Review

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Advances in Non-Chemical Tools to Control Poultry Hematophagous Mites

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Simple Summary: The mites that infest laying hens and broiler chickens in poultry farms have caused great inconvenience to the industry due to the difficulty of controlling or eliminating their populations within the production systems. *Dermanyssus gallinae* and *Ornithonyssus spp.* are the mites that mainly interfere with the well-being of the poultry, harming the animals' health and damaging the production and quality of the end product, with special emphasis on *Ornithonyssus sylviarum* and *Ornithonyssus bursa.* The objective of this article is to analyze the impact of hematophagous mites that infest commercial egg and meat production systems, the consequences of this form of parasitism, and discuss the methods of control it, including chemical and non-chemical means with the use of plants, entomopathogenic fungi, diatomaceious earth-based products and synthetic silica, and new lines of study aimed at developing vaccines as a new way of effectively controlling these pests.

Keywords: ectoparasites; hematophagous; biological; vaccines

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1. Introduction

According to the United Nation's Food and Agriculture Organization (FAO), the growth in the global poultry sector is driven by a greater demand and purchasing power in the consumer market. Egg production has increased considerably in the past three decades, jumping from 15 million tons in 1961 to 87 million tons in 2020, and chicken meat production jumped from 9 million tons to 133 million in 1961 for 2020 [24]. The countries with expressive numbers for the chicken production are the United States, China, Brazil, and the European Union [25]. Brazil exports the most chicken meat to the world [20]. China stands out as the largest egg producer, followed by the United States, the European Union, India, and Mexico, with Brazil currently in sixth place [20,25,89].

The blood-sucking mites *Dermanyssus gallinae* ("red mite"), *Ornithonyssus sylviarum* ("northern fowl mite"), and *Ornithonyssus bursa* ("tropical fowl mite") stand out for causing infestations in commercial poultry farms worldwide [23,53,69,7,86]. These mites directly affect the well-being of

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animals and consequently cause losses in production that reflect in significant economic damage for producers [23][67][69][89].

Dermanyssus gallinae spends its life cycle hiding in nests, cracks, and crevices and feeds on the host at night. In contrast, *Ornithonyssus* sp. spends its entire cycle on the host, located in the feathers and down around the cloaca region. In cases of severe infestations, *Ornithonyssus* sp. can be found throughout the environment [100][106][83]. The mites are transmitted through direct physical contact between animals, indirect contact through instruments, cages, and materials infested with the mites, and through wild birds that frequent the laying hens and broilers houses [36][27][86]. These mites can also bite humans, causing ectoparasitic dermatitis [17][33][7].

The elimination or control of these mites has become increasingly difficult due to their resistance to the chemical products available on the market [51][9][33][59][75][23][81][49][109][58][63][35][101][53][47][93][96][111], combined with a change in the system of raising animals in cages to "*cage free*" systems that make it difficult to control and observe the animals as they start to live free in sheds and roam freely in pastures [34][97][44]. Due to this scenario, new technologies to control the hematophagous mites without the use of chemical acaricides are needed, such as plant-derived products, entomopathogenic fungi, diatomaceous and silica-based, semiochemicals, and vaccines. Therefore, this review aimed to compile information regarding *D. gallinae*, *O. sylviarum*, and *O. bursa*, including geographic distribution and the biotechnological advances in the development of new tools against these mites using non-chemical repellent substances.

2. Materials and Methods

The data involving the geographic distribution and importance of hematophagous mites, chemical control and new technological trends (plant-derived products, entomopathogenic fungi, diatomaceous earth, volatile organic compounds (VOCs), and vaccines) to control them were assessed using the PubMed platform (https://pubmed.ncbi.nlm.nih.gov/) and Medical Subject Headings (MeSH terms). Additional information was searched in the Google Scholar database and government websites with data published on the subject. The information was then grouped according to the subject for further analyses: (a) bird mites, (b) forms of poultry mite control, (c) biological control of poultry mites, (d) chemical control of poultry mites, and (d) vaccines against poultry mites. The information recovery was used to assess: (a) the forms of control that have been currently used against mites present in poultry production farms, (b) the impact caused by infestations of poultry mites, (c) the impact of mite infestation on animal and human health, and (d) the effectiveness of the current control methods and the new perspectives and technologies used or suggested for the control of avian mites.

The review procedure was outlined in topics to maintain the linearity of the information. The topics encompass: (a) the mites' distribution and economic importance in poultry production, (b) the main forms of control that have been used against bird mites and their implications, (c) the new perspectives that have been developed and studied by different study groups in search of new effective ways to control mites in poultry farms, and (d) laboratory and field assays involving mortality and repellency of hematophagous mites.

