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Review

Agronomic and biodiversity impacts of the blister beetles (*Coleoptera: Meloidae*) in the world: A review

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Blister beetles (Meloidae) are cosmopolitan in distribution except from New Zealand, Antarctica and most Polynesian islands. They act as minor pests for some crops and as major pests for others under certain conditions in several parts of the world. The present work reviews the most important agronomic impacts of various beetle species in different African, Asian, European and American countries, both the old world and new world, whether it has direct impact by damaging the foliage and feeding on crops or indirect effect by suppressing the populations of pollinators. Many host plants of the blister beetles belonging to various families were reported. The influenced insect biodiversity (bees and grasshoppers) by blister beetles were discussed. With regard to the management, different mechanical, physical, cultural, behavioral, chemical (synthetic insecticides and botanical insecticides), biological (predators and natural enemies), microbial (fungi, bacteria and nematodes) and genetic measures in different parts of the world were reviewed.

Key words: Host plants, adults, triungulins, insect fauna, bees, grasshoppers, natural enemies, management techniques, control measures.

INTRODUCTION

The Meloidae (blister beetles or oil beetles) is a beetle family (order Coleoptera) with about 120 genera and 3000 species. It is primarily distributed in temperate steppic and arid regions, and in sub-tropical and tropical savannas or other open habitats. These beetles are virtually cosmopolitan but absent only from New Zealand, Antarctica and most Polynesian islands (Bologna, 1991; Bologna and Di Giulio, 2011). Adults of blister beetles can be recognized by soft body, bright colouration and some other diagnostic characters (Borror et al., 1989; Arnett et al., 2002).

Not all species of blister beetles can be considered as serious agricultural pests. Mostly in the New World, all economic pests belonging to family Meloidae are species of vittata group (Meloinae: Epicautini) which are known as pests of garden and field crops (Adams and Selander, 1979) and cause economic damages to potato, tomato, alfalfa, soybeans, sugar beet, cotton and a variety of truck crops and vegetables (Towsend, 2000; Sansone, 2002). Some meloid species had been recorded as agricultural pests in the Old World such as the black oil beetle, *Meloe proscarabaeus* Linnaeus (Zimmermann, 1922; Coleman, 1983; Ali et al., 2005). Plant-host families of some Nearctic meloid beetles are Asclepiadaceae, Capparidaceae, Compositae, Cruciferae, Euphorbiaceae, Labiatae, Leguminosae, Malvaceae, Papaveraceae, Polygonaceae, Solanaceae and Zygophyllaceae (Erickson et al., 1976). Although the presence of blister beetles in different crops is usually not considered to be a serious constraint (Hill, 1975; Zhu et al., 2005), infestations of crops grown in small-holder plots may cause considerable damage because of the gregarious nature of adult beetles (Hall, 1984; Nikbakhtzadeh, 2004). As for example, more than 80% of flowers and developing pods of a prairie legume, *Baptisia australis* (Fabaceae) were damaged by the ash-gray blister beetle *Epicauta fabricii* (LeConte), thereby adversely affecting seed production in Kenya (Evans et al., 1989; Lebesa et al., 2012). On the other hand, the earlier larval instars (triungulins) of some meloid beetles are predaceous on the egg pods of grasshoppers (Orthoptera) and consequently provide a degree of natural (biological) control measure against these grasshoppers. Triungulins of some other meloid beetles are parasitoids or predators

on the solitary wild, or even the social, bees (Hymenoptera) suppressing their populations and subsequently prevent important pollinator measure for several crops (Parker and Wakeland, 1957; Selander, 1983, 1987; Hiller and Wittmann, 1994; Gaglianone, 2005; Zhu et al., 2008; Shanklin et al., 2010).

Cantharidin (as a haemolymph exudation) serves as a feeding deterrent to most predators, thereby protecting blister beetles and their eggs from consumption. However, some insects are attracted to cantharidin, and this compound is involved in the chemical communication among blister beetles (Young, 1984; Klahn, 1987). Because of the poisonous nature of cantharidin, these beetles periodically are inadvertently eaten (with feed such as hay) by the domestic livestock and horses causing severe illness or death. Also, human health can be affected when they come in close contact with the beetle adults or accidentally eating their bodies (Bahme, 1968; Panciera, 1972; MacKay and Wollenman, 1981; Beasley et al., 1983; Capinera et al., 1985; Blodgett et al., 1991).

The present work aims to review the agronomic impacts of blister beetles (Meloidae) and their effects on the biodiversity of some insect species. It discusses, also, the different management techniques in different parts of the world.

ECONOMIC DAMAGE OF AGRICULTURAL CROPS IN THE WORLD

The adult beetles are phytophagous and their damage to plants is caused by this stage only. Several decades ago, blister beetles had been observed feeding on plant materials, particularly of alfalfa, peanuts, soybeans and many other plant species (Ward, 1985). Adults of many meloid species are destructive pests of a wide variety of ornamental flowers and agricultural crops, including potato, tomato, various leguminous plants, flax, pulses, okra, tobacco, sugarbeet, onion, spinach, pumpkin, mango, citrus fruits and some other crops in various countries (Balachowsky, 1962; Beirne, 1971; App and Manglitz, 1972; Zethner and Laurense, 1972). Meloids are feeding on a wide range of host plants within families, particularly Asteraceae, Leguminosae, Compositae, Umbliferae, Solanaceae Fabaceae, Malvaceae, Convolvulaceae and Solanaceae (Selander, 1986; Arnett et al., 2002; Bologna and Pinto, 2002; Lebesa et al., 2011). Although the presence of blister beetles in different crops is usually not considered to be a serious pest (Hill, 1975; Zhu et al., 2005), infestations of crops may cause considerable damage because of the gregarious nature of adult blister beetles (Hall, 1984; Nikbakhtzadeh, 2004). Evans et al. (1989) reported more than 80% of flowers and developing pods of a prairie legume, *Baptisia australis* (Fabaceae) damaged by the blister beetle *E. fabricii*, thereby adversely affecting seed production.

