

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.  
For more information visit [www.intechopen.com](http://www.intechopen.com)



---

# Natural Compounds as an Alternative to Control Farm Diseases: Avian Coccidiosis

---

Mayra E. Cobaxin-Cárdenas

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.72638>

---

## Abstract

Coccidiosis is one of the most aggressive and expensive parasite diseases in poultry industry worldwide. Currently, the most used control techniques are chemoprophylaxis and anticoccidial feed additives. Although there is a great variety of commercial anticoccidial drugs and vaccines in the market, there is also a significant resistance to use them in animals with human as final consumer. To date, none available product offers effective protection toward coccidiosis; however, the search for novel strategies to control this disease continues, and natural products have arisen as a potential way to cope with avian coccidiosis. In this chapter, we highlight recent advances in natural compounds, their anticoccidial properties, and mechanisms.

**Keywords:** chickens, coccidiosis, *Eimeria*, anticoccidial, natural products

---

## 1. Introduction

Chicken is considered an animal food with high consumption around the world; so, the development of novel drugs and vaccines to cope with poultry diseases is essential for worldwide food safety. Today, investment on poultry research is focused on development of anticoccidial treatments that can control pathogens at different stages of growth. Avian coccidiosis is an intestinal disease caused by apicomplexan protozoa belonging to genus *Eimeria* and is considered the most economical important parasitic disease affecting poultry industry globally [1–3].

The study of *Eimeria* spp. has driven the search of new chemical or natural compounds in order to control infections, which may be caused by even more than one species that infect different regions of the chicken intestine. In addition, some other environmental and non-environmental factors can contribute to dispersion of *Eimeria* oocysts, such as *Eimeria* virulence, high oocyst

challenge, poor ventilation, high stocking density, low immune status of the host, bacterial enteritis, high moisture levels in litters humidity and lower efficacy of anticoccidial drugs [4, 5].

Disease control includes vaccines, anticoccidial chemicals, coccidiostats, ionophores, probiotics, natural extracts, and natural compounds. However, the constant use of antibiotics induces selection of multidrug-resistant strains of parasites, besides the fact that drug residues may remain in poultry products for human consumption. This is why animal health regulations were established; for example, in European countries, prophylactic control based on mixtures of food with anticoccidial additives has been strongly limited since 2006 and they withdraw from the market in 2021 (Council Directive of 2011/50/EU of the European Council) [3, 6].

To cope with this situation, vaccination is the only preventive method that may help to control avian coccidiosis. In this regard, the use of natural compounds may be considered as an effective way to control coccidiosis in combination with integrated pest management. Research of natural products and the use of derivatives of plants have potential since these new therapeutic molecules are unknown to *Eimeria* strains and therefore they have not yet developed resistance [7]. The natural products used to control avian coccidiosis include plants [4], prebiotics, probiotics [4, 8], and fungi [9, 10].

## 2. Coccidiosis in poultry industry

Commercial poultry farming is expanding daily, and poultry is the most efficient source of animal-derived protein [11]. Chicken meat is considered as an important source of animal proteins and fats, as well as a source of a whole range of organic and inorganic substances [12].

Worldwide, poultry generation has tripled in the last two decades, and the world's chicken herd is close to 21 billion, but annual production of new individuals is more than 60 billion and delivers more than 1.1 trillion eggs and more than 90 million tons of meat [13].

Chicken meat production is growing rapidly around the world, with a significant increase in the production. In a short period, between 2000 and 2012, the global chicken meat market increased more than 58.48%. Fifty years ago, 79% of the chicken market was absorbed for American and European countries, but currently, Asian and American countries contributed approximately 77% of total world production according to reports in 2014 [4, 14]. Differential growth in production has been observed according to geographical location as follows: The Asian's production had the largest increase with more than 68.83%, the African's production increased in 67.73%, the European's production increased in 65.82%, and the American's production with 47.67%. Currently, the world production is dominated by the USA, China, Brazil, Mexico, Russia, and India [4, 14]. The growing demand of meat is proportional to the increasing number of inhabitants in the world and their rising acquiring power, moreover, to the fact that chicken meat cost is cheaper than other kinds of meat [15].

The poultry industry is still confronted with many diseases like coccidiosis, an intestinal parasitic disease that is considered as one of the most aggressive diseases in poultry, causes strong economic losses, and causes damage in animal health and productivity. The global economic loss has been estimated up to 3 billion dollars worldwide including production losses, prevention, and

treatment costs [4, 13, 16, 17]. Losses are mainly due to morbidity as coccidiosis results in reduction in weight gain and egg production additionally to affect the quality of meat by diminishing feed conversion, malabsorption, and maldigestion and further leads to mortality [18]. The poultry industry operation requires that large groups of chickens are kept on the floor at high humidity in warm conditions, appropriate for the development and transmission of the avian coccidia; therefore, the development of novel and natural compounds that control this disease is imperative [19].

