COLORADO BEETLE: PEST ON THE MOVE

Don Weber from USDA-ARS describes this infamous pest of potato and continuing efforts to outsmart it

Introduction

From Poland to Italy and the United States to Uzbekistan, the Colorado beetle is a ten-striped insect icon. As it approaches its sesquicentennial as an infamous pest of potato, this chrysomelid leaf beetle is all too familiar to most North Americans and Europeans involved with gardening or larger-scale agriculture (Figure 1). Although often slow-moving, this pest is still on the move, spreading into temperate central and east Asia, where over one-fourth of the world's potatoes help to feed half of the world's population. Where potatoes thrive, in the northern hemisphere, the Colorado beetle threatens their growth and yield. To say this beetle is a moving target is a truth on several levels.

A year in the life

Each spring across many of the farms of North America and Europe, overwintered Colorado beetles adults emerge from the soil and begin their search for potato, tomato or aubergine plants to feed upon. This commences with walking, but after a few days if unsuccessful in finding a host plant, beetles may continue their search with flight. So starts the season for this notorious pest, and depending on climate and food it may entail one to several generations (Figure 2). Eggs, laid on leaf undersides in masses of 20 to 60 (several hundred to a few thousand total per female), soon hatch into relentlessly leaf-feeding larvae which eat about 40 cm^2 of foliage. The fourth instar larva drops to the ground and digs down a few cm to pupate, emerging 10 to 20 days later as a soft-shelled adult. Also a voracious leaf-feeder, the adult consumes up to 10 cm^2 per day (Ferro *et al.*, 1985). Depending on food, photoperiod, and temperature, this new adult may mate and reproduce, or after feeding, bury itself and spend months in diapause before emerging from its underground chamber and completing the seasonal cycle.

Extent and damage

When first noticed in 1811 the Colorado beetle fed on the thorny native perennial, buffalobur (*Solanum rostratum*) and related species in western North America. Just four decades later, however, it was recorded in Nebraska attacking the newly popular potato crop. The subsequent explosion in geographic range was spectacular, reaching the US and Canadian Atlantic coast before 1880 (Casagrande, 1987). Following several isolated European introductions, it finally established in France in 1922 and since then spread to all of Europe (except for Scandinavia and the British Isles), and into Turkey, Iran, central Asia, and western China (Jolivet, 1991). Such was the significance and fear of this pest that it was allegedly used several times during World War II to bombard enemy fields (Garrett, 1996). The range is now about 8 million km^2 in North America and a like area in Eurasia. Climatically favorable areas not yet infested

Figure 1. **Adult Colorado beetles (*Leptinotarsa decemlineata*) consume potato foliage voraciously, as do the larvae.**

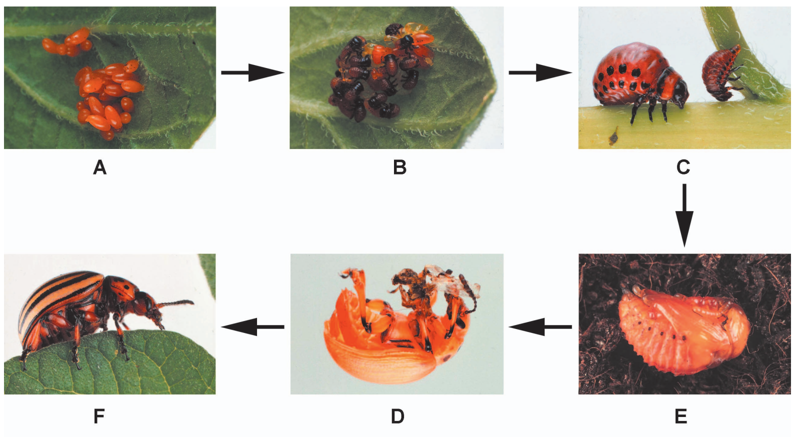

Figure 2. **Life stages of the Colorado beetle: (A) egg mass; (B) hatching egg mass; (C) larvae; (D) pupa under the soil; (E) callow adult just emerged from pupa; and (F) adult. Photos by Doro Röthlisberger, Zoologisches Museum, Universität Zürich.**