In the old world

Cardona (1985) reviewed the insect pests of faba beans, lentils, and chickpeas in North Africa and West Asia and their economic importance. He reported some meloid species in different regions. Abate and Ampofo (1996) recorded the meloid infestation of the bean fields in different parts of the continents. In a study of the pest status and control of blister beetles in West Africa, Gahukar (1991) concluded that the blister beetles have gained importance in species diversity and as pests of food crops. However, severe infestations by meloid beetles reportedly caused considerable yield losses in certain parts of West Africa (Gahukar, 1984; Doumbia and Bonzi, 1985, 1986; Gahukar et al., 1986; Lal and Sastawa, 2000; Bologna and Pinto, 2002). Specifically, the blister beetles *Psalydolytta vestita* (Dufour) and *Psalydolytta fusca* Olivier were recorded as pests of millet (*Pennisetum americanum* Leeke) in Sahelian areas of West Africa (Doumbia, 1992). Grunshawa et al. (1994) observed the blister beetle *Psalydolytta pilipes* Maklin in the pear millet (*Pennisetum glaucum* L.) fields in north-west Mali, and *Pennisetum fusca* is the most serious pest of pearl millet among ten meloid species feeding on millet spikes in the Gambia (Zethner and Laurense, 1988). As observed by Ajayi (1985), blister beetles [such as *Coryna hermanniae* Fabricius, *Cylindrothorax audouini* (Haag-Rutenberg), *Cylindrothorax westermanni* Maklin, *Decapotoma afinis* Olivier, *Mylabris holosericae* Klug., *Mylabris fimbriatus* Mars., *Mylabris partinax* Per., *Psalydolytta aegyptiaca* Maklin] are considerable pests on the pigeonpea in Nigeria feeding on pearl millet panicles. Since they feed on flowers, the pollination is reduced and, thereby, grain yield is reduced as well (Ajayi et al., 1995). Ajayi et al. (1998) conducted some field trials in 1997 in Nigeria and their results indicated that *Coryna* spp. can cause severe yield losses, especially when high populations occur. This may explain why the blister beetle *Coryna hermanniae* was not usually reported as a dangerous pest of pearl millet (Ajayi, 1987; Ratnadass and Ajayi, 1995) and why Jago et al. (1993) did not consider *Coryna* spp. as a seriously economic pest. Nevertheless, Ajayi et al. (1998) obtained results supporting the view expressed by Tanzubil and Yakubu (1997) that pollen beetles are potentially serious pests of pearl millet in West Africa. Although Jago et al. (1993) had argued that blister beetles should not be considered as major economic pests of pearl millet (*P. glaucum*), Tanzubil and Yakubu (1997) reported that meloid beetles caused up to 69% yield loss in millet in Ghana from the onset of flowering until harvest.

Blister beetles are becoming very important pests in East Africa because of increasing demand for *Desmodium* seeds by small-holder farmers adopting the “push-pull” strategy for controlling stem borers and *Striga*. As an introduced crop in eastern Africa, there is limited information on its pests, especially blister beetles, which

represent a significant challenge to *Desmodium* seed production and the “push-pull” farming system (Agnew and Agnew, 1994; Cook et al., 2005; Lebesa et al., 2012). Ross (1998) recorded blister beetles as economic pests on bean in Malawi and Lebesa et al. (2012) recorded the blister beetles, *Hycleus* spp., as pest herbivores of *Desmodium* legumes in western Kenya. The available literature on meloids in Kenya, however, mainly documents *Coryna* and *Mylabris* as being associated with other leguminous crops (Abate and Ampofo, 1996; Hillocks et al., 2000). The *Mylabris* spp. and *Coryna* spp. were found to co-occur frequently on the same plant crop in various sub-Saharan countries (Lal and Sastawa, 2000). In Northern Africa, two meloid pests, *Mylabris oleae* Castelnau and *Mylabris calida* Pallas were reported in the alfa (*Stipa tenacissima* L.) stepp in the high steppic plain of Tlemcen (Algeria) (Khelil, 1994). Also, the influence of the density of *Mylabris* spp. on the damage to the tussock grass *Stipa tenicissima* (Gramineae) in Algeria was studied (Khelil, 1995). In Egypt, adults of *M. proscarabaeus* were observed feeding on leaves and flowers of faba bean (*Vicia faba* L.), peas (*Pisum sativum* L.), alfalfa (*Medicago sativa* L.), Egyptian clover (*Trifolium alexandrinum* L.) and onion (*Allium cepa*) in El-Farafra oasis, Western Desert (Ali et al., 2005). In a field study, El-Sheikh (2007) observed the newly emerged adults of *M. proscarabaeus*, in the same region, moving in swarms from rangeland to faba bean crops where they disperse and start feeding for a period of up to 50 days. Due to strong mandibles and long forelegs, these adult beetles feed on plant leaves and stems and finally destroy the whole plants. Siddig (1982) recorded blister beetles among the major pests of faba bean in the Sudan. Also, during August-September of the rainy season (2001) in Khartoum North, Sudan, an outbreak of the grey blister beetle, *Epicauta aethiops* (Lat.), occurred where an entire field of eggplant seedlings was ruined. High populations of such beetles were observed annually in the same area feeding besides eggplant, on other hosts particularly *Medicago sativa* and a wild solanaceous weed, *Solanum dubium*, where the latter seemed to be the most preferred host (Satti, 2003).

In Asia, blister beetles are widespread in pigeon pea. Adults cause considerable damage to plant due to plant feeding habits (Lawrence and Newton, 1982). In India, Ramamurthy et al. (1970) recorded the orange banded blister beetle *Mylabris pustulata* (Thunb) on cumbu, *Pennisetum typhoides* and determined its damage. Kundu et al. (1971) reported the blister beetles, *Mylabris pustulata* and *Lytta tenuicollis* (Pallas) as serious pests of sorghum in Rajasthan. *Epicauta* spp. were recorded as pests on soybean and eggplant from Himachal Pradesh (Lal, 1973). *M. pustulata* was recorded as a pest on the plant *Tecoma stans* (Shukla and Upadhyaya, 1973). *Cyaneolytta acteon* (Laporte) was recorded as a new pest of maize and bajra (Dhaliwal et al., 1974).