### 3. Etiologic agents of coccidiosis

In poultry, the principal etiologic agents of coccidiosis are obligatory intracellular protozoan parasites of the genus *Eimeria*, subclass Coccidia that belong to family Eimeriidae and the phylum Apicomplexa [2, 18, 20]. This phylum groups many other protozoa of medical and/or veterinary importance. It has been reported around 5000 species of apicomplexan parasites, including some that affect humans as malarial parasites *Plasmodium* spp.; the zoonotic organisms *Cryptosporidium parvum* and *Toxoplasma gondii*; *Babesia* and *Theileria* and the more recently described *Neospora caninum*, cattle parasites; and *Eimeria* spp., with host diversity as cattle and poultry pathogens [4, 18, 21]. The majority of apicomplexans are obligate intracellular parasites that infect new host cells by invasive extracellular stages, that involve a specialized array of cytoskeletal elements and secretory organelles known as the apical complex (micronemes, rhoptries, dense granules, and conoid and polar rings), and that would provide the structural stability necessary during the host invasion process [4, 18, 21, 22].

On the other hand, a single host species was reported for more 1200 *Eimeria* spp., and all of these are restricted to this single species [3, 23]. Also, close to ten *Eimeria* spp. have been reported that can infect *Gallus gallus* var. *domesticus*: *E. mitis* [26], *E. maxima* [26], *E. brunetti* [27], *E. acervulina* [24–26], *E. mivati* [28], *E. necatrix* [29], *E. praecox* [29], *E. tenella* [30], and *E. hagani* [31]. In chicken production, seven *Eimeria* spp. that are associated with clinical coccidiosis have been reported: *E. maxima*, *E. brunetti*, *E. acervulina*, *E. tenella*, *E. praecox*, *E. necatrix*, and *E. mitis*. Of all these, *E. tenella* causes significant economic losses; therefore, it is the most studied strain [32, 33].

### 4. Pathogenicity

*Eimeria* spp. can infect and duplicate inside the mucosal epithelia in several areas of bird by oral means. Subsequently, they cause gut harm (e.g., hemorrhage, diarrhea, inflammation, etc.), morbidity, and mortality in poultry [4, 5]. Each of which species of parasite causes disease. But the clinical signs vary according to the species, and their pathogenicity varies in birds of different genetic backgrounds in a range from mild damage to severe damage, i.e., are considered highly pathogenic: *E. tenella*, *E. maxima*, *E. necatrix*, and *E. brunetti* that has been well characterized in relationship of the neurotic conditions they create, furthermore, the gross lesions that are found in several areas of the gut, however, *E. mitis* and *E. acervulina* do not produce gross lesions or cause mortality in infected host, for their tissue trophism, therefore, are considered mildly pathogenic, whereas *E. praecox* is considered to be the least pathogenic, although in *Eimeria* high densities population levels can potentially cause illness (Table 1) [5, 33–35].

| <i>Eimeria</i><br>species | Site of<br>development  | Oocyst size<br>( $\mu\text{m}$ ) |       | Shape        | Gross lesions  | Pathogenicity | Ref.               |
|---------------------------|-------------------------|----------------------------------|-------|--------------|--|---------------|--------------------|
|                           |                         | Length                           | Width |              |  |               |                    |
| <i>E. necatrix</i>        | Jejunum,<br>ileum, ceca | 12–29                            | 11–24 | Ovoid        | The intestine may be<br>ballooned<br><br>The mucosa thickened and<br>the lumen filled with fluid,<br>blood, and tissue debris<br><br>Lesions in dead birds are<br>observable as black and<br>white plaques (schizont<br>accumulations) | ++++          | [4, 29,<br>43, 44] |
| <i>E. tenella</i>         | Ceca                    | 14–31                            | 9–25  | Ovoid        | Thickened cecal wall and<br>bloody contents at the<br>proximal end<br><br>Distension of cecum<br><br>Villi of the duodenum<br>destruction causing<br>extensive hemorrhage and<br>death   | ++++          | [4, 30,<br>43–45]  |
| <i>E. brunetti</i>        | Ceca, rectum            | 14–34                            | 12–26 | Ovoid        | Inflammation of the<br>intestinal wall with<br>pinpointed hemorrhages<br><br>Sloughing of epithelia  | ++++          | [4, 27,<br>43, 44] |
| <i>E. maxima</i>          | Jejunum,<br>ileum,      | 21–42                            | 16–30 | Ovoid        | Inflammation of the<br>intestinal wall with<br>pinpointed hemorrhages<br><br>Sloughing of epithelia  | +++           | [4, 26,<br>43, 44] |
| <i>E. mitis</i>           | Ileum                   | 10–21                            | 9–18  | Subspherical | Limited enteritis causing<br>fluid loss Malabsorption of<br>nutrients  | ++            | [4, 26,<br>43, 44] |
| <i>E. acervulina</i>      | Duodenum,<br>ileum      | 12–23                            | 9–17  | Ovoid        | Limited enteritis causing<br>fluid loss Malabsorption of<br>nutrients<br><br>Small red spots and white<br>bands<br><br>on the upper part of the<br>small intestine   | ++            | [4, 26,<br>43, 44] |
| <i>E. praecox</i>         | Jejunum,<br>duodenum    | 20–25                            | 16–20 | Ovoid        | Watery intestinal contents<br><br>Mucus and mucoid casts   | +             | [4, 29,<br>43, 46] |

**Table 1.** Important characteristics of *Eimeria* ssp. which are causative agent of coccidiosis.

## 5. Clinical signs and lesions

Birds infected with coccidiosis show signs like huddling, listlessness, diarrhea, loss of appetite, and weight loss [36]. Many *Eimeria* spp. are able to cause observable clinical signs to infected and unprotected birds; nevertheless, however, it is frequently determined by sub-clinical infections. These are often undervalued but frequently result in impaired feed conversion and reduced weight gain [37].