3. Results and Discussion

3.1. Mites' distribution and their economic impact on the poultry production system

Hematophagous mites of importance to laying hens and broilers are worldwide in distribution (Figure 1). *D. gallinae* is considered the most prevalent mite in poultry farms around the world, with emphasis on European breeding models [41][56][64][93]. It is estimated that approximately 83% of European farms are infested by *D. gallinae* [30] with losses between USD 130 million and USD 231 million per year [33][6][92][49][109][76][107].

In addition to affecting laying hen farms, the poultry red mite (RPM) is cosmopolitan in range, being able to infest other animals and humans, leading to intensely itchy dermatitis [55][23][78][53]

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with a zoonotic character [10][78][70] and acts as a transmitter vector of disease-causing pathogens [32][23][40][49][101][78] [65][96].

The role of *D. gallinae* as a vector was demonstrated in *Salmonella spp*. [15] *Escherichia coli* [55][93], avian poxvirus, and eastern equine encephalitis virus [77]. It can also act as a reservoir for some pathogens, such as *Coxiella burnetii*, *Borrelia afzelii*, *Borrelia burgdorferi* [78], *Erysipelothrix rhusiopathiae* [22], *Mycoplasma gallisepticum*, *Mycoplasma synviae*, *Plasmodium spp*., *Tsukamurella spp.* [10][75], and *Listeria monocytogenes* [88]. In cases of infestation, these mites lead the animals to a state of anemia, lower feed conversion and weight loss, psychogenic behavior or somatic stress (irritation, and pecking, cannibalism), dermatitis, decreased immunity and, in extreme cases, death by exsanguination [5][18][23][77][30][109][93]. The affected poultry reduce laying and the eggs lose quality [39][101][40][93][70][69][96].

O. sylviarum is more prevalent in temperate climates and *O. bursa* is described in tropical and subtropical climates [107] as a causative of dermatitis in humans [105][68][107][7][57]. Notably, *O. sylviarum* is the mite mainly responsible for infestations and economic losses in poultry farming systems in the United States [106][63][35][59][61][99][37], impacting egg production systems. Poultry infested with *O. silviarium* lose weight and have a lower feed conversion ratio, reduced production and eggs lose quality. Following a severe infestation, they become anemic, develop dermatitis, exhibit beak trimming behavior, skin wounds, and secondary infections [81][62][100][61].

In a study conducted on a commercial egg farm to evaluate the impact of *O. silviarium* infestations, Mullens (2009) observed a reduction of up to 4% in egg production, a long with a reduction of feed conversion and in egg weight of around 0.5% to 2.2%, resulting in estimated losses of 0.70 to 0.10 euros per animal. These numbers, when multiplied by the number of animals from intensive systems, reveal huge losses when associated with all the maintenance costs of the farms. In addition, *O. bursa* is described as the mite primarily responsible for causing infestations and dermatitis in humans [68].

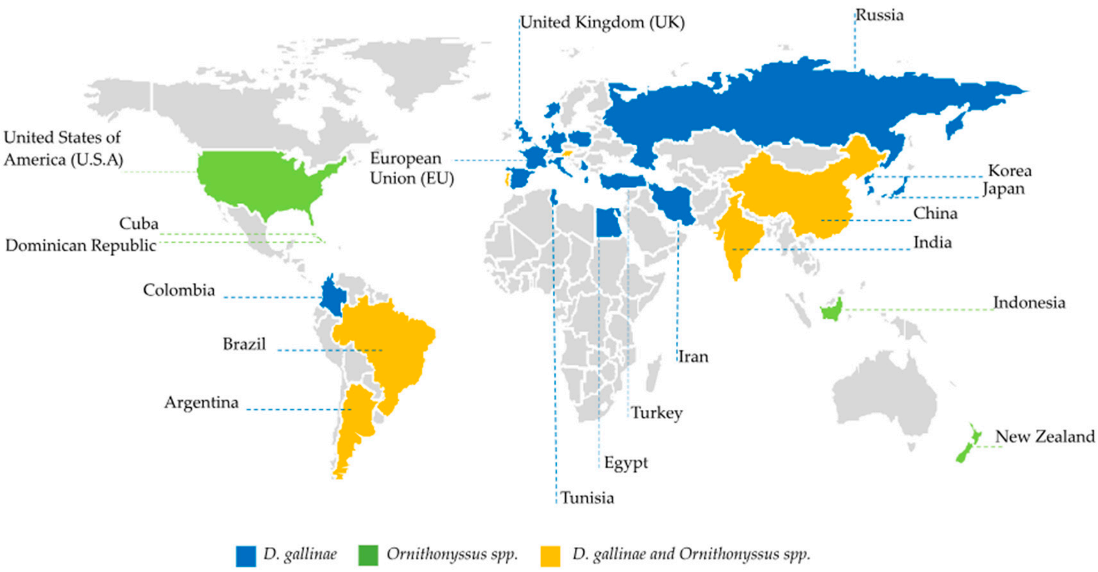

Figure 1. Geographic distribution of *D. gallinae and Ornithonyssus ssp.* throughout the world.

