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The incidence and management of *Varroa* mites of honey bees (*Apis mellifera* Linn.): A review

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Abstract
Varroa destructor is considered as one of the most serious threat to the colonies of honey bees. Most of the time the bee keepers prefers to use the chemical treatments to control the ectoparasite but overuse and mismanagement of the treatment can lead to the development of resistance in *Varroa* mites. Research and development of new natural and safe treatments to treat honey bee varroasis caused by *Varroa* destructor is an important step to embark on organic bee keeping. Through this article, I provide a review of the incidence and control methods of *Varroa*. These includes identification, morphological impact on honey bees, seasonal incidence, damage caused to honey bees and monitoring of *Varroa* mite. Further, I will provide the review of different mechanical, chemical, cultural and biological as well as botanical control methods used against *Varroa* mite globally. My aim is to provide the recent and less damage causing control methods through this review. I hope it will work and will help in protecting the honey bees from mites.

Keywords: *Apis mellifera, Varroa destructor*, seasonal incidence, control

Introduction
Beekeeping of the European honey bee (*Apis mellifera*) is widely practiced in Himachal Pradesh, mainly through migratory methods. In recent years, there has been significant research in the field of honey bees and apiculture, as more people domesticate bees for products like honey and wax. However, *Apis mellifera* faces many threats, and one of the most serious pests is the *Varroa* mite (*Varroa destructor*), belonging to the class Arachnida. This mite is highly destructive, feeding ectoparasitically on bee bodies. Research by Anderson and Trueman (2000) [2], Rosenkranz *et al.* (2010) [38], and Dietemann *et al.* (2013) [41] confirms that the Varroa mite is one of the most dangerous pests to honey bees, damaging colonies both directly and indirectly. Direct harm occurs when the mites feed on worker pupae, reducing the adult bee's lifespan and body weight (Van Dooremalen *et al.* 2012) [13]. Indirectly, the mite spreads viral diseases, further threatening bee colonies (Ball and Allen, 1988; Guzman-Novoa *et al.*, 2010; Boecking and Genersch, 2008; Highfield *et al.*, 2009) [6, 23, 8, 3]. The survey conducted in the Chamba district of Himachal Pradesh on the occurrence and distribution of pests and predators of honey bees (*A. cerana* and *A. mellifera*) revealed that *Varroa destructor* was one of the most harmful. (Chandra and Mattu, 2017) [1]. *Varroa* mites and the viruses they spread are highly damaging to honeybees. To protect honeybees and their colonies, beekeepers must apply treatments multiple times a year to control *Varroa* infestations (Jack and Ellis, 2021) [12]. Research on *Varroa* management includes synthetic chemicals, natural substances like oxalic acid, biotechnical methods such as drone brood trapping, and natural resistance strategies like hygienic behavior (Spivak, 1996; Rinderer *et al.*, 2010) and grooming behavior (Boecking and Spivak, 1999) [9]. However, it's important to note that not only the mites but also the control chemicals themselves can harm honeybees and their colonies, along with their by-products.The natural defence against brood disease is hygienic behaviour in which the worker honey bees uncap the cells containing brood that is dead or infected and remove it (Rothenbuhler, 1964) [39]. If we look the studies of various researchers, bees were exposed to neonicotinoids through ingestion of contaminated nectar, pollen, guttation water, or exuded water droplets. The presence of a wide range of pesticides in honeybee hive resources has also been proved which may be the result of contaminated soil or dust deposited over bees, plants, or both.

Understanding honey bees, the impact of Varroa mites, and effective, bee-safe control methods is crucial for managing this issue. Identifying bee species is crucial for protecting honey bee colonies and managing pests like *Varroa destructor*. Accurate knowledge prevents misallocation of resources, time, and labor, and helps avoid negative impacts on the ecosystem. *Varroa destructor* is a significant pest that disrupts the honey bee life cycle, making its management essential for colony health.

Species of varroa mites

There are 6 species of 2 genera of the specialized mites

Varroa destructor (Anderson and Trueman, 2000) [2], *Varroa* jacobsoni (Oudermans, 1940), *Varroa underwoodi* (Delfinado-Baker and Aggarwal, 1987), Varroa rindereri (De Gurman and Delfinado-Baker, 1996), *Euvarroa sinhai* (Delfinado-Baker, 1974) and *Euvarroa wongsirri* (Lekprayoon and Tangkanasing, 1991). (Anderson and Trueman, 2000) [2].