Young birds are more susceptible and easily display signs of disease; in contrast, older chickens are relatively resistant as a result of prior infection. The factors that influencing on the severity of infections are the number of *Eimeria* spp. sporulated oocysts ingested, age of birds, and immune and environmental status of the group; in addition, the contagion can be aggravated because the infected birds tend to huddle together, and droppings are whitish or bloody and watery, ending with dehydration and poor weight gain as well as mortalities [37].

Many different *Eimeria* spp. can infect several areas of the intestinal mucosa and infringe a degree of epithelial cell damage like inflammation [38]. The damage of coccidiosis infection is measured by the degree of inflammation and damage to the intestinal tract: petechial hemorrhages, necrosis, mucous profuse bleeding in the ceca, and mucoid to blood-tinged exudates (**Table 1**).

The tissue harm in the intestinal tract may permit other colonizations by different microorganisms, for example, *Clostridium perfringens* [39]. It has been reported that the infection for *Histomonas meleagridis* was more severe when combined with *E. tenella* [37, 40]. The damage leads to dehydration, diarrhea, dysentery, rectal prolapse, and death [41]. Moreover, each *Eimeria* sp. varies in infection location in the gastrointestinal tract (ranging from the duodenum to the cecum). For example, *E. mitis* infects in the middle part of the small intestine, *E. necatrix* infects in the small intestine, *E. acervulina* infects in the duodenum, *E. maxima* and *E. tenella* infect in the ceca, and *E. brunetti* develops in the ceca and the rectum (**Table 1**) [5, 33, 42].

## 6. Life cycle

The biological cycle of the protozoa of the genus *Eimeria* is similar to that of other protozoans of the coccidial type. They are obligate intracellular parasites that infect and develop in epithelial cells of the intestinal mucosa causing severe damage to the gut [47]. The life cycles of *Eimeria* spp. are complex, include three different phases, sporogony, merogony, and gametogony, and comprise both sexual and asexual reproductive phases [35, 48]. Some species vary in the number of asexual generations and in the time corresponding to every developmental stage [13, 49].

Infections begin when sporozoites are released from sporocyst and penetrate new cells. Once the sporozoite has achieved to penetrate into the epithelial cell, it forms the vacuola parasitofora and undergoes a process of rounding, transforming into a trophozoite. Then, by multiple nuclear divisions (so-called schizogony), the trophozoites become in the schizonts of the first generation. At the end of the maturation of the schizont, rupture of the membrane of the cell host allows the release of the merozoites to penetrate new cells [50].

These cycles of asexual schizogony (merogony) may be repeated numerous times. The sporozoites undergo merogony resulting in the release from one sporozoite of about 1,000 merozoites; occasionally, this stage is repeated two to four times and after sometimes merozoites develop into either male or female and form into host cell (gametogony, the sexual phase) [33, 50]. Microgametes (male) are flagellated and travel to the immobile macrogametes (female) to fertilize these stages. Upon fertilization, the wall-forming bodies of the macrogametes are externalized and fuse to form the oocyst wall of the unsporulated oocyst that is released from the intestinal mucosa and then is excreted with the feces [4, 33, 49–53].

Once the birds are infected, sporozoites are released within oocysts and penetrate new host cells in the intestinal mucosa, to invade and destroy them and initiate the life cell cycle. As a consequence, infected birds display symptoms of disease such as reduced feed intake, bloody diarrhea, hampered weight gain, loss of appetite, and huddling [2, 4, 36, 50, 54]. The complete process between oocyst ingestion and release may take between 4 and 6 days (depending on the species) [49].

Pathogenic species are typically characterized by at least one large endogenous life cycle stage, which may be asexual (e.g., second-generation schizont of *E. tenella* or *E. necatrix*) or gametocyte (e.g., *E. maxima*). The prepatent period usually fluctuates from 4 to 5 days after oral infection, and maximal oocyst output ranges from day 6 to 9 post-infection [52].

## 7. Modes of transmission

Coccidian parasites are transmitted by direct or indirect contact with the excrement of other infected birds; afterward a bird ingests coccidia, the organism invades the intestinal mucosa causing damages in the tissues as it reproduces [50, 55]. Following infection, coccidia produces immature oocytes, which are expelled with the fecal matter, usually in an unsporulated (no infective state) and cannot infect another bird unless they undergo a process of sporulation (infective state). Oocysts may remain in the environment for months to years, depending on the species and environmental conditions [50]. In the environment, sporozoites are protected from desiccation, as well as climatic conditions, such as cold, hot weather, and chemical disinfection by the oocyst wall. This structure assures successful disease transmission and is essential for the parasite survival in the environment [50, 55]. In this regard, it has been reported that in environmental conditions the sporulated oocyst can survive up to 602 days, while an unsporulated oocyst can survive up to 7 months in the cecal tissue [4, 33].

