shows the possibility that bruchids could adapt to the mung bean defense system as well. These adaptations would have a major bearing on bruchid resistance in mung bean. Bruchids have evolved metabolic pathways to by pass the enzyme block. Protein anti-metabolites, such as proteinase inhibitors, lectins and alpha-amylase inhibitors are governed by a single gene and there is every possibility that bruchids could adapt to them by producing high levels of mid-gut aspartic and cysteine proteinase (Zhu-Salzman *et al.*, 2003). The major digestive cathepsin like cysteine proteases in bruchids are CmCPA and CmCPB (Koo *et al.*, 2008). When fed on a diet containing soybean cysteine protease inhibitor N (scN), *Callosobruchus maculatus* F. expressed high levels of CmCPB to neutralize the effect of protease inhibitors (Ahn *et al.*, 2004). Furthermore, the scN is hydrolyzed by aspartic proteases, which are further degraded by cysteine and serine proteases (Ahn *et al.*, 2004). Bruchids fed on scN-based diet showed the regulation of a large number of genes that are involved in counter defense and stress responses (Chi *et al.*, 2009). In *Callosobruchus maculatus*, the expression of scN-insensitive CmCatB occurs through the regulation of positive HNF-4 and negative CmSvp factors (Zhu-Salzman *et al.*, 2003).

Biotypic variation, i.e., genetic variability of the pest population, is one more challenge for the breeders. Development of biotypes has led to the breakdown of resistance in mung bean against bruchids (Fox *et al.*, 2010). A cultivar resistant to one biotype may be susceptible to another, and the development of acultivar with resistance against multiple biotypes is a complicated process.

### **3. CONTROL OF CALLOSBRUCHUS CHINENSIS**

#### **Cultural practices**

Cultural practice mainly involve manipulation of cropping systems/agronomic practices which are not only contribute for suppression of pest population, but also enhance the activities of natural enemies by creating favorable conditions (Bajwa and Kogan, 2004). These practices make the host environment less attractive and unfavorable for the survival, dispersal, growth and reproduction of the *C. chinensis* (Casida and Quistad, 1998). For instance, adzuki bean beetles infest beans in the field only when the pods are almost dry. Timely harvesting can therefore, ensure that the weevil not carried in to the store along with the beans (Stoll, 1988).

#### **Biological control**

Biological control of bruchids involves utilization of living organisms, known as biological control agents, to maintain the pest populations below damaging level, so that no loss occurs. The biological control agents include predators, parasitoids and pathogens (Mahr and Ridgway, 1993; Altieri *et al.*, 2005). Various species present in the formulation are natural enemies of the pests (Scholler and Flinn, 2000) and actively participate in the effective control of the bruchids. The *Apanteles* - flavipes parasitoid is used to control bean weevil and *Bruchus chinensis* (Stejskal, 2006), while *Dinarmus basal* is mostly used to manage the cowpea weevil and *chinensis* in cowpea (Sanon *et al.*, 1998).

#### **Chemical control**

Many researchers have reported the effectiveness of chemical pesticides including dusts, fumigants and sprays for the prevention of bruchid pests. However, the bruchids showed resistance to many traditional pesticides such as permethrin, lindane, pirimiphos-methyl, phos-toxin, methyl bromide and iodofenphos (Talukder, 2009), and their application at higher doses leads to the accumulation of toxic residues in the treated products. Furthermore, problems associated with chemical pesticides especially pesticide resistance, health hazards and environmental effects, have created a worldwide interest in the development of alternative approaches, such as exploitation of available host plant resistance.