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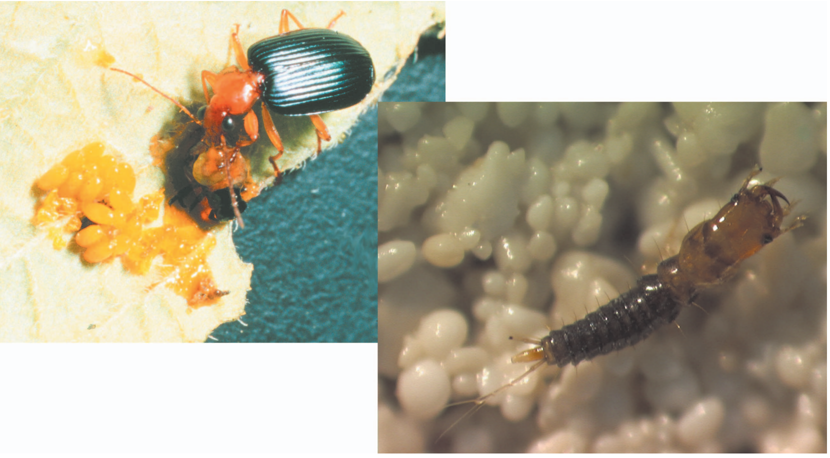

Figure 3. ***Lebia grandis*, a predator and parasitoid of Colorado beetle (A) adult feeds on Colorado beetle larvae and eggs; (B) 1st-instar *Lebia* larvae, which seeks out the Colorado beetle pupa as a host to be eaten underground.**

Figure 4. ***Myiopharus* sp., a tachinid fly parasitoid, emerging head-first from a Colorado beetle adult in which it has overwintered as an early-stage larva.**

include east Asia, parts of the Indian subcontinent, temperate South America and Africa, and Australia.

Colorado beetle attacks potato, aubergine, and in some regions tomatoes, as well as some other plants of the nightshade family. In areas where tomatoes abound, it has evolved an improved fitness on this plant, as in southeastern USA and Uzbekistan. Even where it does not thrive on tomato, large numbers may damage this valuable crop. In contrast, potato plants can tolerate light to moderate defoliation at certain times of year, but without control, major to complete crop loss is common. A typical economic threshold is one adult equivalent per plant, where small larvae are counted as equivalent to 1/4 of one adult, and large larvae (3rd and 4th instars) equate to 2/3 of an adult. Yield impact is dependent on timing, variety, and other crop stresses. In early years, control relied on hand-picking, but this gave way to arsenical insecticides and in the 1940s the more powerful synthetic chemical controls.

Resistance to pesticides

Perhaps no insect better exemplifies the potential of insects to evolve resistance to insecticides. Within the first decade of its introduction to great fanfare, DDT was failing against Colorado beetle in the intensive potato-growing region of Long Island, New York, USA. Resistance to many other chlorinated hydrocarbons, organophosphates, carbamates, and pyrethroids (Forgash, 1985), has prompted development of still more chemical controls, and also a spate of research into a variety of alternatives ranging from the practical to the peculiar. These include native and introduced biological controls, transgenic crops, crop rotation, trap crops, trenches to disrupt crop colonization, propane-fueled flamers, and enormous crop vacuums. Collectively and as complements to chemical control, these are essential tactics to manage the pest and help avert resistance.

Research on the move

For an insect that is the focus of thousands of published scientific articles, there is still surprisingly much to learn. In just the past few years, plant-based attractants as well as a male-produced aggregation pheromone, (*S*)-3,7-dimethyl-2-oxo-6-octene-1,3-diol, have been discovered (Dickens, 2000; Dickens *et al*., 2002). The exact role that these surprising substances will play in pest management remains to be seen, but perhaps in combination with selective toxins and/or antifeedants, a push-pull behavioral strategy can succeed in suppressing the Colorado beetle where whole-field treatments have eventually failed due to selection of resistance.

Natural enemies

Natural enemies of Colorado beetle may sometimes keep the pest below economic threshold, but not reliably in most current cropping systems. Predatory stink bugs (*Podisus* and *Perillus*) as well as several species of lady beetles and carabid ground beetles, spiders and harvestmen are common predators. During the 1980s, the egg parasitoid wasp *Edovum puttleri* was introduced to the USA from Colombia, and enjoyed success as an inundative biocontrol particularly in aubergine (Hough-Goldstein *et al*., 1993; Lashomb *et al*., 1987). Two of the most prominent natural enemies native to North America, however, are quite poorly studied.

Lebia grandis is a carabid ground beetle predator of Colorado beetle eggs and larvae as an adult (Figure 3A), yet its newly-hatched larvae (Figure 3B) have a more unusual behavior: they seek out the prepupae of the Colorado beetle and follow them down into the ground, then adopt a parasitoid habit, obtaining their entire larval food requirement from a single host pupa, and emerging weeks later as blue-metallic and orange, very mobile and hungry adult predator beetle (Riddick, 2003).