## 8. Coccidian oocysts

A defining characteristic of the *Coccidia* spp. is the development of resistant oocysts that are shed with feces. The coccidian oocyst are exogenous stages that are usually unsporulated in the feces and are considered a remarkably hard and persistent structure. It is resistant to mechanical and chemical damage and to proteolytic degradation. They are difficult to eliminate from the environment because they are surrounded by an indestructible wall that confers resistance to chemical disinfection [55–57].

| Plant                             | Compound                             | Species              | Life cycle stages                       | Reference |
|-----------------------------------|--------------------------------------|----------------------|---|-----------|
| <i>Artemisia annua</i>            | Artemisinin                          | <i>E. tenella</i>    | Oocyst formation                        | [58, 59]  |
|                                   |                                      | <i>E. acervulina</i> | Sporulated                              |           |
|                                   |                                      | <i>E. maxima</i>     |   |           |
| <i>Pinus radiata</i>              | Tannin                               | <i>E. tenella</i>    | Sporulated                              | [60]      |
|                                   |                                      | <i>E. acervulina</i> |   |           |
|                                   |                                      | <i>E. maxima</i>     |   |           |
| <i>Azadirachta indica</i>         | Bornyl acetate                       | <i>E. tenella</i>    | Oocyst formation<br>(immune modulation) | [61, 62]  |
|                                   | $\alpha$ -Pinene limonene            |                      |   |           |
|                                   | b-Caryophyllene                      |                      |   |           |
| <i>Sophora flavescens</i>         | 2-Ethyl-1-hexanol<br>geranyl         | <i>E. tenella</i>    | Oocyst formation<br>(immune modulation) | [63, 64]  |
|                                   |                                      | <i>E. acervulina</i> |   |           |
|                                   |                                      | <i>E. maxima</i>     |   |           |
| <i>Berberis lycium</i>            | Berberine                            | <i>E. tenella</i>    | Oocyst formation<br>(immune modulation) | [65–67]   |
|                                   | Berberine palmitine                  | <i>E. acervulina</i> |   |           |
|                                   | Antocyanin<br>berbamine              | <i>E. maxima</i>     |   |           |
| <i>Origanum vulgare</i>           | Thymol                               | <i>E. tenella</i>    | Oocyst formation                        | [68, 69]  |
|                                   | Carvacrol                            | <i>E. acervulina</i> |   |           |
|                                   | $\gamma$ -Terpinene                  | <i>E. maxima</i>     |   |           |
|                                   | p-Cymene                             |                      |   |           |
| <i>Pimpinella anisum</i>          | p-Allylanisole                       | <i>E. tenella</i>    | Sporulated                              | [58]      |
|                                   | Z-a-biosabolene                      |                      |   |           |
| <i>Allium sativum</i>             | Allicin                              | <i>E. tenella</i>    | Sporulated                              | [70]      |
| <i>Bidens pilosa</i>              | Polyacetylene                        | <i>E. tenella</i>    | Oocyst formation<br>(immune modulation) | [71]      |
| <i>Linum<br/>usitatissimum</i>    | N-3fatty acids                       | <i>E. tenella</i>    | Schizogony                              | [72]      |
| <i>Ageratum<br/>conyzoides</i>    | Flavonoids                           | <i>E. tenella</i>    | Schizogony                              | [73]      |
| <i>Carica papaya</i>              | Papain                               | <i>E. tenella</i>    | Oocyst formation<br>(immune modulation) | [74]      |
| <i>Syzygium<br/>aromaticum</i>    | Eugenol and<br>eugenyl acetate       | <i>E. tenella</i>    | Sporulated                              | [75]      |
| <i>Melaleuca<br/>alternifolia</i> | Terpinen-4-ol and<br>gamma-terpinene | <i>E. oocyst</i>     | Oocyst formation                        | [75]      |

**Table 2.** Anticoccidial activity of plants against *Eimeria* spp. and their target life cycle stage.

| Commercial product                               | Composition   | Supplier                      |
|--|---|-------------------------------|
| Solucox  | Vinegar of cider, macerates of red rose ( <i>Rosa gallica</i> ), white thyme ( <i>Thymus vulgare</i> ), goldenrod ( <i>Solidago virga aurea</i> ), oregano ( <i>Origanum vulgare</i> )              | La Ferme de Beaumont          |
| Elan Biotic®                                     | Mixture of plant extracts, herbs, essential oils, organic acids, and tannins  | Olus plus BV                  |
| Elan plus®                                       | Mixture of plant extracts, herbs, essential oils, organic acids, and tannins  | Olus plus BV                  |
| Necotyl®   | Mixture of plant extracts, herbs, essential oils, organic acids, and tannins  | Olus plus BV                  |
| Verm-X Poultry® Pellets                          | Wheat meal, wheatfeed meal, limestone flour, garlic, cinnamon, common thyme, seaweed meal, sunflower oil, nettle, cleavers, fennel, peppermint, slippery elm, quassia, dicalcium phosphate, cayenne | Verm-X                        |
| Verm-X Poultry® Liquid                           | Cinnamon, garlic, common thyme, peppermint, fennel, cleavers, nettle, slippery elm, quassia, elecampane   | Verm-X                        |
| Cocci-Guard                                      | Concentrated saponin extract  | DPI Global                    |
| BP formulation                                   | <i>Bidens pilosa</i> , and other plants   | Ta Fong, Inc.                 |
| Alquernat Zycox                                  | Mixture of plants <i>Holarrhena antidysenterica</i> , <i>Berberis aristata</i> , <i>Embelia ribes</i> , and <i>Acorus calamus</i> , polyphenols, essential oils, and polysaccharides                | Biovet SA                     |
| Plant and extracts having anticoccidial activity | Mixture of <i>Quercus infectoria</i> , <i>Rhus chinensis</i> , and <i>Terminalia chebula</i>  | Kemin Industries              |
| Apacox   | <i>Agrimonia eupatoria</i> , <i>Echinacea angustifolia</i> , <i>Embelia ribes</i> , <i>nigrum</i> , <i>Cinchona succirubra</i>  | GreenVet                      |
| Avihicox   | <i>Bocconia cordata</i> and clove extract   | Centaur                       |
| Nutrimin   | Apple cider vinegar   | Chicken Licken                |
| Kocci Free                                       | Free olive leaf, mustard seed, black seed, cloves, grapefruit seed extract  | Amber Technology              |
| Oil of oregano factors                           | Oregano extra virgin olive oil (80% carvacrol)  | Natural factors               |
| Oilis  | Natural vegetal extracts  | Engormix                      |
| Oreganico  | Oregano oil and essential oils  | Flyte so fancy                |
| Garlic   | Garlic granules   | Flyte So Fancy                |
| Poultry ProVita                                  | Probiotics and prebiotic inulin   | Vets Plus                     |
| CitriStim®                                       | CitriStim Mannan oligosaccharides and beta glucans  | ADM                           |
| Orego-Stim®                                      | Orego-Stim carvacrol (82%) and thymol (2.4%)  | Saife VetMed                  |
| Herban   | Etheric oils, soya oils, oregano oils   | Uncle Ted's Organics Ltd.     |
| Herb 'n' Thrive                                  | Concentrated blend of herbs and essential oils  | Chicken Licken                |
| Eimericox®                                       | Several essential oils (Phytosynthese/Trouw Nutrition)  | Phytosynthese/Trouw Nutrition |