## **Plant resistance**

Host plant resistance, i.e. the inherent ability of crop plants or varieties to restrict, retard or overcome pest infestations Kumar (1984), to insect pests, which provides a potential and sustainable option to be utilized in insect pest management. Resistant varieties have become a crucial element in the success of many on-going insect pest management programmes. For example, possibilities for effective storage insect pest management through genetic improvement of the host for resistance has thoroughly been reviewed for various crops (Shaheen *et al.*, 2006; Somta *et al.*, 2007; 2008). Ahmed and Yusuf (2007) found some level of insect resistance in groundnut (*Arachis hypogea*) to both Indian meal moth (*Plodia interpunctella*) and rust red flour beetle (*Tribolium castaneum*). Derera *et al.* (2000) also observed a kind of partial resistance in maize genotypes to the weevil (*Sitophilus zeamais*). Similarly, Gemechu *et al.* (2012) observed that Ethiopian chickpea landraces had considerable relative resistance to adzuki bean beetle.

## **Categories of Host Plant Resistance**

Host plant resistance is the inherent ability of crop plants or varieties to restrict, retard or overcome pest infestations (Kumar, 1984). Resistant varieties have become a crucial element in the success of many on-going insect pest management programmes. Three approaches (Edwards and Singh, 2006) are pursued by plant breeders to develop resistant cultivars: antibiosis, antixenosis (non-preference) and tolerance. The third approach may not be applicable to storage pests because damage once inflicted, since although seed respiration continues, individual kernels do not possess the capacity to "tolerate". Preferential feeding activities on the germ or starchy endosperm, irreversibly effect seed viability, dry matter loss and increases in moisture content that cannot be compensated for by the grain. Antibiosis and antixenosis are more appropriate forms of resistance against storage insects. Resistance processes involve morphological, physiological and/or biochemical mechanisms which range from simply minimizing the effect of insect attack to total death of insect pest. According to Edwards and Singh (2006), legumes as a group employ an extraordinary array of direct and indirect defenses including structural defenses, secondary metabolites and anti-nutritional compounds.

### **Antixenosis**

Antixenosis refers to non-preference of the insect pest due to one or more unattractiveness or unsuitability of the host for colonization, oviposition or both due to some morphological or biochemical features of the host. Morphologically, varieties with smooth, soft, and thin seed coats are preferred for oviposition than those with rough, hard, wrinkled and somewhat spiny seed coats (Shaheen *et al.*, 2006). A number of antixenotic traits are implicated by plants to avoid insect oviposition in both field plants and storage seeds (War *et al.*, 2013). These traits determine the host plant/seed resistance or susceptibility to oviposition and include surface chemicals, plant volatiles, spines and hairs (War *et al.*, 2013).

Traits contributing to resistance/susceptibility of mung bean to bruchids include seed color, texture, hardness, size and chemical constituents (Somta *et al.*, 2007). The cowpea beetle (*C. maculatus*) prefers smooth seeded to rough seeded cowpeas. Moreover, it doesn't oviposit on seed hilum, which is spongy in texture and rich fibrils. Scanning electron microscopy revealed deep pit in rough coated but not in smooth coated seeds; seeds infested with eggs where less attractive for further oviposition (Nwanze *et al.*, 1975). In faba bean, for instance, Desroches *et al.* (1995) found that the seed coat acted like a physical barrier for two bruchid species (*C. chinensis* and *C. maculatus*) and only 45-58% of the neonate larvae perforated the seed coat and reached the cotyledons. Research conducted in USA with 14 common chickpea varieties using selective preference and no choice tests indicated that the variety G109-1 was least preferred for egg laying by *C. analis*, *C. maculatus*, *C. chinensis*. It has a rough and spiny seed coat, a character deterrent to oviposition and absent in susceptible varieties (Raina, 1971).

Conversely, Lale and Kolo (1998) observed that resistance to *C. maculatus* in three cultivars of cowpea was conferred mainly by a combination of reduced oviposition and reduced egg-hatching which may be a reflection of the chemical rather than the physical characteristics of the seed coat. Likewise, Edde and Amatobi (2003) also found that seed coat has no value in protecting cowpea seed against attack by *Callosobruchus maculatus*.