Characteristics on the poultry management production on the eggs farms, demonstrates a great challenge to establish new practices related with preventive sanitary measures, which may be related to the fact that it is a system where birds remain for longer periods of time [87]. It is important to emphasize that the intensive poultry rearing systems displaying a high density of the animals also presenting additional challenge to control the poultry hematophagous mites [86][102][23][81][73][100][83].

In the context of intensive systems for meat production, the poultry remain on the 41 to 50 days in farms [74] and after of their slaughter, the environment and all materials and instruments undergo cleaning and sanitary void. The short time the animals stay in the environment, combined with the constant cleaning and sanitary void, does not allows the mites to reach concentrations to be considered an infestation (> 100,000 to 500,000 mites/poultry) [30].

Discussions on animal welfare have gained prominence in recent years. The physical spaces where animals are kept do not allow them to express their natural behavior [38][91][97][13][79] in addition to interfering with their welfare and health and, consequently, with the productive gain [97][91][87]. Since 2012, poultry farming in cages has been prohibited in the European Union for ethical reasons and are being replaced by "*cage free*" systems, where the animals remain confined but not in cages [31][56][79][37]. This system makes it difficult to clean the environment, allowing the accumulation of organic matter and creating an ideal environment [37] for mites, such as *D. gallinae* [83], which is reflected in the increase in infestion problems in commercial poulty farms in all the Europe.

In addition to changes in production systems, global climate changes in recent years has become a key factor in the dispersion and distribution of ectoparasites around the world [71][112], accelerating the development of hemoparasites within the vectors [12]. In general, RPMs live well in temperatures ranging from 25°C to 35°C and relative humidity from 60% to 80%, so the rise in temperature, combined with changes in wind and rain, are contributing to the increased dispersion of mites [21]. The cross-transmission of mites between commercial poultry and wild birds is considered responsible for the dissemination and distribution of these ectoparasites [32][23][62].

3.2. Chemical Control

The main form of controlling poultry mites is through the use of commercially available chemicals, such as acaricides belonging to the class of organophosphates, pyrethroid, formadin, isoxazolines, carbamate, macrocyclic lactones, and dichloro-diphenyl-trichloroethane (DDT) [90][40][100][68][83] (Table 1).

Unfortunately, although these acaricides can sprayed into the environment, they not reach in some areas, such as crevices, or pass through feathers the poultry, thus preventing mites from coming into contact with the chemical compounds [109][65][47]. However, the most recent molecule, isoxazoline, can be administered through drinking water [89].

The use of chemicals generates inconvenience for the poultry production industry since most of them are (i) highly toxic, becoming a risk to both the animals and humans; (ii) highly polluting to the environment, leaving residue in water and soil; and (iii) can expose consumers to contaminated eggs and meat [23][40][53][65].

Furthermore, one of the main concerns in using acaricides is the selection of resistant mite populations [90][40][53][65]. These products are used indiscriminately [86][53] and its constant use is expensive for the poultry producers.

Table 1. Chemicals used to control hematophagous poultry mites.

Product	Chemical class	Mite	Test environment	Mortality*	Action	Reference
Metrifonate (trichlorfon)	Organophosphate	*D. gallinae*	Field	99%	Paralysis and death	[14]
D.D.V.P (Dichlorvos) diluted in water[1],D.D. V.P (Dichlorvos) diluted in	Organophosphate[1],organophosphate[2], pyrethroid[3] and formadin[4]	*D. gallinae, O. sylviarum*	Laboratory	DL50=513.34 ppm[1], DL50=314.15 ppm[2], DL50=38	Paralysis and death	[86]