Two species of tachinid parasitoid flies of the genus *Myiopharus*, attack larvae or in the fall even Colorado beetle adults, where they overwinter as an early-instar larva inside their host, then develop and emerge as an adult fly

Figure 5. **The fungus *Beauveria bassiana* has vanquished this Colorado beetle adult. This adult was marked with a bee-label to test its dispersal in the field.**

Figure 6. **Colorado beetle adult in flight, tethered to a flight mill which measures its ability to disperse through the air.**

(Figure 4) in response to some yet unknown trigger (Lopez *et al*, 1992). If the agroecosystem can somehow better nurture these arthropods, and perhaps specific strains of *Beauveria bassiana*, an insect-attacking fungus (Figure 5), then Colorado beetle management may not so frequently require costly and sometimes troublesome insecticidal inputs. On a habitat scale, there are strong indications that providing additional ground cover such as rye straw suppresses Colorado beetle populations, probably by enhancing predation (Zehnder & Hough-Goldstein, 1990; Brust, 1994).

Cultural and physical controls

Crop rotation is an important and effective means to reduce the number of adult beetles which colonize the crop after overwintering. Due to land tenure and other limitations, many farmers cannot rotate the several hundred meters or more which make an effective separation in successive years. Yet even unrotated crops are amenable to border treatments, trap crops or trenches to thwart Colorado beetle colonization, because many adults overwinter in wooded or other non-crop areas adjacent to crop fields (Weber & Ferro, 1994; Hunt & Vernon, 2001). Physical controls of flaming and vacuuming have enjoyed limited success against the pest. One particularly fascinating cultural-physical control guides late-season beetles to concentrated overwintering areas and then removes snow and mulch in midwinter to enhance diapause mortality (Milner *et al*., 1992).

Transgenic potatoes were developed and introduced as the Monsanto cultivar "Newleaf" in the 1990s to prevent larval and adult Colorado beetle feeding by insertion of the beetle-specific BT gene into the plant, later also incorporating resistance to important aphid-transmitted viral infections. Yet this highly effective tactic met with a mixed and then negative reception, first because it was introduced contemporaneously with an effective and broader-spectrum systemic insecticide, imidacloprid, and later because large multinational processors decided that using transgenic potatoes would risk consumer opposition across their global markets. Two years after registration in the US, major buyers announced plans to discontinue Newleaf purchases, and commercial sales have been discontinued (Gianessi *et al*., 2002). It remains to be seen if this technology will be employed elsewhere, for instance in eastern Europe. One prerequisite, as with chemical controls, is the deployment of BT toxins consistent with resistance management plans.

Lab meets field

Increasingly, Colorado beetle is a laboratory "guinea pig" representing herbivorous beetles for purposes of toxicological and physiological research. It is easily maintained on a potato diet, hosting few diseases in the lab, and is also amenable to artificial diet, which aids in precisely controlling its nutrition (Gelman *et al*., 2001). Yet understanding and averting pesticide resistance requires not only laboratory and molecular insights into the mechanisms, but also ecological and behavioral insights, especially into the movement of beetles within and between fields which could lead to the spread or suppression of resistance genes in agricultural populations (Boiteau *et al*., 2003). The quantification of gene flow and frequencies, which in turn depends on selection, dispersal and reproduction, provides the basis for rational deployment of refugia in resistance management. Questions of movement are also critical to effective employment of crop rotation in a variety of regional cropping systems. In some areas, the beetle flies frequently (Figure 6). In others, it flies rarely. In Siberia, it buries deeply over winter. In milder areas, less deeply. Some beetles delay emergence from diapause for years at a time. Those who have studied the beetle evince both reverence and frustration at the variability in its behavior.

Why so flexible?

Just why is the Colorado beetle so able to adapt to changing ecology and toxicology? Part of the reason may lie in its genetic diversity. As a pest in its native continent, in contrast to the bottleneck effect of limited numbers of introduced exotics which account for most pest populations globally, the Colorado beetle may have enjoyed broad and repeated gene exchange among beetles of the original wild populations and the potato-adapted pest populations (Hawthorne, 2001). This may beg the question, however, of why the Old World populations, presumably representing a narrower genetic base, seem every bit as capable as their American ancestors, of evolving pesticide resistance and causing damage in the diverse climes of Eurasia.

Outlook

If this beetle teaches us one thing, it is that one thing alone will not quell it. Witness the latest entry, the chloronicotinyl imidacloprid, starting to fail after about ten years of intensive use in the eastern USA. Integration of multiple effective tactics will be essential for an intelligent and sustainable approach to management of the formidable Colorado beetle.

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Donald C. Weber (weberd@ba.ars.usda.gov) investigates the biology and management of major beetle pests as Research Entomologist with the Insect Biocontrol Laboratory of USDA's Agricultural Research Service in Maryland, USA. He has worked for government, academia, and grower cooperatives, to develop bio-intensive IPM for potatoes, sweet corn, apples, cranberries, and other crops, in the USA, Canada, and Europe. He holds an MS from University of California, Berkeley, and a Ph.D. from the University of Massachusetts, Amherst.