Varroa destructor, *Varroa jacobsoni*, and *Varroa underwoodi* infect colonies of *Apis cerana* bees. *Varroa rindereri* acts solely as a parasite. *Euvarroa sinhai* affects *Apis florea* and *Apis mellifera* and has been recorded in India, Thailand, Sri Lanka, and Iran.

Fig 1: *Varroa destructor*

Fig 2: *Varroa jacobsoni*

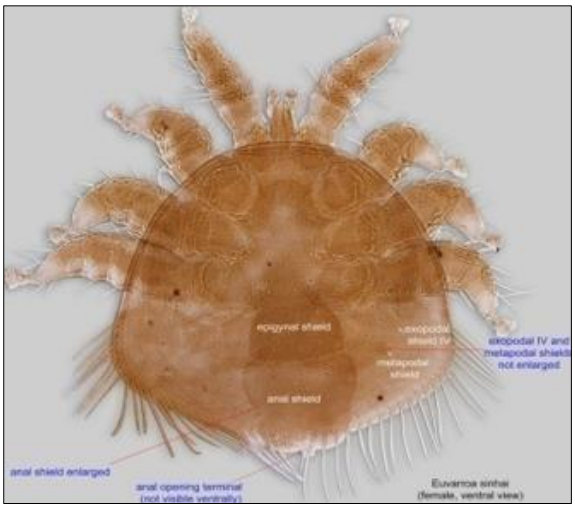

Fig 3: *Euvarroa sinhai*

Morphology

Varroa mites have a distinct idiosoma and gnathosoma (Rosenkranz *et al.*, 2010) [38]. Sex differentiation is straightforward: males are smaller (0.7 mm long, 0.715 mm wide), pale yellow, and oblong with triangular shapes. They also have longer legs compared to females. Females are generally larger (1.1 mm wide, 1.6 mm long), ellipsoid, flattened, reddish-brown, and covered with small bristling setae on their dorsal and ventral surfaces (Roth *et al.*, 2020; Rosenkranz *et al.*, 2010) [33, 38].

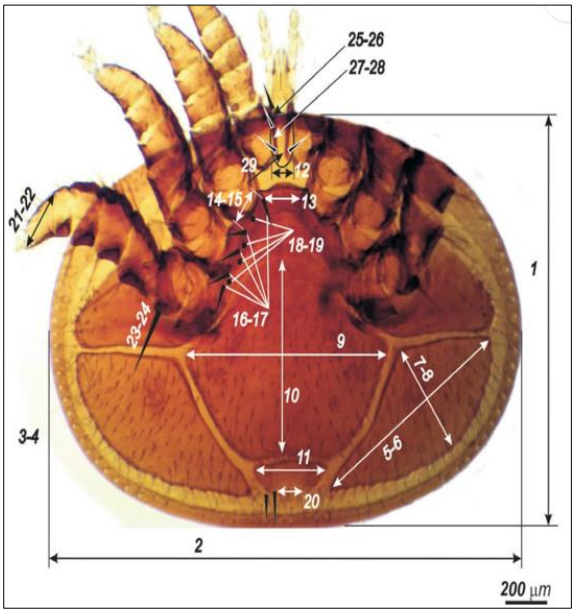

Fig 4: Morphological characters of female *Varroa destructor* mites: 1-length of dorsal shield; 2 - width of dorsal shield; 3-4-number of lancet setae; 5-6-width of pleural shield; 7-8-length of pleural shield; 9-width of genitoventral shield; 10-length of genitoventral shield; 11-width of anal shield; 12- width of gnathosome base; 13-distance between the first pair of setae of sternal shield; 14-15-distance between the first and second pairs of setae of sternal shield; 16-17-number of setae on sternal shield; 18-19-number of pores on sternal shield; 20-distance between anal setae; 21-22-length of tarsus IV; 23-24- length of macrochaeta IV; 25-26-distance between first and second setae of hypostome; 27-28-distance between second and third setae of hypostome; 29-distance between third pairs ofsetae of hypostome

Life Cycle

Varroa mite is closely linked to its host and lacks a free-living stage (Genersch, 2010) [21]. There are two stages in the life cycle of *Varroa* mite females and these are: phoretic phase and reproductive phase (Roth *et al*. 2020) [33]. Nymphal stage of the mite is short lived and can be found only inside the sealed brood cells (Roth *et al*. 2020) [33].