| Commercial product            | Composition   | Supplier      |
|-------------------------------|---|---------------|
| Natustat                      | Several essential oils and yeast cell walls   | Alltech       |
| EnteroGuard                   | Garlic and cinnamon   | Orffa         |
| Xtract Immunocox              | Spanish pepper and turmeric   | Pancosma      |
| Coxynil                       | <i>Allium sativum</i> Linn 15%, <i>Cinnamomum camphora</i> Nees and Eberum 15%, <i>Elephantopus scaber</i> Linn 15%, <i>Valeriana wallichii</i> DC 15%, sulfur dioxide 25% and NaCl 15% | Growell India |
| Ropadiar® (powder and liquid) | Ethereal oil (oregano oil)  | Ropapharm     |
| Modified from [4].            |   |               |

**Table 3.** Natural products available to control coccidiosis.

## 9. Prevention and control of coccidiosis

Avian coccidiosis is hard to eradicate by two principal reason: first, the oocyst wall is environmentally resistant and second, the sporulated oocyst can outlive for long time in the environment. Currently, controls strategies mainly depend on the use of anticoccidial drugs and live vaccines but the use of natural compounds to prevent avian coccidiosis go up daily [33].

These natural products can include plant extracts, probiotics. In poultry, mainly used as diet supplements with diverse effects as stimulation of immune response, anti inflammatory activities, cytoplasmic damage and antioxidant. By other hand, natural compounds from plant extracts possess metabolites with distinct mode of action capable to inhibiting different stages of the *Eimeria* species life cycle (**Tables 2** and **3**) [4, 7].

## 10. Conclusions

Coccidiosis is a frequent cause of diarrhea, morbidity, and mortality in domesticated birds, and notwithstanding a broad number of drugs to control this disease are commercially available. *Eimeria* species have developed resistance to conventional anticoccidial drugs over time. Due to widespread development of resistance and the increase of concern of consumers on food safety, different efforts have been made to search for new agents with anticoccidial activity. In this regard, the investigation on natural alternatives has grown quickly and has been considered the most effective and safe strategy for the control and prevention of coccidiosis. On the other hand, these new strategies are friendly with the environment, so that although they have a higher cost, the advantages that these offer are worth. Finally, recent advances in “omics” provide a novel approach for gene discovery involved in anticoccidial drug resistance and for developing marker-assisted selection strategies like method of disease prevention and control.

## Author details

Mayra E. Cobaxin-Cárdenas

Address all correspondence to: cobaxin.mayra@inifap.gob.mx

Anaplasmosis Unit, National Center for Disciplinary Research in Veterinary Parasitology, CENID-PAVET, INIFAP, Jiutepec, Morelos, México