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Product	Chemical class	Mite	Test environment	Mortality*	Action	Reference
oil 2, deltamethrin3, amitraz4				9.57 ppm3, and DL50=347.24 ppm4#		
Phoxim 50%	Organophosphate	*D. gallinae*	Field	99%	Paralysis and death	[52]
Cypermethrin and Cypermethrin1 + Chlorpyrifos2	Pyrethroid1 and Pyrethroid2	*O. sylviarum*	Laboratory	> 95%	Paralysis and death	[100]
Fluralaner	Isoxazoline	*D. gallinae*	Laboratory	100%	Paralysis and death	[11]
Fluralaner1, Spinosad2, Phoxim3, Propoxur4, Permethrin5 and Deltamethrin6	Isoxazoline1, Macrocyclic lactone2, Organophosphate3, Carbamate4, Pyrethroid5 and Pyrethroid6	*O. sylviarum*	Laboratory	100%1, 98% 2, 100%3, 100%4, 12%5, and 14%6	Paralysis and death	[58]
Fluralaner	Isoxazoline	*O. sylviarum*	Laboratory	>90%	Paralysis and death	[35]
Fluralaner	Isoxazoline	*D. gallinae*	Field1 and laboratory2	190,6%, and 2100%	Paralysis and death	[101]
Phoxim	Organophosphate	*D. gallinae*	Field1 and laboratory2	100%1, and 100%2	Paralysis and death	[101]
Cypermethrin	Pyrethroid	*D. gallinae*	1Field	15.6%	Paralysis and death	[101]
Moxidectin1, ivermectin2 and	Macrocyclic lactone	*D. gallinae*	Laboratory	45.60%1, 71.32%2, and 100%3	Paralysis and death	[110]

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Product	Chemical class	Mite	Test environment	Mortality*	Action	Reference
eprinomectin[3]						
Cypermethrin + Chlorpyrifos + Piperonyl Butoxide[1], Alkyl Benzyl Dimethyl Ammonium, Chloride + Glutaraldehyde + Deltamethrin[2], Dichlorvos[3], and Fluralaner[4]	Pyrethroid + organophosphosphateus[1] + organic compound, pyrethroid[2], organophosphate[3] and isoxazoline[4]	*D. gallinae*	Laboratory	[1]97.5%, [2]100%, [3]100%, and [4]100%	Paralysis and death	[94]

* Result considering higher dose and after the end of the last treatment dose; # 100% mortality dilution of mites. The numbers 1,2,3,4,5,6 express correspondence between Product, Chemical class, Test environment, and Mortality.

3.3. Non-chemical measures against blood-sucking mites

Extracts and oils from plants and seeds, entomopathogenic fungi, semiochemicals, powder such as diatomaceous earth and silica-based products, and vaccines show promising results and could be investigated as alternatives in addition to being safer methods [75][81][49][65]. Better ways of applying these methods need to be tested in the field and could be part of an integrated management plan that would reduce the use of chemical acaricides[37].

3.3.1. Plant-derived compounds

Isolated compounds of plant extracts and essential oils are being studied as possible weapons to be used to combat mites on commercial farms [26][66][53][65] (Table 2). These compounds cause mortality or repellence [95]. However, few field assays have been developed. Plant-based products are a promising method because they do not contaminate the environment and can be controlled in doses that do not cause health problems in animals and humans and do not leave residue in food products [23][40][53][65][75].

Table 2. Plant-derived compounds against hematophagous mites.

Product	Mite	Type of assay	Mortality (M)/Repellency (R)	Action	Reference
Coffea aqueous extract[1] and *Coffea* chloroform extract[2]	*D. gallinae*	Laboratory	M =25%[1], and 100%[2]	Intoxication*	[51]
Neem Oil[1], Assist[2]	*D. gallinae,*	Laboratory	M = 42.86%[1], and 15%[2]	Intoxication	[86]