Phoretic phase

In this phase female mite uses honey bee as food source and vector. Adult foraging and swarming bees helps in transporting the *Varroa* females to brood cells for their reproduction (Kuenen and Calderone, 1997) [27]. The mites suck the haemolymph from both adult and the larval stages of honey bee.

Reproductive phase

In this phase the mite enters an unsealed brood cell with a 5th stage bee larva and lay eggs (Roth *et al.* 2020) [33]. The reproduction of the *Varroa* mites takes place inside the capped worker and drone brood cells.

Reproduction

Reproduction of *Varroa* mites occurs inside the sealed honey bee brood cells during the reproductive phase (Rosenkranz, 2010) [38]. Mature female or mother mite or females enters the brood cells prior to capping of the cells. They pierce the cuticle of the larvae to feed and the same becomes the feeding area of mite progenies. Feeding of the brood begins with first 6 hours and the first egg laid by the female develops into male and the second one develops into a female mite. A female lays approximately 30 eggs in its lifetime. A female lays the first egg in about 70 hours after capping of the cell (Rosenkraze *et al.* 2010) [38]. The egg hatching and mite emergence is then followed by the protonymph and deutonymph stage of mites (Boecking and Genersch, 2008) [8]. The reproductive stage ends with the female mite exiting the brood cell with honey bee.

Seasonal Incidence

The incidence of the *Varroa* mite is closely linked to brood availability and colony size, with larger, denser colonies experiencing higher infestation rates (Frey and Rosenkranz, 2014) [20]. When Varroa mites first infest a colony, their population can rapidly grow within a few years (Büchler, 1994) [11]. The population of female mites depends on their reproductive ability and food availability, with notable variations across climates. In cold and temperate regions, mite populations can increase tenfold annually, leading to colony collapse within four years (Ritter, 1984) [24]. In tropical climates, uninterrupted brood availability allows continuous mite reproduction. In Himachal Pradesh, Pooja's research shows peak mite incidence in July and a decrease from October to January.

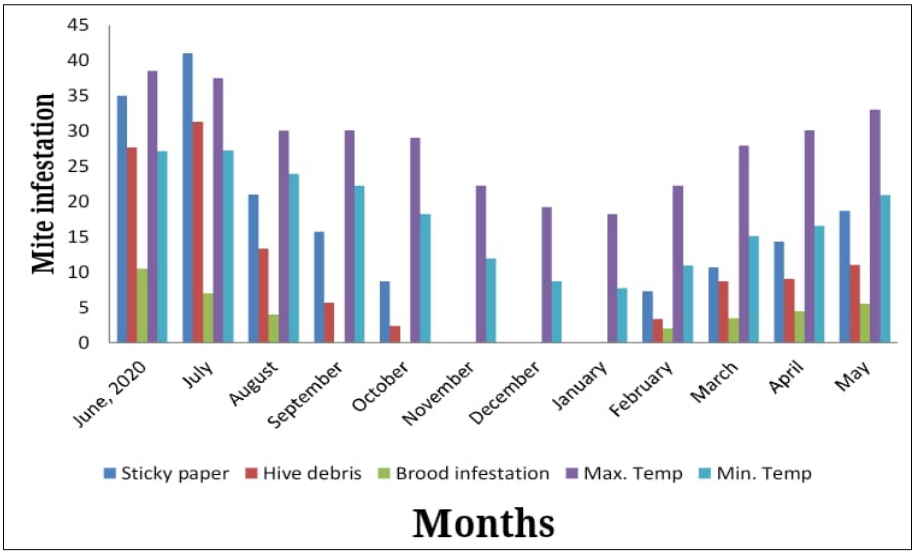

Fig 5: Seasonal incidence of varroa mite, *Varroa destructor* (Pooja, 2021) [34]