Anand (1978, 1979) recorded some blister beetles as pests on agricultural crops and suggested some control measures. Suman and Wahi (1981) reported the blister beetle *M. pustulata* as a common insect pest of many field crops (Khan et al., 2005b). Some blister beetles had been observed feeding on pigeonpea and other crops in the Kumaon Hills of Uttar Pradesh (Garg, 1985; Prasad, 1995). The Chinese blister beetle *Mylabris phalerata* (Pallas) was recorded as a serious pest of pigeonpea in the lower hills of Uttar Pradesh (Dutta and Singh, 1989). The blister beetles *Zonabris pustulata* Thunb. and *M. pustulata* were mentioned as pests on Cashew apple in Andhra Pradesh (Ayyanna and Ramadevi, 1987; Sreedevi et al., 2009). Considerable yield losses caused by blister beetle, *Mylabris* spp. in pigeonpea had been estimated in cowpea by Durairaj and Ganapathy (2000). Banded blister beetle *M. pustulata* was recorded as a pest on orchids in Kerala (Kumari and Lyla, 2001). The blister beetle *M. oculata* was reported as a serious pest of numerous ornamental, fruit and vegetable crops (Picker et al., 2002). The blister beetle, *Mylabris indica* Herbst was recorded as a polyphagous insect pest on oil seeds, pulse, ornamental and vegetable crops, which make a heavy loss by means of devouring the flowers (Selvisabhanayagam and Mathivannan, 2010). In cotton fields, *M. pustulata* was recorded as a minor or major pest (Sahayaraj and Borgio, 2010). Blister beetle, *M. pustulata* was observed by Rolania et al. (2012) feeding on flowers of cucurbitaceous vegetables, okra, cotton, mungbean, pigeonpea, and other plants. The cashew (*Anacardium occidentale*), a tropical evergreen tree grows now in many tropical countries including East Africa, S.E. Asia, India, Australia and others. Ayyanna and Ramadevi (1987) passively reported *M. pustulata* damage on cashew apple. Dwomoh et al. (2008) observed *Mylabris bifasciata* (DeGeer), feeding on inflorescence and tender foliage, but not on cashew apples. However, monitoring the blister beetle and its management are essential because the apple development is very important for quality yield of nuts (Sreedevi et al., 2009). Several meloid species were collected from the cotton fields and surrounding grasslands in Iran, such as *Alosimus syriacus rauterbergi* (Linnaeus), *Apalus necydaleus* (Pallas), *Zonitis (Zonitis) flava* Fabricius. The blister beetles *Mylabris beguttata* Gelb, *Mylabris frolovi* Germ, and *Mylabris schrenki* Gebl were reported as cotton pests in the Khorezm region and Karakalpakstan (Uzbekistan) (Khamraev and Davenport, 2004). The blister beetles, *Mylabris minae* Makhan & Ezzatpanah and *Hycleus golnaze* Makhan & Ezzatpanah, were collected from the flowers of *Citrullus vulgaris* from Mahallat, Markazi Province, Iran (Makhan and Ezzatpanah, 2011a, b). Some meloid species were observed in some cotton fields in the northern parts of Iran during 2008-2010 (Ghahari et al., 2012). The blister beetle *Epicauta waterhousei* (Haag-Rutenberg) was recorded as pest on groundnut, soybean, eggplants,

tomato, and slender amaranth (*Amaranthus viridis*) in Thailand (Kemal and Koçak, 2008). The adults of *M. phalerata* were found usually on flowers of cowpea (*Vigna unguiculata*) and loofah (*Luffa cylindrical*) in China (Zhu et al., 2006). Bhagwat et al. (1996) recorded some species of blister beetles during a survey of pigeonpea pests in Sri Lanka. Hong et al. (1992) achieved the first survey of pigeonpea insect pests, including blister beetles, in Vietnam. Pandey (1996) recorded some meloid species during a survey of pigeonpea insect pests in Nepal. Hariri and Tahhan (1983) evaluated the damage of major insects which infest faba bean lentil and chickpea, including the blister beetles, in Syria.

In Europe, the violet blister beetle *Meloe violaceus* Marsham had been reported to be attacking potatoes in Norway (Schoyen, 1916) and ornamental anemone in England (Hodson and Beaumont, 1929). Dealing with the feeding of *M. proscarabaeus* on the plant crops, Zimmermann (1922) found it as a serious pest damaging fields of red clover in Germany. Adult females of *M. proscarabaeus* had been observed grazing on the plant *Ranuchus* sp. in Cornwall (UK) (Coleman, 1983). Some species of Meloidae were reported as pests on various cultivated plants in Turkey (Bodenheimer, 1958; Nizamlıoğlu, 1964; Özer and Duran, 1968; Özbek, 1979; Giray, 1985; Stebnicka, 1987; Yildirim and Özbek, 1992). The four-spotted blister beetle *Mylabris quadripunctata* (Motschulsky) was recorded as a pest of soft wheat grains in Turkey (Ozbek and Szaloki, 1998). In Turkey, also, *Micromerus erivanicus* (Maran) is an important pest of flowers of *Vicia* spp. and *Onobrychis sativa*; also, *M. quadripunctata* is a pest on the soft grain of wheat (Özbek and Szaloki, 1998). The blister beetle *Teratolytta kulzeri* Kaszab inhabits locally at upper heights of the mountains of Turkey with the plant cover of malacophyllous steppe. This beetle was seen in copula on *Vicia* (Fabaceae), as well as on other plants like Poaceae (Kemal and Koçak, 2011). Alcobendas et al. (2008) observed the blister beetles *Epicauta haroldi* Heyden and *Epicauta quadrimaculata* (Fabricius) feeding together on flowers of Apiaceae in Central Spain.