Product	Mite	Type of assay	Mortality (M)/Repellency (R)	Action	Reference
	O. sylviarum				
Oil (individual) of bay, cade, cumin seed, ceylon cardamin, cedarwood, cinnamon, clove bud, clover leaf, coriander, eucalyptus, fir needle, ginger, horseradish, juniper berry, lavender, lemon 10, lemongrass, limedis 5F, mandarin orange, marjoram, mustard, oregano, palmarosa, pennyroyal, peppermint, pimento berry, rosemary, rosemary, peppermint, tea tree, thyme, haiti vetiver and absinthe	*D. gallinae*	Laboratory	M = 100%	Intoxication	[42]
Basil[1] oil or extract, java citronella[2], clary sage[3], geranium[4], nutmeg[5] and sage[6]	*D. gallinae*	Laboratory	M = 56%[1], 96%[2], 92%[3], 93%[4], 51%[5], and 89% [6]	Intoxication	[42]
Neem oil	*D. gallinae*	Field	M = 92%	Intoxication	[48]
Neem seed extract	*D. gallinae*	Field	M = 80%	Intoxication	[1]
Eucalyptus essential oil: *Eucalyptus citriodora*[1], *E. staigeriana*[2], *E. globulus*[3] and *E. radiata*[4].	*D. gallinae*	Laboratory	M = 85%[1],>65%[2], 11%[3], and 19% [4]	Intoxication	[31]
2% liquid neem leaf extract + mineral oil + 0.1% degerming agent	*O. sylviarum*	Laboratory	M = > 50%	Intoxication	[90]
Thyme oil	*D. gallinae*	Laboratory	M = 50%	Intoxication	[29]
Lavender oil[1], thyme oil [2], oregano oil[3], juniper oil[4]	*D. gallinae*	Laboratory	M =>97%[1], 84%[2], 50%[3], and 50%[4]	Intoxication	[67]
Acerola cherry oil (individual), bergamot peel, caraway, cinnamon bark, cinnamon leaf, java citronella, clary sage, clove bud, garlic, gurjan balm, hyssop, lavender, lemon peel, lemongrass,	*D. gallinae*	Laboratory	M = 100%	Intoxication	[43]

Product	Mite	Type of assay	Mortality (M)/Repellency (R)	Action	Reference
lime, marjoram, mint avensis, mustard, onion, pennyroyal, peppermint, pine, rosemary, white thyme					
Cedarwood oil[1], redhead oil[2], grapefruit oil[3], lemon oil[4], peanut [5] oil, sandalwood oil[6]	*D. gallinae*	Laboratory	M = 48.9%[1], 42;2%[2], 8;9%[3], 33.3%[4], 8.9% [5], and 20%[6]	Intoxication	[43]
Clove bud and leaf oil[1], steamed lychee oil[2], hemp essential oil[3]	*D. gallinae*	Laboratory	M = 100%[1], 80%[2], and 79.26%[3]	Intoxication	[96]
Diatomaceous earth 10%[1], Diatomaceous earth 10% + mechanical cleaning[2]	*D. gallinae*	Laboratory	M = 93.4%[1], and 90%[2]	Intoxication and paralysis	[3]
Ajowan essential oil and ajowan alcoholic extract	*D. gallinae*	Laboratory	>90%	Intoxication	[4]

Intoxication*: The authors described general toxic effect on the mites without any association with the system affected. The numbers [1,2,3,4,5,6] express correspondence between Product, Chemical class, and Mortality.

Under laboratory conditions in which almost all contact between mites and plant-derived oils and extracts is guaranteed, it was possible to obtain mortality rates above 80%, demonstrating the effectiveness of the products [51][42][31][67][43][96][3][4]

Lundh (2005) and Abdel-Ghaffar (2008) obtained good efficacy in tests conducted in the field on laying farms using oil and vegetable extracts impregnated in traps. However, for the oil or extract to have an effect on the mite, it needs to come into contact with the product and its effectiveness when used in a trap is limited to captured mites [48]. When used as a spray, it is necessary to develop new methods that ensure the dispersion and maintenance of the product in the environment and in animals for a longer period of time [95], in addition to avoiding the formation of oil films [47].

3.3.2. Entomopathogenic fungi

These fungi occur naturally in the environment and as a mechanism of action, they germinate and penetrate the body of arthropods through the cuticle causing paralysis of essential organs resulting in the host's death [53]. Entomopathogenic fungi are being studied as a tool for use in the control of mites on commercial farms for egg production through spraying or impregnated in traps [40][53][65][47] (Table 3).

Table 3. Entomopathogenic fungi used to control hematophagous poultry mites.

Product	Mite	Test environment	Mortality*	Reference
Entomopathogenic fungi: *Beauveria bassiana*[1] and *Metarhizium anisopliae*[2]	*D. gallinae*	Laboratory	78%[1], and 44%[2]	[40]
Solution of entomopathogenic fungi: *Beauveria bassiana* + *Metarhizium anisopliae*	*D. gallinae*	Field	61.7%	[40]

Fungus Trap: *Trichoderma album*	*D. gallinae*	Field and laboratory	100%	[65]
Fungus Trap: *Beauveria bassiana*	*D. gallinae*	Field[1] and laboratory[2]	80%[1], and 100%[2]	[65]
Formulated with entomopathogenic fungi: *Beauveria bassiana*	*D. gallinae*	Laboratory	98%	[53]
Entomopathogenic fungus: *Aspergillus oryzae*	*D. gallinae*	Laboratory	24.83%	[108]

* Result considering higher dose and after the end of the last treatment dose. The numbers [1,2] express correspondence between Product, Chemical class, Test environment, and Mortality.