## References

- [1] De Gussem M. Coccidiosis in poultry: Review on diagnosis, control, prevention and interaction with overall gut health. In: Proceedings of the 16th European Symposium on Poultry Nutrition. 2007. pp. 253-261
- [2] Gilbert ER, Cox PM, Williams CM, et al. *Eimeria* species and genetic background influence the serum protein profile of broilers with coccidiosis. PLoS ONE. 2011;6(1). Article ID: e14636
- [3] Chapman HD, Barta JR, Blake D, Gruber A, Jenkins M, Smith NC, Suo X, Tomley FM. A selective review of advances in coccidiosis research. Advances in Parasitology. 2013;83: 93-171
- [4] Quiroz-Castañeda RE, Dantán-González E. Control of avian coccidiosis: Future and present natural alternatives. BioMed Research International. 2015;2015:11. Article ID: 430610. <http://dx.doi.org/10.1155/2015/430610>
- [5] Shivaramaiah C, Barta JR, Hernandez-Velasco X, Téllez G, Hargis B. Coccidiosis: Recent advancements in the immunobiology of *Eimeria* species, preventive measures, and the importance of vaccination as a control tool against these Apicomplexan parasites. Veterinary Medicine: Research and Reports. 2014;5:23-34. DOI: 10.2147/VMRR.S57839
- [6] Muthamilselvan T, Kuo TF, Wu YC, Yang WC. Herbal remedies for coccidiosis control: A review of plants, compounds, and anticoccidial actions. Evidence-Based Complementary and Alternative Medicine. 2016;2016:19. Article ID: 2657981. <http://dx.doi.org/10.1155/2016/2657981>
- [7] Abbas RZ, Colwell DD, Gilleard J. Botanicals: An alternative approach for the control of avian coccidiosis. World's Poultry Science Journal. 2012;68:203-215. DOI: 10.1017/S0043933912000268
- [8] Peek HW, Landman WJM. Coccidiosis in poultry: Anticoccidial products, vaccines and other prevention strategies. Veterinary Quarterly. 2011;31:143-161. DOI: 10.1080/01652176.2011.605247
- [9] Guo FC, Kwakkel RP, Williams BA, Suo X, Li WK, Verstegen MW. Coccidiosis immunization: Effects of mushroom and herb polysaccharides on immune responses of chickens with *Eimeria tenella*. Avian Disease. 2005;49:70-73
- [10] Guven E, Avcioglu H, Aslan A, Hayirli A. Anticoccidial Efficacy of Usnic Acid in Broilers. Kafkas Üniversitesi Veteriner Fakültesi Dergis. 2016;22(4):551-556

- [11] Smil V. Worldwide transformation of diets, burdens of meat production and opportunities for novel food proteins. *Enzyme and Microbial Technology*. 2002;**30**(3):305-311
- [12] Bogosavljevic-Boskovic S, Mitrovic S, Djokovic R, Doskovic V, Djermanovic V. Chemical composition of chicken meat produced in extensive indoor and free range rearing systems. *African Journal of Biotechnology*. 2010;**9**(53):9069-9075
- [13] Blake DP, Tomley FM. Securing poultry production from the ever-present *Eimeria* challenge. *Trends in Parasitology*. 2014;**30**:12-19. DOI: 10.1016/j.pt.2013.10.003
- [14] FAOSTAT. 2014. Livestock poultry production. <http://faostat.fao.org/>
- [15] Belova AV, Smutka L, Rosochatecká E. World chicken meta market—Its development and current status. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*. 2012;**60**(4):15-30
- [16] Blake DP, Clark EL, Macdonald SE, Thenmozhi V, Kundu K, Garg R, Reid AJ. Population, genetic, and antigenic diversity of the apicomplexan *Eimeria tenella* and their relevance to vaccine development. *Proceedings of the National Academy of Science*. 2015;**112**(38):E5343-E5350
- [17] Dalloul RA, Lillehoj HS. Poultry coccidiosis: Recent advancements in control measures and vaccine development. *Expert Review of Vaccines*. 2006;**5**(1):143-163
- [18] Oz HS. Selective induced altered coccidians to immunize and prevent enteritis. *Gastroenterology Research and Practice*. 2016;**2016**:8. Article ID: 3952534. <http://dx.doi.org/10.1155/2016/3952534>
- [19] Shirley MW, Smith AL, Tomley FM. The biology of avian *Eimeria* with an emphasis on their control by vaccination. *Advances in Parasitology*. 2005;**60**:285-330
- [20] Ahmad TA, El-Sayed BA, El-Sayed LH. Development of immunization trials against *Eimeria* spp. *Trials in Vaccinology*. 2016;**5**:38-47
- [21] Morrison DA. Evolution of the Apicomplexa: Where are we now? *Trends in Parasitology*. 2009;**25**(8):375-382
- [22] Hu K, Johnson J, Florens L, et al. Cytoskeletal components of an invasion machine the apical complex of *Toxoplasma gondii*. *PLoS Pathogens*. 2006;**2**(2):e13
- [23] Reid AJ, Blake DP, Ansari HR, Billington K, Browne HP, Bryant J, Malas TB. Genomic analysis of the causative agents of coccidiosis in domestic chickens. *Genome Research*. 2014;**24**(10):1676-1685
- [24] Morgan JAT, Morris GM, Wlodek BM, et al. Real time polymerase chain reaction (PCR) assays for the specific detection and quantification of seven *Eimeria* species that cause coccidiosis in chickens. *Molecular and Cellular Probes*. 2009;**23**(2):83-89
- [25] Haug A, Gjevre AG, Thebo P, Mattsson JG, Kaldhusdal M. Coccidial infections in commercial broilers: Epidemiological aspects and comparison of *Eimeria* species identification by morphometric and polymerase chain reaction techniques. *Avian Pathology*. 2008;**37**(2):161-170