In the new world

Early reports on the occurrence and economic damage of blister beetles in USA are easily seen in the literature (Sherman, 1913; Brimley, 1938). Gilbertson and Horsfall (1940) carried out a study on the blister beetles, as agricultural pests, in South Dakota. Adults of both the dark blister beetle *Epicauta murina* (LeConte) and *E. fabricii* favor food plants in Fabaceae (Werner, 1945). The blister beetle *M. campanicollis* was recorded as a pest attacking wheat, clover, oats and alfalfa, *Meloe niger* Kirby as a pest attacking asparagus and onions, *Meloe impressus* Kirby as a pest attacking rutabaga and potatoes, *Meloe tropicus* Motschulsky and *Meloe laevis* Leach as pests attacking potatoes (Pinto and Selander, 1970). The blister beetle *E. murina* had been observed feeding on alfalfa, *Convolvulus arvensis*, flax, legumes, *Melilotus officinalis*, potato plants, radish leaves and sugar beet (Arnold, 1976). The blister beetle *E. fabricii* had been observed feeding on flowers, foliage, or both alfalfa, *Amorpha canescens* (flowers), *Astragalus*, *Baptisia leucantha*, *Baptisia tinctoria*, beans, Siberian pea, clover, cowpeas, honey locust, Kentucky coffee tree, lupines, *Melilotus alba*, *Melilotus officinalis*, peas, Robinia pseudo-acacia and soybeans in Fabaceae, as well as on anemones, chrysanthemums, ironweed, potato, sugar beet, sweet potato, and tomato in other families (Werner et al., 1966; Blodgett and Higgins, 1988). There are several reports of *E. fabricii* damaging potato vines (Kirk and Balsbaugh, 1975), but these reports of other non-leguminous food plants (Kirk and Balsbaugh, 1975) may warrant confirmation. Attacks by Nuttall blister beetle, *Lytta nuttalli* Say, on the commercial canola crops were not frequent enough to constitute a major problem (Burgess, 1983). Adults of Clematis blister beetle *Epicauta cincerea* Fabricius had been reported to feed only on Clematis (Pinto, 1991). The first report of *E. cinerea* feeding on *Anemone canadensis* foliage in Wisconsin was provided by Pinto (1991). Adults of margined blister beetle *Epicauta funebris* Horn had been reported to feed on a variety of plants, including both native species in *Solanum* and crops in Solanaceae (Pinto, 1991). Adults were often found on flowers and had been collected on *Lupinus*, feeding on its flowers and seed pods (Halstead and Haines, 1992), on *Trifolium wormskioldii* in dried vernal pools, and on *Eriodium* (Selander, 1960). Blodgett and Sutherland (1984) and Blodgett et al. (1995) reported some blister beetles in alfalfa fields in New Mexico State. Certain species of *Lytta* in the western USA had been identified as 'species of concern' by the U.S. Fish and Wildlife Service (Halstead and Haines, 1992). Bailey et al. (1993) studied the management of Molestan blister beetle *Lytta molesta* (Horn) in alfalfa occurring in Central California. The first report of *E. murina* feeding on *Lathyrus venosus* foliage and of *E. fabricii* feeding on *Lupinus perennis* flowers was provided by Williams and Young (1999).

As documented in the present century, the striped blister beetle *Epicauta vittata* (Fabricius) had been observed as pests on some cultivated plants (Selander and Fasulo, 2000). Towsend (2000) studied the blister beetles in alfalfa in Kentucky. Striped blister beetle, *E. vittata* was observed feeding on vegetable crops such as bean, beet, carrot, cabbage, Chinese cabbage, corn, eggplant and melon. Among many vegetable crops, adults of *E. vittata* highly preferred the pigweed *Amarantus* spp (Capinera, 2003). The blister beetle *Lytta unguicularis* (LeConte), in the Great Smoky Mountains National Park, had been identified as 'species of concern' by the U.S. Fish and Wildlife Service (Mayor et al., 2006). Black blister beetle, *Epicauta pennsylvanica* De Geer, and spotted blister beetle, *Epicauta maculata* (Say) are

more widespread. Several other blister beetles may also be present in alfalfa, including *E. fabricii*, *Epicauta sericans* LeConte, *Epicauta immaculata* (Say), and *M. laevis* (Kinney et al., 2010). According to Blodgett et al. (2010), blister beetles occurring in Montana are most frequently in alfalfa hay and canola, but have been reported from other crops.

Blister beetles can be both direct and indirect pests depending on the crop and damage potential. The blister beetle *L. nuttalli*, a large purple and green blister beetle, was commonly observed feeding on caragana (*Caragana arborescens* Lam.) in the Canadian prairies and attacking on rapeseed crops near caragana hedges. The gregarious behaviour of these beetles, and their habit of assembling in clusters on their food plants, are well known (Selander, 1960). The same blister beetle readily attacks rapeseed in western Canada (Church and Gerber, 1977). The blister beetle *Epicauta atomaria* (Germar) was observed feeding on passion fruit (*Passiflora edulis* f. sp. *flavicarpa*) in the west region of São Paulo state, Brazil and losses in the yield were estimated by Rodrigues Netto and Guilhem (2000). Some notes were written by Martinez (1992) on the seasonal distribution of meloid adults and food plants, in the northwestern Argentine province of Salta. Some of these meloids are *Protomeloe wagneri* (Pic), *Acrolytta colon* Burmeister, *Pyrota homcioi* Martinez & Selander, and *Pseudomnitis impressithorax* (Pic). In Argentine, also, the blister beetle *Epicauta adspersa* (Klug) was found among the most abundant species of the amaranth pests during the vegetative stages (Fomsgaard et al., 2010). The blister beetles of the genus *Epicauta* were reported as the most important chewing herbivores in the dry forest of Santa Rosa National Park, Costa Rica (Chaves and Avalos, 2006). These blister beetles were also observed feeding on eggplant and sweet pepper in Chile (Leite et al., 2011).

In addition to feeding on foliage of several vegetable crops, Mohd et al. (1996) observed blister beetles during a study of the occurrence of broad bean bushy dwarf virus strain in Uttar Pradesh (India). Thus, some species of blister beetles have been implicated in the transmission of bean *pod mottle virus* to soybean (Capinera, 2003).