Impact On Honey Bees

V. destructor acts as the parasite to honey bees and decreases its body weight and fluid content. With increased number of female mites the weight of adult bees increases (Bowen-Walker and Gunn, 2001) [10] In honey bees, the number of spermatozoids are correlated with the body size of drone (Duay and Engels 2003) [17]. When the size of the drone decreases, *Varroa* induce a deficit in sperm production. *Varroa* also alters flying, homing and orientation abilities in foragers, which limits efficiency inability to collect resources needed for colony development (Kralj and Fuchs, 2006) [26]. It provokes the down-regulation of immune gene expression in the emerging infested adults (Marche *et al.* 2019) [28], and proteomic changes in the honey bee's immune response. *Varroa* reduces the number of haemocytes and it also lowers the expression of prophenol oxidase involved in the synthesis of melanin (Koleoglu *et al.* 2018) [25]. Weakening of the immunity of honey bees is linked to that the mites feeds on fat bodies and these organs play a major role in immunity (Arrese and Soulages, 2010 and Annoscia *et al.* 2019) [5, 4]. The emerging adult bees that were parasitized during the pupal stage shows higher infection rate of DWV as compared to the non-parasitized individuals (Marche *et al.* 2019) [28]. DWV infection will induce the pathological effects like crumpled wings and it will reduce the body size leading to behavioural impairment. The DWV infestation in honey bee increases when immunity of the bee decreases (Zhao *et al*. 2019) [42]. DWV virus can also immunocompromise bees, which results in a beneficial effect on the reproduction of *Varroa* (Di Prisco *et al.* 2016) [16]. The population of *Varroa destructor* in a

colony is closely related to the amount of brood present and consequently to the overall size of the colony. One of the strategy with which a colony can use to reduce the mite population is by creating a broodless period. Increasing the frequency of reproductive behaviors, such as swarming, can serve as an adaptive defense mechanism for honey bee colonies to manage mite overpopulation.

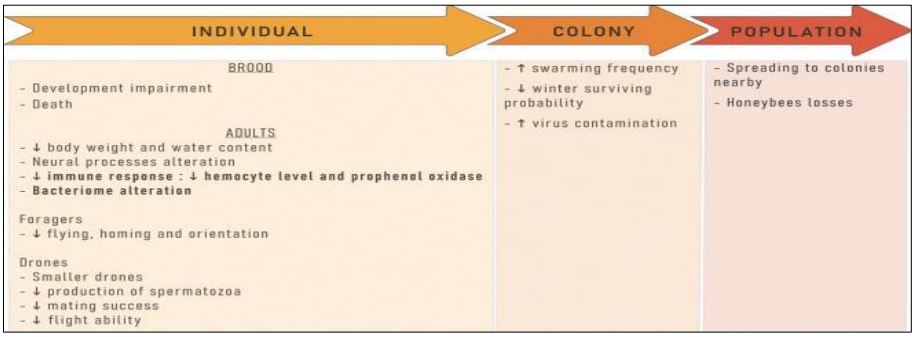

Fig 6: Impact of *Varroa* mite on honey bees

Damage Symptoms

As the colony population increases, more damage symptoms become visible, while fewer symptoms are observed in smaller populations. The escalation of *Varroa* mite infestation can take 3 to 4 years and often leads to scattered brood, crawling and crippled honey bees, impaired flight performance, reduced weight, and shortened lifespan. These symptoms are collectively known as parasitic mite syndrome. In this condition, the honey bee colony begins to deteriorate, dwindles away and eventually dies. The brood pattern becomes abnormal with sunken and chewed cappings, and larvae appear slumped at the bottom and sides of the cells. These issues contribute to a decline in the honey bee population. *Varroa* mites feed through a feeding hole located on the 5th abdominal sclerite of the bees (Roth *et al.*, 2020 and Donzé and Guerin, 1994) [33, 22]. The mites continuously feed on larvae, pupae, and adult honey bees, resulting in weakened immunity. During ontogenic development, bees lose hemolymph within the brood cell due to mite feeding, significantly decreasing the body weight of emerging bees (Rosenkranz *et al*., 2010) [38]. A single infestation can result in an average body weight loss of about 7% in honey bees (Rosenkranz *et al*., 2010 and De Jong *et al*., 1982) [38, 14].

Monitoring

Monitoring bee mites in colonies is crucial for determining the appropriate measures to control their population. Various methods are available for this purpose, such as brood uncapping, sugar rolls, and alcohol washes. According to Robyn and Margarita (2019), alcohol washing is particularly effective for monitoring mite populations. Beekeepers are advised to sample at least twice annually, once in early spring and again in late summer. Additionally, it may be beneficial to take samples both before and after treatment to assess its effectiveness.

