Causes of bee colony mortality

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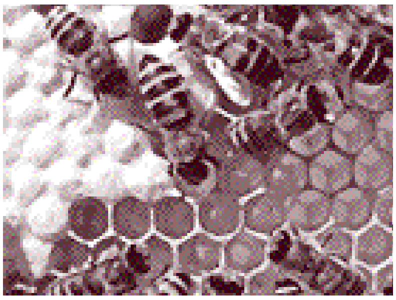

The environment and agriculture depend on a wide variety of pollinating species, including 20,000 species of hymenoptera, the most important being the domestic honey bee (*Apis mellifera*). Worldwide, the annual value of this ecological service is estimated to be in excess of a hundred billion dollars. Since 1997, numerous eye-witness accounts and published articles have reported an apparent weakening and mortality of bee colonies in various countries around the world. The beekeeping profession estimates that national production of honey fell by 20 to 30% between 1997 and 2009.

The depopulation observed in apiaries is sometimes severe, leading to a reduction in honey production in the same proportion as the reduction in the number of bees. The weakening that occurs at the end of the beekeeping year may also result in a higher frequency of mortalities in winter.

One can define six categories of causes of mortality of bee colonies:
– bee diseases and parasites;
– chemical products;
– the environment;
– beekeeping practices;
– agricultural practices;
– treatment of varroosis.

Bee diseases and parasites

The pathogens responsible for diseases and parasitic infestations are predators: parasites, fungi, bacteria and viruses.

To date, there are 29 known pathogens of bees. This precise figure is based on numerous bibliographic references, including recent studies on the decline of bee populations. While all of them have the potential to cause mortality of bee colonies, some have been highlighted in the most recent investigations into the phenomenon of weakening, collapse and mortality of bee colonies, either individually or in association with others. This is the case with *Varroa destructor*, alone or in association with other biological pathogens (viruses; *Tropilaelaps mercedesae* and *Nosema ceranae*).

Chemical products

Like all living organisms, bees may be exposed to a variety of chemical substances potentially present in the environment. In crop producing areas, most of these chemical substances come under the heading of phytosanitary products or pesticides. A phytopharmaceutical product is any product that, through its mode of action, is designed to protect a crop

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from a harmful organism and usually has a specific action for a given type of target. Such products include fungicides, herbicides, insecticides, nematocides, molluscicides, rodenticides and avicides. The catalogue of phytosanitary products lists some 450 active agents and some 5,000 corresponding commercial products (survey conducted by the French association ACTA (*Association de coordination technique agricole*).

The environment

The environment is frequently mentioned as a potential cause of mortality of bee colonies: two factors that have been incriminated are food resources and climatic factors.

Food resources

Carbohydrates are among the most important food constituents, covering the energy requirements for thermoregulation, various tasks involved in maintaining the hive such as cleaning cells, feeding the brood, foraging, etc. Carbohydrates are usually stored in the body as fat. The sugars present in floral secretions (nectar) are metabolised by bees (glucose, fructose, trehalose, maltose), whereas those present in the secretion (honeydew) of certain insects are not (raffinose). Thermoregulation is a very important requirement, in particular to maintain a temperature of 34°C in the presence of brood.

In winter, the temperature of the swarm should not fall below 13°C. In temperate regions, a bee colony's sugar consumption can range from 19 to 25 kg in winter and total around 80 kg during a full year. Numerous factors affect the quantity and quality of pollen and nectar gathering by an apiary.

Protein is provided by pollen. A sufficient intake is essential for a bee colony, to ensure growth and maintain all the vital functions, such as enzymatic functions and reproduction. Pollen is notably involved in the development of the hypopharyngeal glands of young bees and their fat body.

If the pollen intake is insufficient these glands do not develop correctly in nurse bees, whose production of royal jelly no longer allows normal development of the brood or adequate food for the queen (the protein supplied by hypopharyngeal secretions represents about 95% of the protein required for the development of a larva). Pollen is stored in cells in the form of bee bread, comparable to silage, and has a higher biological value than fresh pollen due to fermentation (through the action of three strains of *Saccharomyces* and a strain of lactobacilli) (Pain & Maugenet, 1966). Since the protein content varies according to the botanical source, the required amount of pollen to supply a given quality of protein can therefore be 50% less if the protein level increases from 20% to 30%. In a period of medium honey flow, this level must be at least 25%, and exceeds 30% during periods of heavy honey flow (Kleinschmidt, 1986). The balance between amino acids varies considerably according to the plant source.

Very little information is currently available on the nutritional requirements of bees in terms of lipids (fatty acids, sterols and phospholipids). These requirements are provided for by the consumption of pollen. Of the lipids, sterols are involved in the production of the moulting hormone (ecdysone) and are therefore indispensable.

Mineral and vitamin requirements do not appear to pose such serious problems as protein, carbohydrates or water requirements (Bruneau, 2006).

It should be emphasised that an adequate supply of water can be a serious problem, especially during periods of heat wave, since the decline in the availability of water can be an important limiting factor for the survival of colonies.

