Colony Collapse Disorder and GM Crops

The Bt Cry toxins in genetically modified crops are thought to be responsible, at least in part, for impairing the immune response, memory and navigation ability of worker bees and causing them to disappear from their beehives.

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Mystery of the Disappearing Bees

Over recent years, a problem has developed with honey bees which is causing increasing loss of bees across the United States and in some other countries. Many scientists have studied the problem, but according to Cox-Foster *et al.* (2009) "no single culprit has been identified" as the cause of Colony Collapse Disorder (CCD).[1] This article will suggest that a cause for CCD can easily be identified, but that there may not be the political will to admit openly that a cause for CCD has been found. Simply put, bees have an immune response to the *Bacillus thuringiensis* (Bt) toxin in genetically modified (GM) crops, and this immune response impairs the bees' memory and thus the worker bee is simply unable to find its way back to the beehive. Hence the bees disappear.

In order to make sure that one has the true cause of CCD, it is crucial to define accurately what CCD refers to. CCD does not refer to something that is killing large numbers of bees, so that one finds many thousands of dead bees, either in the hive or immediately outside the hive. That is not CCD. Instead, as Wikipedia states, in CCD the "worker bees from a beehive or European honey bee colony abruptly disappear".[2] This disappearance of the worker bees, rather than the observation of a large number of dead bees, is what largely distinguishes CCD from the many well-known pests and diseases of bees. For example, *Varroa* mite infestation can kill bees so quickly that "thousands of dead bees will pile in front of the hive".[3] Thus, although *Varroa* mite infestation is a very serious disease of honeybees, its symptoms clearly do not match the specific symptoms observed in CCD: the abrupt disappearance of the worker bees.

In the case of the viruses and pathogens that have been suggested as causes of CCD, these usually result in large numbers of dead bees either inside or outside of the beehive. Dead bees are found outside the hive because worker bees carry the dead bees outside. Over the years, many different things have been suggested as the cause of CCD. Bees are susceptible not only to many different pests and diseases but also to a wide variety of chemical sprays used in agriculture. Virtually anyone can name something that can kill large numbers of bees. Here we are interested in what makes the bees disappear, not in what kills them.

The story becomes more intriguing, as colony collapse disorder was originally called Autumn Collapse or Fall Dwindle Disease.[4] Autumn collapse and fall dwindle refer to the fact that the disappearance of the worker bees was clearly observed to occur in the autumn/fall season and was not something that happened at any random time during the year. This specific timing of CCD gives us a second specific criterion which can be used to distinguish CCD from the many other events which harm bees. When we find a cause for CCD, it should be able to explain why the disease has a history of occurring at a specific time of the year: autumn.

Bee scientists looking for the cause of CCD have concentrated on dissecting bees in the hope of finding a pathogen that they are well familiar with and to which they can attribute blame for the recent large-scale disappearance of worker bees. While it is necessary to have a number of investigators looking with a very narrow focus for specific viruses, bacteria and parasites that may be the cause of the problem, it is also necessary to look with unblinkered vision and consider a very wide range of possibilities for causes of CCD.

When enquiring about the disappearance of worker bees from the beehive, it is important to investigate the lifestyle and habits of the bee. In doing so, one quickly discovers that the bee is a very highly specialised and adapted insect. Bees, like many other creatures, have developed a number of unique and highly complex behaviours and abilities that are essential to their survival. How would an eagle survive if it were blind? How would a bat function without its radar? Bees have the adaptive advantage of specialised cognitive abilities which are essential for their survival: the abilities to remember where a certain flower is located and what it smells like,[5] to navigate back to the hive and to calculate how far it can fly with the amount of honey fuel it is carrying.

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Just as the captain of a plane calculates how much fuel to carry in order to complete a journey, so it is that the bee also calculates how much honey fuel to carry to complete its journey. If the bee encounters unexpected head-winds and runs out of honey fuel, the result is similar to if a plane runs out of fuel. The bee can land if it runs out of fuel, but it can no longer complete the journey back to the hive and it will soon be carried away by hungry ants. Impairing the specialised cognitive processes of bees would be like impairing the specialised eyesight of eagles.

Having knowledge of the habits and lifestyle of the bee dramatically changes our perception of what may be causing the bees to disappear. Part of the problem is that entomologists who examine bees are always looking specifically for the presence of fungi, viruses or bacteria as the cause for CCD. They don't look for an interaction between any pathogen that they discover and the specialised lifestyle of the bee that might result in indirect mortality to bees. They simply look for something that is directly lethal to bees.