Kasburg (2016), Nascimento (2019), and Tabari (2020) obtained good results when using entomopathogenic fungi, mainly under laboratory conditions, to control the mite population. The efficiency of using these fungi to combat bird mites in the field may face some challenges, such as the capacity for fungus proliferation in an uncontrolled environment with changes in humidity, wind speed, and temperature ,and the ability of the fungus to colonize the mites [40]. However, it is a safe method that does not pose risks to animal and human health and does not leave any residue in the end products [40][53][65].

3.3.3. Diatomaceous earth and synthetic silica-based products

Both diatomaceous earth (DE) and silica-based products are a wettable powder that acts on mites with acaricidal efficacy. Their main ingredient, silicon dioxide (SiO_2), adheres to the mite's body and immobilizes it. leading to desiccation and death [84]. Diatomaceous earth-based products can be safely sprayed in the environment and on the animal so that it comes into contact with the mites [53].

Table 4. Diatomaceous earth and synthetic silica-based products.

Product	Mite	Test environment	Mortality*	Action	Reference
Neutral detergent 10%[1], diatomaceous earth 10%[2]	*D. gallinae*	Laboratory	100%[1], and 97%[2]	Intoxication	[53]
Diatomaceous earth 10%[1], diatomaceous earth 10% + mechanical cleaning[2]	*D. gallinae*	Laboratory	93.4%[1], and 90%[2]	Intoxication and paralysis	[3]
Natural diatomaceous earth	*D. gallinae*	Laboratory	100%	Intoxication	[104]

The numbers [1,2] express correspondence between Product, Chemical class, and Mortality.

The method ensures safety for animals and humans as it does not pose a risk of intoxication [84]. The mite remains inside crevices, in organic materials, protected from contact with the products [84][53][65]. Ulrich (2020) obtained good mortality results against *D. gallinae* with products based on diatomaceous earth under laboratory conditions, but did not obtain significant results when using the same products in field tests, which may have been influenced by the physical properties of the products [104] or changes in climate that did not allow the mites to absorb the products [84].

3.3.4. Semiochemicals

Hematophagous arthropods use chemical cues (semiochemicals) to find their hosts and mates. Chemical cues produced by other mites of the same species (pheromones) attract them. However, chemicals produced by hosts (allelochemicals) can either attract (kairomones) or repel (allomones) [98]. In France, a commercial product (No Reds®) is available against *D. gallinae*. This product is an allomone comprising a mixture of bis (2 - ethylhexyl) adipate and 2,2,4 and trimethyl 1,3 pentanediol

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diisobutyrate. The volatile organic compounds (VOCs) were isolated from the uropygial gland of a duck (a non-host for the mite). The product can be added directly in the chicken feed. After ingestion, the chickens release these compounds through the uropygial gland. which repel the mites, disrupting their feeding and social behavior [72]. Unfortunately, chemical ecology studies involving repellence in hematophagous mites are still poorly understood and the sale of the product is restricted to Europe.

3.4.5. Vaccines

Vaccine research aimed at identifying additional forms of poultry mite control has presented new perspectives in recent years [6][40][53][111] (Table 5), driven by an increase in egg and meat production and consumer demand that it be done in an environmentally responsible and organic way [29][75].

Importantly, vaccines are recognized as solutions able to confer greater protection and .therefore, are applied to reduce expenses associated with the costs of acaricides and labor for spray application. Additionally, vaccines are safe for animals, do not pollute the environment or result in depositing residue on eggs and meat, and do not pose a risk of triggering resistance in the mites [6][49][53][75]. Currently, studies have shown the effectiveness of vaccines against ectoparasites, such as the transmission blocking vaccines (TBVs) [19][2][16][75][50][82], and possible vaccines are being tested against the mite *D. gallinae*. [6][40][53][111] (Table 5).

The vaccination process triggers a memory immune response with specific antibody production against the antigenic target, thus providing protection against pathogens that can be controlled by the humoral immune response [44]. TBVs, unlike conventional vaccines, aim to generate a humoral immune response in the vaccinated host, triggering the specific antibody production that is transferred to ectoparasites during blood feeding [9][19][2][16][82][75]. The transferred antibodies act by binding to proteins that are essential ectoparasite's survival, disrupting its reproduction, and transmission of pathogens [85][44][82][75][50].