- [26] Tyzzer EE. Coccidiosis in gallinaceous birds. American Journal of Hygiene. 1929;**10**: 269-383
- [27] Levine PP. A new coccidium pathogenic for chickens, *Eimeria brunetti* n. sp. (Protozoa: Eimeriidae). Cornell. Veterinarian. 1942;**32**:430-439
- [28] Edgar SA, Siebold CT. A New coccidium of chickens, *Eimeria mivati* sp. n. (Protozoa: Eimeriidae), with details of its life history. Journal of Parasitology. 1964;**50**:193-204
- [29] Johnson WT. Coccidiosis of the chicken with special reference to species. Standard Bulletin Oregon Agriculture Experiment station. 1938;**358**:3-33
- [30] Raillet A, Lucet A. Note sur quelques especes de coccidies encore peu etudiees. Bulletin de la Société Zoologique de France. 1891;**16**:246-250
- [31] Levine PP. *Eimeria hagani* n. sp. (Protozoa: Eimeriidae) a new coccidium of the chicken. Cornell Veterinarian. 1938;**28**:263-266
- [32] Williams RB. A compartmentalised model for the estimation of the cost of coccidiosis to the world's chicken production industry. International Journal for Parasitology. 1999;**29**:1209-1229
- [33] Price KR. Use of live vaccines for coccidiosis control in replacement layer pullets. Journal of Applied Poultry Research. 2012;**21**(3):679-692
- [34] Jadhav BN, Nikam SV, Bhamre SN, Jaid EL. Study of *Eimeria necatrix* in broiler chicken from Aurangabad district of Maharashtra state India. International Multidisciplinary Research Journal. 2011;**1**(11):11-12
- [35] Lillehoj HS. Influence of inoculation dose, inoculation schedule, chicken age, and host genetics on disease susceptibility and development of resistance to *Eimeria tenella* infection. Avian Diseases. 1988;**32**:437-444
- [36] McDonald V, Shirley MW. Past and future: Vaccination against *Eimeria*. Parasitology. 2009;**136**(12):1477-1489
- [37] Hafez HM. Poultry coccidiosis: Prevention and control approaches. Archiv fur Geflugelkunde. 2008;**72**(1):2-7
- [38] Finlay RC, Roberts SJ, Hayday AC. Dynamic response of murine gut intraepithelial T cells after infection by the coccidian parasite *Eimeria*. European Journal of Immunology. 1993;**23**:2557-2564
- [39] Helmbolt CF, Bryant ES. The pathology of necrotic enteritis in domestic fowl. Avian Diseases. 1971;**15**:775-780
- [40] McDougald LR, Hu J. Blackhead disease (*Histomonas meleagridis*) aggravated in broiler chickens by concurrent infection with cecal coccidiosis (*Eimeria tenella*). Avian Diseases. 2001;**45**:307-312
- [41] Cook GC. Small intestinal coccidiosis: And emergent clinical problem. Journal of Infection. 1988;**16**:213-219

- [42] Raman M, Banu SS, Gomathinayagam S, Raj GD. Lesion scoring technique for assessing the virulence and pathogenicity of Indian field isolates of avian *Eimeria* species. *Veterinarski Archive*. 2011;**81**(2):259-271
- [43] Peek HW, Landman WJM. Coccidiosis in poultry: Anticoccidial products and alternative prevention strategies (a review). *Veterinary Quarterly*, 31;3:143-161. <http://dx.doi.org/10.1080/01652176.2011.605247>
- [44] Chapman HD. Milestones in avian coccidiosis research: A review. *Poultry Science*. 2014;**93**(3):501-511
- [45] Duffy CF, Mathis GF, Power RF. Effects of Natustat supplementation on performance, feed efficiency and intestinal lesion scores in broiler chickens challenged with *Eimeria acervulina*, *Eimeria maxima* and *Eimeria tenella*. *Veterinary Parasitology*. 2005;**130**(3-4): 185-190
- [46] McDougald LR, Fitz-Coy SH. Protozoal infections. In: Saif YM, editor. *Diseases of Poultry*. Ames, Iowa, USA: Blackwell Publishing; 2009. p. 1352
- [47] Min W, Dalloul RA, Lillehoj HS. Application of biotechnological tools for coccidia vaccine development. *Journal of Veterinary Science*. 2004;**5**(4):279-288
- [48] Hammond DM. Life cycles and development of coccidian. In: Hammond DM, Long PL, editors. *The Coccidia*. Baltimore, MD: University Park Press; 1982. pp. 45-79
- [49] McDougald LR. Coccidiosis. In: Swayne DE, editor. *Diseases of Poultry*. Wiley-Blackwell; 2013. p. 1408
- [50] Barta JR. Coccidiosis. *Encyclopedia of Life Sciences*. 2001;**19**(April):1-8. DOI: 10.1038/npg.els.0001947
- [51] Seemann E, Kurth T, Entzeroth R. Insight into the ultrastructural organisation of sporulated oocysts of *Eimeria nieschulzi* (Coccidia, Apicomplexa). *Parasitology Research*. 2012;**111**:2143-2147
- [52] Reid WM, Long PL. A diagnostic chart for nine species of fowl coccidia. In: Bowen NB, editor. *Georgia Agric. Exp. Stn. Tech. Bull*. Athens: College of Agriculture, University of Georgia; 1979. pp. 5-24
- [53] Kheysin YM. Sporulation of oocysts and their survival in the external environment. In: Todd Jr KS, editor. *Life Cycles of Coccidia of Domestic Animals*. Baltimore, MD: University Park Press; 1972;**33**:149-161
- [54] Dalloul RA, Lillehoj HS. Recent advances in immunomodulation and vaccination strategies against coccidiosis. *Avian Diseases*. 2005;**49**(1):1-8
- [55] Belli SI, Smith NC, Ferguson DJ. The coccidian oocyst: A tough nut to crack! *Trends in Parasitology*. 2006;**22**(9):416-423
- [56] Kreier JP, editor. *Parasitic Protozoa*. Vol. 10. San Diego (California): Academic Press. 2013. pp. 225-422