Control

Cultural Control

This method involves traditional practices passed down by our ancestors to help in reduction of mite populations. Key strategies include maintaining resistant bee populations, providing brood breaks, and using small cell combs (Underwood and Uribe, 2019) [37].

Mite-Resistant varieties: Breeding mite-resistant bees can effectively reduce the need for other control methods, lowering costs and improving colony survival. Greg Hunt, a retired bee biologist from Purdue University, highlighted that this approach decreases reliance on treatments and reduces the number of colonies needing replacement annually. In 2011, Andino and Hunt found that the proportion of damaged mites could indicate grooming behavior, suggesting bees were chewing the mites. In 2016, Hunt's team at Purdue collaborated with Midwest beekeepers to select bees with the 'mite-biting' trait, enhancing resistance to Varroa destructor. A 2020 study by Morfin *et al*. showed that bees selected for mite-biting behavior had lower *Varroa* infestations. Behavioral traits impacting *Varroa* mite populations include absconding tendencies, hygienic behavior, high swarming, and grooming. Studies by Kefuss *et al*. (2016) suggest using bees with naturally low mite populations to introduce their genetic material into other bee gene pools.

Small Cell Comb: Research on small cell combs for reducing mite populations shows mixed results. Melissa *et al.* (2019) found that smaller cells significantly reduced mite reproduction, especially in colonies with certain reproductive conditions, though not universally. In contrast, studies byal Seeley and Griffin (2011), Berry *et al*. (2010) [7], and Coffey *et al*. (2010) reported that small cell combs did not significantly lower mite numbers compared to regular-sized combs.

Mechanical Control

Varroa mites can be effectively controlled through various mechanical methods. Some of these methods include:

Mite Trapping: Research by Devi *et al*. (2019) [40] indicated that Varroa mite infestations are notably higher in drone brood cells compared to worker cells. Mites reproduce more rapidly in drone cells, with 2.2-2.6% offspring per reproductive attempt, versus 1.3-1.4% in worker cells. Additionally, the attractive period for mites is longer in drone brood (40-50 hours) than in worker brood (15-30 hours), making trapping techniques more effective in drone cells. Underwood and Uribe (2019) [37] and Devi *et al.* (2019) [40] also observed that mite populations under drone cell cappings can increase sixfold compared to worker cells. Despite these findings, the use of small cell combs has not been shown to effectively reduce *Varroa* infestations in bee colonies (Berry

et al., 2010) [7].

Powdered Sugar: Sprinkling powdered sugar on bees can enhance their grooming behaviour, leading to an increased number of mites falling onto the bottom boards. According to studies by Ellis *et al*. (2009), powdered sugar treatments had no significant effect on the adult bee population, total brood area, total mites per colony, mites per brood cell, or mites per adult bee.

Screened Bottom Board: Screened bottom boards provide a natural method for controlling *Varroa* mites and can contribute to improved colony health (Delaplane *et al.*, 2005) [15].

Biological Control

Entomopathogenic Fungi: *Varroa destructor* is susceptible to several entomopathogenic fungi, including *Metarhizium anisopliae*, *Beauveria bassiana*, *Verticillium lecanii*, and *Hirsutella* spp. (Rodriguez *et al*., 2009) [36]. Studies by Rodríguez *et al.* (2009) [36] and Ahmed and Abd Elhady (2013) found that applying *Metarhizium anisopliae* can result in an 85% mortality rate in bee mites. Additionally, research by Araya *et al*. (2019) showed that under laboratory conditions, both *Beauveria bassiana* and *Metarhizium anisopliae* can effectively control Varroa mites without harming bees.

Mite Predator: Fagan *et al*. (2012) tested pseudoscorpions as a biological control agent against bee mites and observed no harmful effects on the bee larvae population. It has been reported that up to 25 predatory creatures can be managed in a single bee colony for effective mite control.

Chemical control

Chemical control of *Varroa* is difficult. The mites are always found associated with hosts, so only mite specific chemicals that do little or no harm to the colonies can be used. At present there are no satisfactory chemical means of eliminating *Varroa* from the colony but there are chemicals which can reduce the number of mites. Two different chemicals reported for the management of bee mite namely soft chemicals and hard chemicals (Rosenkranz *et al.* 2010) [38].