Climatic factors

After a period of excessive drought, the flowering of melliferous and polleniferous plants can rapidly die down during the summer and stop completely. Low temperatures and especially sudden cold spells affect the development of bee colonies. Temperature is a determining factor for the vitality of a colony; bees maintain the brood temperature at 34.5 ± 0.5°C, regardless of fluctuations in the ambient temperature. If, however, the brood temperature is raised, the emerging bees, though morphologically normal in appearance, present impaired learning and memorisation (Tautz *et al.*, 2003; Jones *et al.*, 2005). Bühler *et al.* studied the effects of CO_2 concentrations and temperature on bees within the hive: when climatic conditions were the same as those normally found during the brood period (1.5% CO_2 and 35°C within the hive), the physiology of the bees corresponded to that of summer bees, with a very short lifespan. When the CO_2 concentration was held steady but the temperature was lowered from 35°C to 27°C, worker bees became physiologically similar to winter worker bees (Bühler *et al.*, 1983).

Crailsheim *et al.* demonstrated that climate disturbances affect the behaviour of nurse bees and foraging bees, in particular with regard to collection of nectar for the hive and food distribution within the hive. Climatic conditions can therefore influence the development of the colony and lifespan of the bees (Crailsheim *et al.*, 1999).

Beekeeping practices

It is essential for colonies to maintain a balanced population, given the complex organisation and working relationships between their individual members. A shortage of workers, nurse bees or foraging bees can lead to disturbances within colonies. During beekeeping procedures a demographic balance must be maintained. The beekeeper's role is to use the appropriate techniques and methods to promote the sustainability of colonies so as to ensure their annual production of honey. A lack of workers and therefore of nutritional resources will lead to a slower development of the colonies and an insufficient population. If there are not enough bees during the winter period, they will be unable to maintain the necessary temperature to ensure the survival of the swarm. Loss of the queen can result in the death of the colony if it occurs during the period when there are no males and consequently no insemination. Whenever the colony is visited, every care must be taken not to disturb the queen. Beekeepers must also keep a check on the age of queens by marking them. Regular renewal of queens will help to maintain optimal vitality, which is usually limited to the first two years of their life. Colonies should not be divided too late in the year, so as to reduce the risk of the new colonies being insufficiently developed in winter.

General apiary maintenance is also important. To encourage colonies to thrive, commonsense rules must apply: humidity should be kept as low as possible within the hives, the beekeeper must insulate the hives from the ground and ensure that rainwater does not accumulate; the apiary must be kept clear of vegetation and the supports used for the hives should not retain water; the flight path must be kept free from obstruction and a source of drinking water must be provided near the apiary.

Regular visits should be made in spring and early summer to prevent or halt swarming wherever possible. During swarming, nearly half – and sometimes as many as two-thirds – of the population leave the hive to start a new colony.

This phenomenon may be triggered by the temporary absence of a fertile queen. Visiting the colonies provides the opportunity, where necessary, to:

– prevent swarming from getting underway: increasing the volume of the hive, creating artificial swarms, etc.;

– avoid swarming due to the destruction of royal cells;
– determine the cause of colony population decline.

In temperate regions, swarming may occur up to the end of June and it may take several weeks for the colony's population to return to normal. In addition to the fall in the number of bees, there is also a considerable drop in honey production. Moreover, after swarming has taken place the beekeeper must adapt the volume of the hive to the remaining population to minimise any unnecessary expenditure of energy and avoid the development of parasites, and especially wax moths, in empty spaces.

The life cycle of a colony, and indeed its survival, are highly dependent on the vegetation in the environment and more specifically on the available sources of pollen and nectar. Two factors must be taken into account when setting up an apiary:
– the nutritional resources available throughout the season and more especially before the critical winter period;
– the number of colonies per apiary.

A large number of colonies per site can be considered during the flowering of highly melliferous and polleniferous plants. However, when food becomes scarcer the number of colonies per site must be adapted so that each of them will have sufficient reserves of proteins and nutrients for the development of the longer-living winter bees.

When pollen traps are permanently installed in colonies, this can lead to food deficiency and poor requeening.

Another proven cause of mortality is a lack of food during the winter period.

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Indeed, after collecting the honey and therefore the reserves of carbohydrate stored in the supers, the beekeeper must provide the bees with a substitute, since lack of food will lead to the death of the colony. Four different situations can give rise to starvation:
– an insufficient quantity of food;
– beekeeping methods (provision of food) unsuited to the needs of a new strain of bees;
– unfavourable climatic conditions, lasting into spring, and preventing food collection;
– climatic conditions with the alternation of short warm spells and longer periods of cold weather, leading to the opening and closing of the swarm of bees, some way from the still abundant food stored in the hive (Haubruge *et al.*, 2006).

The selection of queens can be a risk factor related to beekeeping practices.