- [57] Mai K, Sharman PA, Walker RA, Katrib M, Souza DD, McConville MJ, Smith NC. Oocyst wall formation and composition in coccidian parasites. *Memorias do Instituto Oswaldo Cruz*. 2009;**104**(2):281-289
- [58] Drăgan L, Titilincu A, Dan I, Dunca I, Drăgan M, Mircean V. Effects of *Artemisia annua* and *Pimpinella anisum* on *Eimeria tenella* (Phylum Apicomplexa) low infection in chickens. *Scientia Parasitologica*. 2010;**11**(2):77-82
- [59] del Cacho E, Gallego M, Francesch M, Quílez J, Sánchez-Acedo C. Effect of artemisinin on oocyst wall formation and sporulation during *Eimeria tenella* infection. *Parasitology International*. 2010;**59**(4):506-511
- [60] Molan AL, Liu Z, De S. Effect of pine bark (*Pinus radiata*) extracts on sporulation of coccidian oocysts. *Folia Parasitologica*. 2009;**56**(1):1
- [61] Biu AA, Yusuf SD, Rabo JS. Use of neem (*Azadirachta indica*) aqueous extract as a treatment for poultry coccidiosis in Borno State Nigeria. *African Scientist*. 2006;**7**:147-153
- [62] Pandey IP, Ahmed SF, Chhimwal S, Pandey S. Chemical composition and wound healing activity of volatile oil of leaves of *Azadirachta indica* A. juss. *Advances in Pure and Applied Chemistry*. 2012;**1**:62-66
- [63] Sundar SB, Harikrishnan TJ, Latha BR, Sarath G, Kumar CTS. Anticoccidial drug resistance in chicken coccidiosis and promising solutions: A review. *Journal of Entomology and Zoology Studies*. 2017;**5**(4):1526-1529
- [64] Li A, Han L, Han CC. Antioxidant and neuroprotective activities of essential oil, isolated from Chinese herb pairs of *angelica sinensis* and *sophora flavescens*. *Journal of Applied Pharmaceutical Science*. 2012;**2**(5):01-04. DOI: 10.7324/JAPS.2012.2505
- [65] Malik TA, Kamili AN, Chishti MZ, Tanveer S, Ahad S, Johri RK. *In vivo* anticoccidial activity of berberine [18, 5, 6-dihydro-9, 10-dimethoxybenzo (g)-1, 3-benzodioxolo (5, 6-a) quinolizinium]—an isoquinoline alkaloid present in the root bark of *Berberis lycium*. *Phytomedicine*. 2014;**21**(5):663-669
- [66] Nidaullah H, Durrani FR, Ahmad S, Jan IU, Gul S. Aqueous extract from different medicinal plants as anticoccidial, growth promotive and immunostimulant in broilers. *Journal of Agricultural and Biological Science*. 2010;**5**(1):53-59
- [67] Shabbir A, Shahzad M, Arfat Y, Ali L, Aziz RS, Murtaza G, Waqar SA. *Berberis lycium* Royle: A review of its traditional uses, phytochemistry and pharmacology. *African Journal of Pharmacy and Pharmacology*. 2012;**6**(31):2346-2353
- [68] Waldenstedt L. Effect of vaccination against coccidiosis in combination with an antibacterial oregano (*Origanum vulgare*) compound in organic broiler production. *Acta Agriculturae Scandinavica, Section A-Animal Science*. 2003;**53**(2):101-109
- [69] D'Antuono LF, Galletti GC, Bocchini P. Variability of essential oil content and composition of *Origanum vulgare* L. populations from a North Mediterranean Area (Liguria Region, Northern Italy). *Annals of Botany*. 2000;**86**(3):471-478

- [70] Alnassan AA, Thabet A, Dauschies A, Bangoura B. *In vitro* efficacy of allicin on chicken *Eimeria tenella* sporozoites. Parasitology Research. 2015;**114**(10):3913-3915
- [71] Yang WC, Tien YJ, Chung CY, Chen YC, Chiou WH, Hsu SY, et al. Effect of *Bidens pilosa* on infection and drug resistance of *Eimeria* in chickens. Research in Veterinary Science. 2015;**98**:74-81
- [72] Allen PC, Danforth HARRY, Levander OA. Interaction of dietary flaxseed with coccidia infections in chickens. Poultry Science. 1997;**76**(6):822-827
- [73] Nweze NE, Obiwulu IS. Anticoccidial effects of *Ageratum conyzoides*. Journal of Ethnopharmacology. 2009;**122**(1):6-9
- [74] Al-Fifi ZIA. Effect of leaves extract of *Carica papaya*, *Vernonia amigdalina* and *Azadirachta indica* on the coccidiosis in free-range chickens. Asian Journal of Animal Sciences. 2007;**1**(1):26-32
- [75] Remmal A, Achahbar S, Bouddine L, Chami N, Chami F. *In vitro* destruction of *Eimeria* oocysts by essential oils. Veterinary Parasitology. 2011;**182**(2):121-126