The development of TBVs applied to vector-borne diseases was previously described against the sporozoite forms of *Plasmodium* that cause malaria. The specific antibody production triggered by the recombinant Pfs25 protein acts within the insect vector, interfering in pathogen transmission [2][50]. The antibodies that are transferred during vector blood feeding recognize the gamete surface antigen of *Plasmodium*, affecting the parasite's life cycle inside the mosquito by preventing its sexual development and interrupting its biological cycle and transmission [9][85][2][16][50]. According to Shimp Junior et. al (2013), in the first clinical trials, the experimental sporozoite vaccine reduced the incidence of disease over a 14-month period in about 50% of vaccinated infants and children by preventing subsequent blood-stage infection.

Another example includes the vaccines against *Rhipicephalus microplus*, the cattle tick, TickGARD® in Australia and Gavac® in Cuba, developed from the recombinant Bm86 glycoprotein extracted from the tick's gut [32][109][8][82][75]. The mechanism of action is associated with the induction of specific antibodies that target cells in the tick's gut and either impede their development or cause their death [111][82][75]. Table 5 describes the potential vaccine trials aimed at identifying antigenic targets for blocking the transmission of *D. gallinae*.

Table 5. Antigens used as vaccine candidates against *Dermanyssus gallinae*.

Antigen	**Presentation**	**IgY levels ***	**Feeding challenge/model**	**Efficiency / mortality**	**Action**	**Reference**
DGE	Brute	↑ ($p \leq 0.05$)	*in vitro*/laboratory	50.60%	Tissue paralysis	[33]
Bm86	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	23.03%	Interference with the	[32]

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Antigen	Presentation	IgY levels *	Feeding challenge/model	Efficiency / mortality	Action	Reference
					digestive system	
Subolesin	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	35.10%	Interference in the expression of gene regulation of transcription	[32]
Tropomyosin *D. gallinae* (Der g 10)	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	19%	Interference with muscle movement and structural integrity of tissue	[109]
Paramyosin (Der g 11)	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	23%	interference with muscle movement and structural integrity of tissue	[109]
SME	Brute	↑ ($p \leq 0.05$)	*in vitro*/laboratory	78.00%	–	[5]
(Deg-VIT-1) +(Deg-SRP-1) +(Deg-PUF -1)	Recombinant	↑ ($p \leq 0.05$)	*In vivo*/Field	0%	–	[5]
PRM	Brute	↑ ($p \leq 0.05$)	*in vitro*/laboratory	58.30%	–	[5]
Deg-AKR	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	42%*	–	[45]
CatD-1 in Montanide ™ ISA 71 VG adjuvant	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	50%*	–	[76]
Dg-CatD-1 DNA	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	0%	–	[76]
Dg-CatD-1 *E. tenella*	Transgenic	↑ ($p \leq 0.05$)	*in vitro*/laboratory	0%	–	[76]

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Antigen	Presentation	IgY levels *	Feeding challenge/model	Efficiency / mortality	Action	Reference
rDg-CatD-1 (Cathepsin D, CatD)	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	63.40%	Interference in the digestive process	[111]
rDg-CatL-1(Cathepsin L, CatL)	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	48.01%	Interference in the digestive process	[111]
rDg-Lgm (legumain, Lgm)	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	18.37%	Interference in the digestive process	[111]
Dg-APMAP	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	61.88%	Plasma membrane interference	[27]
Deg-CPR-1	Recombinant	↑ ($p \leq 0.05$)	*in vitro*/laboratory	>50%	Interference in the digestive process	[60]

* DGE: extract with the mite *D. gallinae*; ↑ ($p \leq 0.05$): there was an increase in the measured levels of IgY when comparing the control group (non-vaccinated) with the vaccinated group. Bm86: recombinant protein from the tick *R. Microplus*; SME: soluble dust mite extract. Deg-VIT-1: Vitellogenin-1; Deg-SRP-1: Serpine-1; Deg-PUF -1: Protein of Unknown Function-1; DRP: *D. gallinae* protein.

Harrington (2008) used an extract of *D. gallinae* and obtained efficacy of around 50% in a laboratory study. Harrington (2008) hypothesized that the feeding chamber interfered with the mite's feeding, reducing the transfer of antibodies induced by vaccination. Similarly, Xu (2020) proposed that their low protection rate could be explained by interference from the feeding chamber, as reported by Harrington (2008).

Harrington (2009) used recombinant antigen Bm86 and Subolesin from *R. microplus* against *D. gallina*e, which were able to generate an immune response, but with low efficacy (23.03% and 35.1%, respectively). Bm86 and Subolesin are not found in *D. gallinae*, a fact that may have hampered the development of an effective immune response [32].