INFLUENCED INSECT BIODIVERSITY

Meloid beetles are probably the most diverse and wide-spread group of Coleoptera that parasitize bee nests, especially the subfamily Nemognathinae (Selander, 1987). Many reports have been found in the literature for the parasitizing (or predation) by the first instar larvae (triungulins) of many blister beetles on the eggs and provisions (such as pollens) of the wild solitary bees. The larvae of some meloid species seem to feed principally on ground nesting bees (Hymenoptera: Andrenidae, Halictidae, perhaps others) and the bees' nest provisions (Capinera, 2003). On the other hand, larvae of the blister beetle, *M. phalerata* were recorded as predators on eggs of the grasshopper *Chondracris rosea rosea* De Geer (Orthoptera: Acridiidae) in China (Zhu et al., 2006) and larvae of the blister beetles *Epicauta* spp. were reported as predators on eggs of the grasshoppers (including many crop-damaging *Melanoplus* spp.) and crickets. In rare cases, larvae of certain blister beetles of subfamily Meloinae parasitize wasps (Hymenoptera: Sphecidae and Vespidae) (El-Gharbawy, 2006).

Effects on solitary and social bees

In general, triungulins of the blister beetles of other than Epicautini and Mylabrini were observed feeding on the immature stages and provisions of wild and solitary bees (Selander and Fasulo, 2010). For some details, reports on the blister beetle *Tetraonyx (Tetraonyx) sexguttata* Latreille showed evidence that it parasitizes on soil-nesting bees, such as *Epicharis dejeanii*, *Epicharis nigrita* and *Centris* (Selander, 1983; Hiller and Wittmann, 1994; Gaglianone, 2005). The first larval instar of blister beetle *Meloe franciscanus* Van Dyke highly adapted to phoresy on the solitary bee *Habropoda pallida* in California (USA) (Hafernik and Saul-Gershenz, 2000; Bologna et al., 2008).

Concerning the social bees, triungulins of *Meloe* spp. frequently attach honey bees visiting flowers in an association known as “phoresy” which is a special kind of commensal relationship in which one organism 'phoront' attaches to another 'host' for a limited time period to enhance dispersal of the phoront from the natal (birth) habitat, resulting in colonization of a new and potentially better habitat (Resh and Carde, 2003). Larvae of *Meloe cavensis* Petagna were reported as less pest to honey bees in Libya (north Africa) (Zanon, 1922) and larvae of the variegated blister beetle *Meloe variegatus* Donovan were reported to have seriously damaged or destroyed colonies of honey bees in this way in Eurasia (Minkov and Moiseev, 1953). Some other authors reported the attacking of certain *Meloe* spp. on the social bee hives, particularly the honey bee *Apis mellifera* (Hymenoptera: Apidae) causing a serious damage of this beneficial insect. Liakos and Katrali (1984) observed the attacking of triungulins of *M. proscarabaeus* on the honey bee as a first record in Greece. Leka (1986) recorded similar attacks on honey bees in Albania as the first record.

To imagine how damage can be caused to bees by the phoretic meloid larvae, some meloid species require only the pollen contents of one bee's larval cell to complete their development, but others need more and attack several cells. In doing so, larvae of these species frequently kill and consume the immature stages of the host bee as well as consuming their pollen stores (Selander, 1960). Although a heavily attacked bee may die within minutes due to the damage of its nervous system since the invasion of meloid larvae has been

carried out from the ventral side, Zanon (1922) suggested that the death of the infested bee has been caused by a venom containing cantharidin. In addition, it was suggested that the death may be due to the ingested haemolymph of the bee by the larvae of *M. variegatus* (Orosi-Pal, 1936; Bailey and Ball, 1991). As discussed by Pinto and Selander (1970), much serious damage to colonies of honey bees results from infestations of larvae of species classified in the subgenus *Lampromeloe*. The larvae burrow through the intersegmental membranes of the abdomen of the adult bee and partially enter the body cavity. This frequently kills the host, and as infested bees die in the hive the beetle larvae apparently abandon them and infest other bees, often including the queen herself. Triungulins of *Meloe* spp., as for example, are sometimes so numerous that they can kill the bees simply by overloading. The triungulins, safe from their hosts, are transported by them right into the hives. Once inside the colonies, the triungulins drop off, attack and devour eggs, brood (*M. franciscanus*) and honey (*M. proscarabaeus*). Although several reports indicated some limitation of various bee species as pollinators, Blochtein and Wittmann (1988) obtained results indicating a low level of parasitism by the meloid beetle *Nemognatha nigrotarsata* (Fairmaire and Germain) and thus should not limit the use of leafcutter bees as pollinators in Rio Grande do Sul (Brazil).

Effects on grasshoppers

On the basis of the grasshopper egg surveys in the western and mid-western parts of USA (between 1936 and 1950), destruction of egg pods of the grasshoppers *Melanoplus* spp. and *Camnula pellucida* (Scudd.)(Orthoptera: Acrididae) was caused by the meloids *E. maculata*, *Epicauta puncticollis* Mannh. and *E. fabricii* (Parker and Wakeland, 1957). Thereafter, Rees (1973) listed 26 species of Meloidae whose larvae are known to attack grasshopper eggs in North America. Striped blister beetle, *E. vittata*, was reportedly closely associated with grasshoppers that produce large egg-pods, particularly two-striped grasshopper, *Melanoplus bivittatus* (Say) and differential grasshopper, *Melanoplus differentialis* Thomas (Selander, 1982). The Chinese blister beetle, *M. phalerata*, is a natural enemy of the grasshopper *Chondracris rosea rosea* (De Geer) (Zhu et al., 2008) and the black blister beetle *E. pennsylvanica* is considered among the egg predators of the grasshoppers, such as red-legged grasshopper *Melanoplus femurrubrum*, two-striped grasshopper *M. bivittaatus* and *M. differentialis* in USA (Shanklin et al., 2010). Predatory meloid species on the grasshopper *Patanga succinct* are: bean blister beetle *Epicauta maclini* Haag-Rutenberg, *E. waterhousei* and *M. phalerata* (Suasa-ard, 2010). In general, larvae (triungulins) of the meloid genera and species in the tribes Epicautini and Mylabrini feed on the grasshoppers' eggs (Selander and Fasulo, 2010).