Immune Response, Cognition and Bt Cry Toxins

Have you ever noticed that when you are sick, you can't think quite so quickly and clearly? The internal battle that the body is fighting somehow seems to affect one's mental abilities. As it happens, it has recently been shown that the entire insect kingdom is even more affected by such an internal response to sickness than humans are. In 2003, a peer-reviewed article was published, titled "Immune response inhibits associative learning in insects". The authors stated that they had discovered "a link between the immune system and the nervous system in insects" and that "an immune response therefore not only affects survival of the host...but also everyday behaviour and memory formation".[6] Thus it is very clear that if insects have an immune response, their cognitive processes such as memory formation are adversely affected—meaning that insects can't learn things or remember things when they have an immune response. Bees, of course, are insects.

Is there something new that has not been considered which could be causing an immune response in insects such as bees? Whereas plant breeding has historically focused on producing crops with bigger and better yields, the most common traits that have been introduced into the recent genetically modified crops are herbicide resistance and insect resistance. The insect resistance feature in GM crops usually comes from the insertion of a gene for *Bacillus thuringiensis*, which is a naturally occurring, toxic, soil organism. The Bt gene in the GM crops produce what are called Cry toxins, which are crystalline protein substances that kill some insects, like caterpillars, if they eat the GM crop. Bees, however, are resistant to Bt Cry toxins and so are not killed by GM Bt crops. Every bee scientist knows that Bt Cry toxins do not kill bees.

Why is it that bees are not killed by the Bt Cry toxins found in GM crops? An insect's resistance to Bt Cry toxins is correlated with its immune response to the Bt Cry toxins. Recent peer-reviewed studies have shown that "Cry toxin resistance may be induced in invertebrates [insects] as an active immune response".[7] For example, in the Mediterranean flour moth, *Ephestia kuehniella*, a non-lethal response to Bt Cry toxins and "tolerance [of Bt] correlates with an elevated immune response" to the Bt toxins.[8] For many creatures, such a simple non-lethal immune response, which protects the creature from the Bt toxins, is of little significance. However, as described above, an "immune response inhibits associative learning in insects",[9] and bees are insects which are totally dependent upon specialised mental processes, such as navigation skills, for their survival. Thus the immune response that bees have to the Bt Cry toxins, which gives them resistance to those toxins, may be impairing the mental processes, learning and memory of bees. Like a blinded eagle, bees simply

cannot survive if their specialised learning processes are impaired by an immune response to Bt Cry toxins.

As mentioned, bees only carry just enough honey fuel to fly to the target flower, collect the pollen and then fly straight back to the beehive. They don't carry enough honey fuel to allow them to survive getting lost and spending time searching for the beehive. Sometimes a person cannot quickly find their car in a very large car park and can spend a minute or two trying to find their car. However, bees must fly directly from the flower to the beehive or they will run out of honey fuel, fall to the ground and be carried away by hungry ants. Memory impairment is not lethal to humans, but memory and learning impairments are indeed lethal to bees.

If all the worker bees experienced cognitive impairment due to an immune response to Bt Cry toxins, then they would all get lost, run out of honey fuel, fall to the ground and be carried away by hungry ants, and thus they would all suddenly disappear from the beehive. This is exactly what is observed in colony collapse disorder: "worker bees from a beehive or European honey bee colony abruptly disappear".[10] As a detective would say, the GM Bt Cry toxins appear to have the means, motive and opportunity to be the cause of the CCD.

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Of course, it might be that bees are somehow different to other insects and do not experience any learning impairment or cognitive malfunction as a result of an immune response to Bt Cry toxins. However, when bees were tested for learning impairment or cognitive malfunction after ingesting Bt Cry toxins, the results clearly showed that bees do indeed experience exactly the same cognitive malfunction that all insects do when they have an immune response. A study by Ramirez-Romero *et al*. showed that learning in bees is indeed impaired after exposure to Bt Cry toxins: "honey bees exposed to 5000 ppb of Cry1Ab had disturbed learning performances".[11]

Perfect navigation requires perfect cognitive function. That's why car drivers are tested for alcohol consumption: the alcohol impairs their cognitive function. The *Encyclopaedia Britannica* states of CCD that it "appears to affect the adult bees' ability to navigate",[12] thus suggesting that worker bees fly out from the high hive to collect food but get lost and never return. It has been clearly demonstrated above that insects resist Bt Cry toxins through an effective immune response, and that an immune response in insects causes cognitive impairment in those insects. It has also been specifically demonstrated that consumption of Bt Cry toxins produces cognitive impairment or disturbed learning performances in bees. Bt Cry toxins are not directly lethal to bees, just as alcohol is not directly lethal to car drivers. Nevertheless, lots of car drivers have died from sub-lethal doses of alcohol, and bees, like car drivers, die if they don't have perfect navigation.