Wright (2016) and Price (2019) extracted proteins from *D. gallinae* macerate to act as possible vaccine candidates but obtained results below 50%. Additionally, Price (2019) proposed that the low efficacy may have occurred because of the lack of a specific humoral immune response to the antigen used due to low levels of antigen expression or incorrect folding of the expressed protein.

Bartley et al. (2017) obtained a potential vaccine candidate using extracted protein from *D. gallinae* macerate, achieving results of around 50% of protection under laboratory conditions, but it was ineffective when using recombinant proteins and submitting it to a field test. The reason may have been the lack of proper selection of antigen, inducing an inadequate protective immune response [5]. Xu (2020), Fujisawa (2021), and Murata (2021) developed recombinant proteins, rDg-CatD-1, Dg-APMAP-N and Deg-CPR-1, respectively with an efficacy rate above 50 % under laboratory conditions, thus paving the way for new studies.

The transmission blocking vaccines against poultry mites need to be improved in terms of efficacy, especially for applicability in the field. Poultry farms have large numbers of animals that make administering vaccines time-consuming and costly for the producer. Yet, the expense and time

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would be justified if poultry farmers had access to effective vaccines that yielded long-term results, making them an advantageous, competitive option compared to the low-cost acaricides currently available on the market [50][75]. In fact, consumers are pressuring the market by sustainable products, particularly food products that replace the use of chemicals with vaccines.

The control methods now in use still show a wide variation in effectiveness, making it difficult to determine their treatment efficacy, especially in the field (Figure 2).

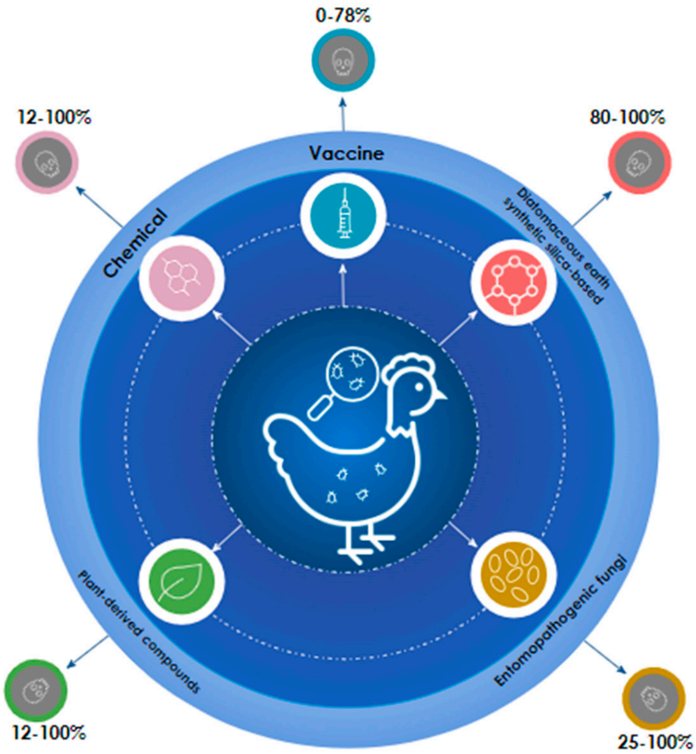

Figure 2. Distinct approaches to controlling mites in laying hens and broilers.

For mites that infest and feed on the feathers and epidermis of poultry, such as *Megninia spp*. [102][80] and *Allopsoroptoides galli* [54][103][89], and for the hematophagous mite *Ornithonyssus spp*. no published references of ongoing research to identify antigens for possible vaccine development were found. With regard to the mites that infest the feathers and epidermis of poultry, antigenic compounds that trigger specific antibodies cannot be transferred to the ectoparasite during the blood meal because the form of feeding does not contain blood, thus limiting the application of TBVs.

4. Conclusions

Poultry mites present on commercial farms continue to be a problem that needs to be addressed. The accelerated multiplication of mites and the expansion of their geographic distribution due to climate change, associated with the difficulty of developing effective forms of control and their role as a vector, call attention to the role mites play in the poultry industry.

The chemical methods currently used to control or eliminate them are proving to be less effective as they develop resistance. Those chemicals that are still effective can also become less effective over time due to their indiscriminate use. Biological control methods offer many advantages related to animal, human, and food safety, but their efficiency remains low when used in poultry farms, making the need for integrated controls even more essential, but generating higher costs.

The development of products based on plant oils and extracts, powders of plant origin, fungi, and new antigens aimed at developing transmission-blocking vaccines against poultry mites provide some encouraging options for the rational control of these ectoparasites.

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