Economically, studies of grasshopper egg-pod destruction in western states of USA during a period of grasshopper abundance, for example, documented that 8.8% of pods were damaged by *Epicauta* blister beetles. Those meloid species of the genera *Zonabris*, *Epicauta* and a few species of *Tetraonyx* and *Macrobasis* attack and develop on the egg-pods of grasshoppers destroying huge numbers of eggs annually. Although the blister beetles eventually contribute materially to the suppression of grasshopper population outbreaks and may be used as a biological control measure against these grasshoppers, the higher numbers of blister beetles often cause greater crop injury during, and immediately after, the periods of grasshopper abundance (Parker and Wakeland, 1957). It is noteworthy that larvae of some meloid beetles predate on eggs of some other meloid beetles (Selander, 1982). Finally, meloid larvae have not yet been used as an effective biological control measure for the grasshopper pests.

CONTROL MEASURES AND MANAGEMENT TECHNIQUES

Mechanical and physical control

To an earlier point in time, Baerg (1925) discussed some control measures for blister beetles in Arkansas (USA). Different types of alfalfa harvest equipment and operation were evaluated by Blodgett et al. (1995). The agronomic impacts of blister beetles of the genera *Lytta* and *Epicauta* had been studied in Montana by Blodgett et al. (2010) who discussed some of the control measures. If blister beetles are present at harvest, it is important to use harvest equipment that allows the beetles to escape from mowed and swathed forage because the type of equipment and its operation has an impact on blister beetle mortality during hay harvest. In Gambia, the blister beetle *P. fusca* is the most serious pest of pearl millet (*Pennisetum glaucum*) among ten meloid species feeding on millet spikes. A traditional control method using fires in the fields was shown to repel *P. fusca* from spikes when a fuel which produced heavy smoke (groundnut Shells, moist wood) was used (Zethner and Laurense, 1988).

Cultural control

Cultural control involves modification of standard farm practices to avoid pests or to make the environment less favorable for them. There are several commonly used methods such as crop rotation, sanitation, polyculture, strip cropping and trap cropping (adapted from Mahr and Ridgway, 1993). Concerning the blister beetles, Gahukar (1991) recommended a regular intensive weeding and early crop establishment for the management of *P. fusca* and *P. vestita* which are among the economically serious pests of food crops in West Africa. Nead (1994) studied

the development of alternative control strategies for blister beetles on lupin in the northern Great Plains. Then, Nead et al. (1996) examined several alternative legumes for potential production in the western prairie regions of North America, including lupins (*Lupinus* spp.), faba bean (*Vicia faba* L.), chickpea (*Cicer arietinum* L.) and lentil (*Lens culinaris* Medikus). In USA, reducing weedy host plants and harvesting prior to bloom are sound management tactics (Kinney et al., 2010). Several management options were given by McBride (2012) to reduce the number of blister beetles found in forage crops but none eliminated the problem.

Behavioral control

The majority of insect species uses sex pheromones to mediate mate finding by way of sexual attraction. Most sex pheromones stimulate behavior directly related to mating. Generally, this behavior is either attraction to the opposite sex or part of courtship interaction (Landolt, 1997). As available to this study, literature contains no reports on the use of behavioral control agents against the blister beetles other than the following study. The blister beetle *Mylabris designata hacolyssa* Rochcbrune is a pest of a variety of crops in the western provinces of the Sudan. Hall (1984) carried out a field study for estimating the responses of these beetles to visually attractive traps. About 43.3% of approaching beetles were captured by a blue Manitoba trap whereas 50 to 80% efficiency of blue sticky targets decreased to 10-20% over three days due to an increasing close range olfactory repellent effect on the beetles. These traps may be used as a cheap and environmentally acceptable alternative to the use of insecticides for control of this blister beetle.

Chemical control

In most cropping systems, insecticides are still the principal means of controlling pests once the economic threshold has been reached (Hoffmann and Frodsham, 1993). The synthetic and natural pesticides are usually used for controlling the blister beetles in several parts of the world, but the majority of literature reports concerned with the evaluation of the insecticide toxicity, whatever their origin. With regard to the synthetic insecticides, six compounds (Thiodan, ethion, malathion, Dibrom, Sevin and Trithion) were tested on vegetable crops (Young and Ditman, 1959). All insecticides were highly effective against the margined blister beetle *Epicauta pestifera* Werner. In India, the relative toxicity of some important pesticides was determined to the adults of *M. pustulata* (Singh et al., 1968), *L. tenuicollis* (Gupta and Kishore, 1973), and *Cylindrothorax tunuicollis* (Pallas) (Kumar et al., 1984). Comparative toxicity of organochlorine, organophosphorus, carbamate and pyrethroid insecticides was evaluated on the blister beetle *M. phalerata* and oil beetle *Epicauta* sp. (Barwal and Rao, 1988). The histopathological effects of insecticides propetamphos and dichlorvos on the ovaries of *M. pustulata* were studied using beetles collected from the field in Maharashtra, India (Mulmule et al., 1988). In Swaziland (Southern Africa), Mensah (1988) carried out some field trials for two seasons on the effects of insecticides dichlorvos, cypermethrin and monocrotophos on the blister beetle *Mylabris amplectens* Gerstaecker to determine the damage and yield losses of three cowpea cultivars. In the second season, cypermethrin and monocrotophos were most effective. Zethner and Laurense (1988) assessed the toxicity of carbaryl, trichlorphon and malathion against the adult blister beetle *P. fusca* and obtained satisfactory results. After treatment with carbaryl, the egg masses of *M. pustulata* were dehydrated and their carbohydrate and lipid reserves were depleted which caused deterioration in the egg hatchability in addition to a suppression of the oviposition (Bharathi and Govindappa, 1990). In Pakistan, acetylcholinesterase activity in *M. pustulata* was reduced by the synthetic insecticides, malathion and chlorpyriphos (Tahir et al., 1992). The development of resistance in *M. pustulata* to synthetic pyrethroids, carbamate, organophosphates and chlorinated hydrocarbons was experimentally determined (Dhingra and Prakash, 1992). Adults of *M. pustulata*, also, were treated with two organophosphrus insecticides, malathion and monocrotophos and the histopathological effects on digestive tract were investigated (Awasthi and Dubey, 1995). In addition, Bhardwaj (1996) achieved a study to evaluate the toxicity of some insecticides on this blister beetle. The effect of carbaryl on the aminotransferases in the mingut of *M. pustulata* was investigated. In a study, it was concluded that cypermethrin + neem oil and cypermethrin + citronella oil provided the desired combination to overcome resistance in *M. pustulata* (Dhingra, 1996).