As mentioned previously, CCD was originally called autumn collapse or fall dwindle disease. How could that relate to genetically modified crops? Beekeepers know that bees are active on sunny days in spring and summer, when all the flowers are open. But in autumn and winter there are very few flowers, so bees can't get any pollen at that time. Bees get all their protein from the pollen in flowers, so during autumn, when there are no flowers, bees experience a sudden drop in their protein intake.

Protein intake is very important for bees, for both immune response and cognitive processes. "Insects have an efficient defense system against infections. Their antibacterial immune proteins have been well characterized".[13] Bees use protein in forming their immune response, but they also use protein to form their memories. "[I]mmune-challenged bees perform poorly in memory tests", and it has been shown that "protein levels mediate this memory reduction. The effect disappears if the bees can increase their protein intake".[14] Pollen means protein for the bees, and protein for bees is like oil for an engine: it's needed to keep things working.

Studies have also shown that an "immune response reduces learning in protein-starved bumblebees" and that the "immune-induced reduction in memory only becomes apparent after the bees are deprived of pollen"[15] because pollen is the only source of protein for bees. During summer, when protein from pollen is plentiful, the bees can have an immune response, which uses protein from their reserves, and still have enough protein available to form memories with, but in autumn the flowers close, the protein supply stops and then all the remaining available protein is used up in the bees' immune response to GM Bt Cry toxins.

This confirms that the situation which applies generally to insects—learning impairment or cognitive

malfunction as a result of an immune response[16]—also applies specifically but conditionally to bees—the condition being that to ensure cognitive impairment in bees, there should be a shortage of available protein, as occurs in the autumn. So we have autumn collapse or fall dwindle disease of bees, also known as colony collapse disorder.

Sub-Lethal Effects and Disease Susceptibility

It is important to note that Bt is not the only insecticide that has been shown to cause cognitive impairment in bees. In the USA, vanEngelsdorp *et al.* mentioned that neonicotinoid insecticides can produce sub-lethal effects, such as learning impairment, and that, as a result of such learning impairment, bees "may not be able to learn the location of the hive"[17] and thus may be unable to navigate back to the hive.

So there is a recognised trend of learning impairment in bees, caused by insecticide exposure at a sub-lethal dose. VanEngelsdorp *et al.* clearly state that if bees are eating "pollen contaminated with these chemicals at low levels, they may not cause mortality but may impact the bee's ability to learn or make memories".[18] That is very similar to the previously mentioned finding from Ramirez-Romero *et al.*, who found "disturbed learning performances" in bees after consumption of GM Bt pollen.[19] So the learning impairment in bees, induced by consumption of insecticidal GM Bt pollen, can be seen as part of a larger trend for sub-lethal doses of some insecticides to produce learning impairment in bees.

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The difference between neonicotinoid insecticide sprays and the Bt insecticide in genetically modified crops is that the former is very easy to restrict or recall and has even been banned in various European countries, whereas the GM Bt Cry toxins may prove impossible to recall. With genetic materials, the quantity of GM material in existence gets bigger and bigger as time passes. If problems develop with GM crops, then those problems will likely increase as time passes. For example, bans on exotic pests like fire ants do not mean that such imported pests suddenly disappear. It can be incredibly difficult to get rid of biological pests.

When trying to find the cause for CCD, scientists often discover a variety of diseases in the bees remaining in the hive. Perhaps those diseases in the bees remaining in the hive are the real cause of colony collapse disorder. The Bt Cry toxins in GM crops are crystals of proteinaceous insecticidal endotoxins, whose mode of action is to form a pore or make a hole in the insect's gut cell membranes.[20] While investigating CCD in the USA, Cox-Foster *et al.* noted that their bee autopsies found symptoms never observed before: scar tissue in the internal organs.[21] Perhaps these internal scars are the result of non-lethal damage to the bee's gut, caused by the pore-forming Bt Cry toxins.