1. **Hard Chemicals:** Apistan (fluvalinate), Checkmites (coumaphos), Perizin (coumaphos), Bayvarol (flumethrin) and Apivar (amitraz), these chemicals give efficient mite control in order of 97-100%.
2. **Soft chemicals:** Soft chemicals consists of natural derived substance like essential oils, hop beta acids and organic acids which do not have any kind of side effect on the colonies. So, such chemicals should be used before the use of hard chemicals (Devi *et al*. 2019) [40].

Formic Acid

Formic acid, naturally produced inside worker honey bees, can penetrate wax cappings and effectively target and kill reproducing *Varroa* mites. It is present in higher concentrations in bee venom (Devi *et al.*, 2019) [40]. In a study by Eliza and Dumitru (2022), brushing capped brood with formic acid at a 65% concentration in one or two applications resulted in significant differences in the percentage of infested cells between treated and control groups during the July-August period. Additionally, Rafael *et al.* (2014) found that formic acid treatment led to 86% mite mortality in capped brood cells.

Oxalic Acid

Oxalic acid is an organic compound with acaricidal properties, commonly found in vegetable crops like kale, beets, and spinach. It can be applied in various forms, such as vapour, trickling, spraying, or crystals, and is most effective during autumn and winter when bees are broodless (Roth *et al.*, 2020) [33]. The most common application method is trickling, where an oxalic acid solution is administered with a syringe on the top bars of the frames. While effective during broodless periods, oxalic acid does not penetrate cell cappings (Underwood and Uribe, 2019; Devi *et al.*, 2019) [37, 40].

Thymol: Thymol, an essential oil extracted from the thyme plant, is an effective natural treatment for controlling *Varroa* mites (Underwood and Uribe, 2019; Devi *et al.*, 2019) [37, 40]. Essential oils like thymol work by affecting the neurological systems of *Varroa* mites (Roth *et al*., 2020) [33]. Thymol is considered a highly efficient and safe treatment when used according to recommendations, particularly effective against mites present on adult bees. However, it cannot penetrate cell cappings, making it ineffective against mites within capped brood cells.

Botanical Control

According to Gomez *et al*. (2016), using appropriate concentrations of neem oil can effectively control *Varroa destructor* while not harming bee colonies. Maul (1982) [29] found Japanese medicinal plant oil effective against *V. jacobsoni* mites. Moffett *et al.* (1989) [31] tested menthol for controlling *Acarapis woodi* in honey bees. The highest menthol dosage (30 g) achieved 82% mite reduction, while 25 g resulted in 53% reduction. No significant difference was found with 10 g of menthol. Wintergreen oil has been used for *Varroa* control. Laboratory tests showed that 15 ml of wintergreen oil killed 95% of mites but caused 7% bee mortality. Field trials with a combination of wintergreen oil and heat treatment resulted in 55-82% mite mortality, with a second treatment achieving 90-95% control. Another trial noted 31% bee mortality and 69% mite reduction (Hoppe and Ritter, 1989) [24]. Fathy and Fouly (1997) [19] investigated the effects of natural volatile plant oils on *A. mellifera* honeybees infested with *V. jacobsoni*. The study found that the oils were safe for bees at these concentrations: up to 10 ppm for *Cymbopogon flexuosus* (lemon grass) and *Thymus vulgaris*, and up to 100 ppm for *Rosmarinus officinalis*, *Marjorana hortensis*, *Foeniculum vulgare*, and *Salvia officinalis*.

Summary and Conclusion

The *Varroa* mite remains a significant problem for beekeepers as it feeds on bees' lipids and hemolymph. Since blocking mite entry is not feasible, continuous monitoring and management are essential for controlling their population. Effective strategies include, Cultural Methods: Rearing resistant bee varieties, using small cell combs, and implementing brood breaks. Mechanical Methods: Employing mite traps, screened bottom boards, and powdered sugar. Biological Methods: Utilizing entomopathogenic fungi and mite predators: Botanical methods like essential oils. In severe cases, chemical treatments may be necessary, with a

preference for softer chemicals like oxalic acid, formic acid, and thymol, rather than harsher chemicals like amitraz.

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