In the present century, bioefficacy studies for the insecticides Beta-cyfluthrin, deltamethrin, endosulfan were carried out on the sponge gourd against blister beetle, *M. pustulata* in India. Beta-cyfluthrin and deltamethrin treatments effectively controlled blister beetles in sponge gourd in comparison to endosulfan and neemAzal (Dikshit et al., 2001). Actellic (25 EC), a synthetic insecticide, was applied against the blister beetles *Mylabris temporalis* Wellni and *Mylabris trifasciata* (Thumb.) in the okra (*Abelmoschus esculentus*) field in Ghana. It caused a significant reduction in the insect damage to leaves, flowers and fruits (Obeng-Ofori and Sackey, 2003). The sublethal doses of carbaryl markedly inhibited the activity levels of enzymes in *M. pustulata*. So, it is possible that chronic exposures of the beetles to carbaryl may induce impairment in protein synthesis (Bharathi, 2008). Blister beetles of the genera *Lytta* and *Epicauta* in Montana (USA) were controlled by insecticides for reducing their

populations.

However, since blister beetles are mobile and may move into the crop at any time, the residual activity of registered insecticides may not be sufficient to control these beetles up to harvest (Blodgett et al., 2010). In view of the significant damage potential of *M. pustulata* in India, a number of insecticides were evaluated against the beetles in the laboratory. The insecticides thiodicarb, chlorpyriphos, quinalphos and cypermethrin significantly reduced the blister beetle population (Rolania et al., 2012). In USA, several insecticides, registered for use on alfalfa, dry beans, soybeans, potatoes and sugarbeets, showed good activity on some blister beetles (Kinney et al., 2010; McBride, 2012).

Although the majority of synthetic insecticides are typically more effective and usually used to control several pests, economic justification is needed for the research and development of such products. On the other hand, the more specialized market of the biorationals makes their long-term economic return less favorable (Hoffmann and Frodsham, 1993). However, there are problems of synthetic insecticide resistance and negative effects on non-target organisms including man and the environment (Dorow and Rembold, 1993). Botanical pesticides, as alternatives to the synthetic pesticides, have been used in different parts of the world for controlling many of the serious pests. In connection with the blister beetles, Tahir et al. (1992) evaluated the bioefficacy of nicotine and azadirachtin on *M. pustulata* and the acetylcholinesterase activity was inhibited in 29 and 59%, respectively, at the higher concentrations while the lower concentrations of azadirachtin stimulated the enzyme activity. Aqueous leaf extracts of 20 plant species were sprayed by Oudhia (2000) on *Hibiscus rosasinensis* flowers to determine their toxicity against *M. pustulata*. He obtained mortality of 23-35% against this beetle with the aqueous leaf extract of *Lantana camara*. Extracts of some plant species exhibited high toxicity while the other did not cause mortality. Aqueous seed extracts of the neem tree *Azadirachta indica* were applied against the blister beetles *M. temporalis* and *M. trifasciata* in the okra field in Ghana. It caused a significant reduction in insect damage to the leaves, flowers and fruits (Obeng-Ofori and Sackey, 2003). The blister beetle *M. pustulata*, as an important pest on cowpea in Nigeria, had been treated with aqueous extracts of *Zanthroxylum zanthroxloides, Allium sativum, Datura metel* and *Annanas senegalensis* in comparison with Decis, as a synthetic insecticide (Degri et al., 2010). Histopathological effects of the sublethal concentration of Vijay neem on the fat body of males of the polyphagous pest *M. indica* were evaluated. Drastic changes were observed in the fat body cells including nuclei and cytoplasm (Vivekananthan et al., 2010). As concluded by these authors, these plant extracts which are readily available, effective and very easy to prepare could be an alternative to synthetic insecticides for protecting cowpea flowers from *Mylabris* species. The ovicidal action of seven plant origin insecticides was studied against eggs of *M. pustulata*.

Among the botanical extracts tested, *Caesalpinia crista* (seed-glycosides) was found to be comparatively most toxic against the eggs followed by *Centratherum anthelminticum* (seed-oils) (Johri et al., 2004; Johri and Johri, 2011).

Biological control

Predators help to maintain a balance among organisms, both by consuming prey and by altering prey behavior and prey habitat selection (Smee, 2012). Predators may increase the biodiversity of communities by preventing a single species from becoming dominant. Such predators are known as keystone species and may have a profound influence on the balance of organisms in a particular ecosystem (Botkin and Keller, 2010). Surprisingly, little is known concerning the natural enemies of blister beetles, reflecting their minor status as crop pests and the subterranean habits of larvae. Undoubtedly, starvation of first instars is a very important factor during most seasons, and cannibalism is prevalent among larvae. Ant-like flower beetles (Coleoptera: Anthicidae), false ant-like flower beetles (Coleoptera: Pedilidae), and some plant bugs (Hemiptera: Miridae) have been implicated as mortality agents of blister beetles (Selander, 1981). The larva of the blister beetle *Epicauta atrata* (Fabricius) had also been shown as predatory on eggs of *E. pensylvanica* (Selander, 1982). In addition, *E. vittata* are attacked by robber flies (Diptera: Asilidae) and avian predators, including meadowlark, *Sturnella neglecta* Audubon; bluebird, *Sialia sialis* (Linnaeus); and scissor-tailed flycatcher, *Muscivora forficata* (Gmelin). There are reports of predation of striped blister beetle eggs by the predatory blister beetle *E. atrata* (Capinera, 2003). The natural enemies of immaculate blister beetle *E. immaculata* were not precisely defined, but undoubtedly are the same or similar to those affecting black blister beetle, *E. pennsylvanica*, and *E. vittata* (Werner, 1945; Pinto, 1991).