Wikipedia describes leaky gut syndrome as "a condition of altered or damaged bowel lining, caused by toxins...which has led to increased permeability of the gut wall to substances which normally remain isolated".[22]

German research has shown that bees which were fed Bt became greatly more susceptible to a subsequent disease challenge. The University of Jena study showed that mortality in bees exposed to a parasite was far greater in bees that had previously been fed Bt, compared to bees that were not previously fed Bt[23]—meaning that Bt increased the susceptibility of bees to the pathogen and thus Bt multiplied the mortality caused by the pathogen. AIDS is known to increase mortality from pathogens in humans. In regard to the increased mortality, the German study authors concluded: "[T]he significant differences indicate an interaction of toxin and pathogen on the epithelial cells of the honeybee intestine. The underlying mechanism which causes this effect is unknown".[24] Could it be that the Bt Cry toxin makes a non-lethal hole in the bee's gut lining, which then allows a pathogen to gain entry, as described above in leaky gut syndrome?

Cox-Foster *et al.* said of the CCD bee colonies that they studied: "[W]e hypothesized that something had compromised the bees' immune system, making them susceptible to any number of infections that healthy colonies would normally fend off".[25] VanEngelsdorp *et al.* noted that during the autopsies "when wet mounts were examined they appeared to have crystalline arrays" and that "[c]rystal-like formations were observed in the thorax".[26] Bt Cry toxins are crystalline.

Cox-Foster *et al.* did consider the possibility that bees with CCD may have been poisoned by pollen from genetically modified crops. However, these CCD Working Group members simply referred to earlier research showing that the Bt toxin is only activated in

certain insects and, in contrast to the findings of the University of Jena trials above, Cox-Foster *et al.* stated that "the digestive tracts of honeybees and of many other insects do not allow Bt to work".[27] Thus, because of prior research showing that bees are not directly killed by Bt, many bee scientists have avoided testing Bt on bees for sub-lethal, behaviour-altering effects and have quickly ruled out GM Bt as a possible cause of CCD.

An Indirect Cause of Colony Collapse Disorder?

Scientists looking for a cause for CCD have looked for a *direct* cause, something such as a virus or a parasite that is directly killing the bees. The *New York Times* recently reported that the cause of CCD has finally been discovered: the combination of a parasite and a virus.[28] The article failed to mention that the lead author of the described study had been the recipient of a significant research grant from Bayer Crop Science and that he is the "CEO of the company developing scanners to diagnose bee diseases" and thus "could benefit financially" as a result of the findings.[29]

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Bee scientists have a tendency simply to look for diseases in the surviving bees. No lateral thinking is involved. No consideration is given to impairment of the specialised cognitive functions of the bee, such as its navigation ability which is necessary to prevent the worker bee from getting lost in the field. There is a big difference between asking "What is killing all the bees?" and asking "Why are all the bees getting lost?"

This is not the first time that a cause for CCD has been named. Previously, a virus originating in Australia was said to be the cause, even though CCD does not exist in Australia, and at one time a virus from Israel was blamed.

Research is again currently underway in Europe to confirm increased mortality from a parasite combined with GM Bt Cry toxins, as was originally discovered in the Jena University study.[30] If the GM Bt Cry toxins make holes in the bees' gut and if increased susceptibility to a pathogen is shown to be a result of such Bt Cry toxin–pathogen interaction, then simply naming the pathogen without acknowledging the synergy of the combination or the effect on cognitive processes of the bee will not lead to a solution for the problem of colony collapse disorder. Meanwhile, the worker bees fly out of the beehive and then fail to return.

Science does not work by simply connecting the dots. Science works by the gradual acceptance by larger and larger numbers of scientists over a period of time that a concept is proven. When the starting point is that all the bee scientists in the world have read that Bt Cry toxins do not kill bees, then it is a substantial uphill battle to change the minds of those scientists gradually. When politics and big business are also involved, then the situation can be difficult to change. Few people realise the extent to which the world's ecology is dependent on the humble bee. ∞

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Peter Olson is an Australian researcher who began beekeeping in the 1970s and has spent a number of years reading journal articles to find the cause of Colony Collapse Disorder of bees. His article "The Medical Benefits of Beta-1,3,d-Glucan" was published in NEXUS 8/02. He can be emailed at beeccd@yahoo.com.

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