Current selection criteria are considered to be inadequate to ensure healthy, strong and productive colonies (Imdorf *et al.*, 2007). Up to now, selection has always been based on:
– the behaviour, and more specifically the absence of aggressiveness, of bee colonies;
– honey productivity.

These selection criteria were used to the detriment of the criterion of the hygienic behaviour of bees to one another and to the brood, the latter having been far less taken into account than the previous two criteria.

Another factor arising from apiculture is related to the way beekeepers use products to control the various pathogens that can develop in their apiaries. For a number of years, phenomena of resistance to acaricides have appeared in a number of countries, reducing the effectiveness of the molecules approved for use against *V. destructor*. This resistance phenomenon is thought to be largely due to the application of a control strategy based on the use of a very small number of acaricidal molecules in apiaries, without any alternation in their use. Resistance to fluvalinate and other acaricides has been described in many countries and could have major consequences for treatment efficacy (Elzen *et al.*, 1998; Pettis, 2004; Faucon, 2000; Shahrouzi, 2007). Thus, it could be insufficient for beekeepers to apply a single treatment against mites in autumn, since the damage inflicted on the population of the colony could already be too great.

Beekeepers may contaminate apiaries by:

– introducing bees (introduction of healthy hives, brood or bees from affected or contaminated colonies);
– combining healthy colonies with colonies that have been cured but are still carrying other pathogens;
– reusing hives without prior disinfection.

Agricultural practices

There have been considerable changes in agricultural practices during the last few decades.

In the majority of production areas, crop management has been simplified, leading to a scarcity of some melliferous plant species and especially leguminous plants.

Cereal crops often predominate in these areas, to the detriment of insect-pollinated species (rape, field beans, clover, etc.). It is important to emphasise the damaging effects of single-crop farming, which tends to result in an alternation of over-supply and shortages and is also based on plants that are poor in pollen and nectar (e.g. cereals and sunflower). Furthermore, there is also a destructive management of the fixed features of the landscape, such as embankments, hedges, roadside verges, and grassland alongside rivers and communication routes. Intensive agricultural practices thus result in a decline in food resources for honey bees. The decline in the biodiversity of polleniferous and melliferous plants in agricultural environments is the direct consequence of a combination of two factors: the use of herbicides, whether non-selective or selective, and single-crop farming, especially when it involves crops such as cereals that are of no value to bees. Fields of phacelia or white clover and sainfoin are very often visited by foraging bees but are often mown before the end of flowering, resulting in a considerable loss of bees through lack of food.

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Treatment of varroosis

The first treatment must be carried out in late September or early October to give overwintering bees the optimum potential for survival. It must be sufficiently effective to ensure that at the end of the treatment there will be fewer than 50 parasites within treated hives. Effective treatment applied at the appropriate time is of prime importance. There are several risk factors in addition to the parasite burden, such as the nutritional quality of the bees' supply of pollen in autumn (for the development of fat), the presence of opportunistic parasites such as *Nosema* sp., the beekeeping environment (degree of contamination from infested apiaries in the surrounding area), the severity of the coming winter, etc.

If an apiary's colonies are located in an area conducive to the early rearing of brood (potential source of development for the parasite), the second treatment must be carried out in early spring.

However, experience has shown that, whatever the treatment, a small but variable number of colonies will retain a high level of parasitism and thus be a source of contamination and weakening for other colonies in the apiary.

Of the medicinal products that have received marketing authorisation, Apivar NT and Bayvarol® currently have a sufficient level of efficacy and should therefore be given priority.

Colony collapse disorder

Colony collapse disorder (CCD) has been described as a syndrome involving a rapid decline in a colony's adult bee population without any dead bees being found in or around the colony (Oldroyd, 2007; Stokstad, 2007a, 2007b). In the terminal phase, the queen is reported to be no longer surrounded by more than a few newly emerged bees despite the fact that the hive still contains reserves of food and capped brood cells. The CCD phenomenon has principally been observed during winter losses and the bees analysed are those that have survived (CCD having caused the disappearance of the majority of the colony's population). Some authors have emphasised the no doubt important role of *V. destructor* in this phenomenon. The initial studies on CCD had revealed the presence of numerous pathogens without being able to pinpoint any one specific cause for the phenomenon (Pettis *et al.*, 2007). Nevertheless, preliminary observations tend to show that CCD is transmissible and therefore potentially due to one or more pathogens.

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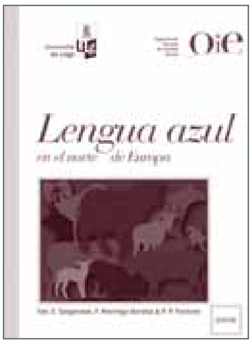

Bluetongue (BT) is an infectious, viral and vector-borne disease of improved breeds of sheep and some species of deer that is of major international importance. The infection is usually unapparent in cattle, which acts as reservoir for the virus. However, some serotypes such as serotype 8 (BTV-8), which recently caused a severe epizootic of BT in northern Europe, exhibit a more important virulence in cattle.

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