### **Antibiosis**

Antibiosis is the mechanism by which a colonized host is resistant, because it has an adverse effect on an insect's development, reproduction and survival (Dent, 2000). The mechanism where the pests feed but factors in the plant have an adverse effect on them usually expressed as reduce the reproduction potential, slow the rate of development or kill the insect pest or indirectly affect the insect by increasing its exposure to its natural enemies (Panda and Khush, 1995; War *et al.*, 2012). According to Dahms (1972) mortality of early instars are considered as evidence of antibiosis. Some times the resistance plant contains a level of some nutrients that is too low to support the insects which therefore cannot deterrent or a larval growth inhibitor or a combination of these would confer resistance to pest attack. For example stem - borer infestation in rice may be influenced by the plant which in resistance varieties adversely affects larva growth. Again on the same crop resistance to green leaf hoper attack either possesses toxic materials or are unable to provide for the nutrition of the insect (Pathak, 1969). Allelochemicals are generally associated with antibiosis. Primary plant metabolites serve as the starting materials for the biosynthesis of secondary metabolites like lignin and tannin, alkaloid, quinine play an important role in the defense against insects as repellents, feeding inhibitors and toxins (Panda and Khush, 1995; War *et al.*, 2012).

Different studies have shown that antibiosis leads the insect pest to death. For example arcelins, phyto-hemagglutinins, alpha-amylases and anti-nutritional proteins collectively called lectins, which were cloned and sequenced in cultivated and wild species (Edwards and Singh, 2006). Similarly in Mung bean seeds contain lignins, quinines, alkaloids, saponins, non-protein amino acids and polysaccharides, and anti-nutritional seed proteins such as lectins, phyto-hemagglutinins, and proteinase inhibitors involved in resistance against bruchids (Wisessing *et al.*, 2008). Lectins are often resistant to proteolytic activity and function by binding to chitin or to carbohydrate targets in the insect mid gut, thereby blocking nutrient assimilation proteinase (War *et al.*, 2012).

In all the grain legumes the presence of  $\alpha$ AI-1 in their cotyledons, consequences significant increment in within-seed larval mortality and increases level of resistance to the bruchid species *C. chinensis*, *C. maculatus*, *C. analis* and *Bruchus pisorum* (Solleti *et al.*, 2008).

Again in maize, resistant hybrids have high levels of phenolic acids, which cause adverse effects in weevil feeding and survival (Sen *et al.*, 1994). In beans the existence of high concentration of heteropolysaccharide, which contain arabinose, xylose, rhamnose, glucose, and galactose play a significant role in controlling against *C. chinensis* and *A. obtectus*.

The failure of *C. chinensis* to develop in soybeans is attributed partly to the presence of saponins. Larvae of *Callosobruchus* spp. do not hydrolyze in vitro; Saponins may therefore be regarded as specific metabolic defense mechanism of the soybean against insects (Horber, 1974). Arcelin in the cotyledons, tannins in the seed coat, and phytohemagglutinin (PHA) within the seed including  $\alpha$ -amylase inhibitors, have been reported to confer resistance to storage pests (Gatehouse, 1990).

### **4. CONCLUSION**

The interactions between bruchids and legumes are highly specific, as one insect species feeds on a very few seed species. legumes have produced many toxic compounds to kill or deter bruchids. Although the biochemical defenses utilized by legumes against bruchids are effective, bruchids have developed counter-adaptations to most of these toxic. Also the bruchids, in turn, have developed adaptive strategies to combat the effect of these toxic compounds.

Resistance processes involve morphological, physiological and/or biochemical mechanisms which range from simply minimizing the effect of insect attack to total death of insect pest. legumes as a group employ an extraordinary array of direct and indirect defenses including structural defenses, secondary metabolites and anti-nutritional compounds.

In general, the inherent ability of crop plants or varieties to restrict, retard or overcome pest infestations, which provides a potential and sustainable option to be utilized in insect pest management.

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