There have been few observations of meloids being eaten by amphibians (Larson, 1943) and lizards such as *Phrynosoma* (Selander et al., 1963) and Texas horned lizard, *Phrynosoma cornutum* which predates on the meloid beetle *Megetra cancellata* (Brandt and Erichson) (Cohen and Cohen, 1990). The female southern house spiders, *Kukulcania hibernalis*, readily consumed blister beetles, *Lytta polita*, regardless of the cantharidin content. In contrast, free-ranging raccoons, *Procyon lotor*, initially ate many *L. polita*, particularly female beetles that contained only one-third as much cantharidin as males, but when retested the raccoons ate only a few meloids (Carrel, 1999). Unfortunately, the available literature contains no valuable studies on the use of natural enemies as a control measure against the blister beetles.

Microbial control

As biopesticides is used against the blister beetles, the available literature contains several reported works about fungi, but there are very few reports about bacteria and no report about viruses and nematodes. Recent advances in fungal production, stabilization, formulation, and application have led the way toward commercialization of a large number of new fungus-based insecticide products (Faria and Wraight, 2007; Wraight et al., 2001). Since simple, viable and cheapest mass production technology (Sahayaraj and Namasivayam, 2008) fungi are available in the literature, it is worthwhile to test their bioefficacy and possible utilization of these fungi in the integrated pest management (IPM) programs. *Beauveria bassiana* Bals. Vuillemin is the most popular among the registered mycoinsecticides. One of the principal reasons for its popularity is its very wide host range of ~750 insect species (Khan et al., 2005a).

Several reports focused on the pathogenicity of fungi, of certain families, against blister beetles. Rojas (1983) determined the pathogenicity of *Beauveria* for the control of three defoliating Coleoptera among which was a blister beetle *Epicauta* species in Peru. Miranpuri and Khachatourians (1994) examined the effectiveness of various *Beauveria bassiana* strains isolated from certain insect species other than blister beetles. The *B. bassiana* strain SG 8702 proved to be the most effective against the Nuttall blister beetle *L. nuttali*. Samples of 34 *B. bassiana* isolates were bioassayed on *M. pustulata* at four conidial concentrations. The lowest dose tested (104 conidia/insect) did not cause insect mortality. The isolates that induced mortality at the lowest dose tested were concluded to be highly virulent with a lower threshold dose required for successful infection (Devi and Rao, 2006). The fungus *Metarhizium anisopliae* has a wide host range and individual isolates can be considerably host-specific. In Tamil Nadu, India, Sahayaraj and Borgio (2010) reported that adults of *M. pustulata* may be useful to be controlled by the fungi *B. bassiana* and *Verticillium lecani* Viegas in field conditions. Identification of genes expressed during pathogen-host interactions (cuticular penetration) helps to understand the genetic basis of *B. bassiana* pathogenicity. Khan et al. (2005a) carried out a study to determine the expression profile of selected genes using PCR amplification from the RNA samples obtained from cultures grown on different insect cuticles among which was the blister beetle *M. pustulata.*

Concerning the bacteria, a commercial formulation of *Bacillus thurigiensis* was applied against *M. temporalis*, *M. trifasciata* in the okra field in Ghana. The application resulted in higher yield of marketable fruit of okra than untreated plants (Obeng-Ofori and Sackey, 2003). Regarding the Nematoda, no trials were carried out for their use as control agent against blister beetles. As a first record of the nematode association with blister beetles, some species belonging to family Mermithidae were isolated from the meloid beetle *Meloe violaceus* Marsham. Also, the rates of their parasitism could be influenced by the toxic compound cantharidin that these beetles possess (Lückmann and Poinar, 2003). However, there is no report in the available literature on the use of nematodes as control agent against blister beetles.

Genetic control

“Genetic control” is one of the more interesting aspects of the blister beetles' management. This advanced trend includes some genetic engineering technologies to produce resistant plant varieties against the pests. However, the available literature contains no reports about the genetically engineered strategic crop plants with additional defensive capabilities against blister beetles, but only some works about the evaluation of naturally occurring plant varieties. It is noteworthy to mention that these efforts may be necessary and represent the first step in the main scope since host plant resistance among crop plants is a major part of IPM programs (Sachan, 1990; Jallow et al., 2004). In several cereal and forage crops, the host plant resistance to insects has been an extremely successful technique for suppressing pest populations or damage. In contrast, there has been much less use of this method for the management of insect pests in commercial vegetable production (Smith, 1989).

Thirty-one soybean (*Glycine max*) cultivars in the seedling stage were subjected to *E. vittata* infestation in USA. The cultivar PI2270H7 exhibited a high level of resistance to the pest and sustained only a small amount of feeding damage (Clark et al., 1972). Zhu and Higgins (1994) investigated the responses of blister beetles to three alfalfa varieties. The three-striped blister beetle, *E. occidentalis*, and margined blister beetle, *E. funebris* consumed greater amounts of younger alfalfa than of mature alfalfa. These authors concluded that several plant parameters may partially influence the occurrence of the blister beetle *E*. *occidentalis*. In India, the feeding activity of gloomy blister beetle *Rhobdopalpa atripennis* Fabricius on the host plant *Luffa cylindrica* was studied under the laboratory conditions (Shukla and Singh, 1982). The beetle was observed feeding on the leaves of *L*. *cylindrical* significantly more than other plant parts. It had been suggested that the plant leaves have certain chemical attractant to the beetle. Because adults of the blister beetle *P. fusca* are the most serious pest of pearl millet in The Gambia, Zethner and Laurense (1988) carried out a study to determine the resistant varieties of the plant against this pest. Varieties of millet with long-bristled spikes were shown to be far less susceptible to *P. fusca* than varieties with very short-bristled spikes. Because the blister beetles *Mylabris* and *Coryna* spp. infest the pearl millet in the Nigerian Sudan savanna, Lal and Sastawa (2000) carried out a study to estimate the

resistance of 6 millet cultivars against these pests.

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