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Parasite Adaptation Strategies and Mechanisms for Overcoming Them

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Abstract

The study aims to identify the adaptation strategies used by parasites to survive within the host and to clarify the mechanisms these parasites rely on to evade the host's immune system, on the one hand, and to resist antibiotics, on the other. The study also aims to propose ways to overcome these strategies and the proposed pharmacological or biological interactions. This is done using a methodology based on a literature review of previous studies and research, especially those that are reliable and free of bias in data or results. The results indicated that there are several strategies for adapting to the host, including altering surface proteins to evade immune recognition, in addition to secreting immune-suppressing molecules and hiding within protected cells or tissues such as the liver or blood. Some parasites produce enzymes that degrade antibodies, while others reduce the activity of immune cells. To overcome these strategies, it is necessary to develop drugs that target these enzymes and altered surface proteins and apply them. Vaccines to stimulate the immune system and the use of inhibitors of immune masking pathways, in addition to relying on modern techniques such as gene therapy to combat the adaptation strategies used by parasites to survive within the host.

Keywords: adaptation strategies, parasites, host, coping mechanisms, pharmacological interventions, immunity, research review.

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استراتيجيات التكيف للطفيليات مع العائل وآلية التغلب عليها

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مُلخص:

تهدف الدراسة إلى تحديد استراتيجيات التكيف التي تستخدمها الطفيليات للبقاء على قيد الحياة داخل المضـيف، وتوضـيح الآليات التي تعتمد عليها هذه الطفيليات للتهرب من الجهاز المناعي للمضـيف من جهة، ومقاومة المضـادات الحيوية من جهة أخرى. كما تهدف الدراسـة إلى اقتراح طرق للتغلب على هذه الاسـتراتيجيات والتفاعلات الدوائية أو البيولوجية المقترحة. ويتم ذلك باسـتخدام منهجية تعتمد على مراجعة الأدبيات للدراسـات والأبحاث السـابقة، وخاصـة تلك الموثوقة والخالية من التحيز في البيانات أو النتائج. وأشـارت النتائج إلى وجود عدة اسـتراتيجيات للتكيف مع المضـيف، بما في ذلك تغيير البروتينات السـطحية للتهرب من التعرف المناعي، بالإضـافة إلى إفراز جزيئات تثبيط المناعة والاختباء داخل الخلايا أو الأنسـجة المحمية مثل الكبد أو الدم. تنتج بعض الطفيليات إنزيمات تحلل الأجسام المضـادة، بينما يقلل البعض الآخر من نشاط الخلايا المناعية. وللتغلب على هذه الاسـتراتيجيات، من الضـروري تطوير أدوية تسـتهدف هذه الإنزيمات والبروتينات السـطحية المتغيرة وتطبيقها. وتطوير لقاحات لتحفيز الجهاز المناعي واستخدام مثبطات مسارات إخفاء المناعة، بالإضافة إلى الاعتماد على التقنيات الحديثة مثل العلاج الجيني لمكافحة اسـتراتيجيات التكيف التي تسـتخدمها الطفيليات للبقاء على قيد الحياة داخل المضيف.

الكلمات المفتاحية: استراتيجيات التكيف، الطفيليات، المضيف، آليات التأقلم، التدخلات الدوائية، المناعة، مراجعة الأبحاث.

1. Introduction

In light of the aspiration for sustainability in all sectors, including the medical sector, especially with regard to human health, many studies have been directed towards identifying the most important pathogens that affect humans and animals (**Nardulli et al., 2023).** and then identifying mechanisms to combat these diseases. Parasites and bacteria are considered among the most important pathogens, as

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they cause many diseases such as respiratory diseases, immunodeficiency diseases, blood and liver diseases, and other diseases that negatively affect human health **(Hunter et al., 2025).** This study aims to identify parasite strategies for adaptation within the host, in addition to identifying the mechanism by which these parasites adapt, and thus identifying the appropriate mechanisms to overcome and resist these strategies and identify appropriate pharmaceutical interventions to eliminate them. The study also aims to identify the obstacles and mechanisms facing this type of study and to identify proposals and solutions to overcome these obstacles. Hence, the study's importance, as it is a comprehensive study that identified obstacles, proposed solutions, and avoided bias in data and results. Furthermore, it contributed to understanding the dynamics of the interaction between parasites and their hosts. By understanding this dynamic, treatments can be developed that target parasite weaknesses, reduce parasitic disease rates, and improve public health. Through this study, visions and strategies can be formulated to support control and prevention programs based on accurate scientific foundations **(Zhang et al,. 2025).** The main research problem in this study is that parasites have developed advanced adaptation mechanisms to survive within the host, such as altering their surface composition, producing immunosuppressive proteins, and hiding in hard-to-reach locations. This allows them to hide from the immune system, leading to persistent and recurring infections despite available treatments. Another fundamental problem is that understanding the dynamics of parasite-host interactions requires further research, significant effort, and financial resources to develop insights and strategies that support scientifically based control and prevention programs. Furthermore, many studies addressing the topic have not covered all aspects of the topic, meaning they have not been comprehensive. Furthermore, there is some bias in the data and results of previous studies.

2. Theoretical background and basic concepts

This section presents the theoretical background and basic concepts of the study, which enable the reader to form an insightful perspective on the study's procedures, objectives, importance, methodology, and key findings. This is presented in a flexible and accessible manner, enabling the reader to gain a conscious understanding of the study's stages and objectives.

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2.1. Basic Concepts

There are some basic concepts related to the study. These concepts help the reader follow the study's procedures and gain a conscious understanding of them. The most important of these concepts are the following:

1. **Parasites**

Parasites are a group of organisms that depend for their survival and reproduction on another organism called a host, whether this host is a human, animal, or plant. They are among the most important causes of disease in living organisms, causing varying degrees of damage. They are divided into several types based on the relationship between the parasite and the host. There are internal parasites, meaning they live inside the host's body, such as amoebas, tapeworms, and others. There are external parasites, which live on the surface of the body, such as ticks and lice (**Elayaraja et al., 2024).** Parasites can also be classified according to the length of time they remain with the host. There are permanent parasites, such as intestinal worms, and temporary parasites, which visit the host for a short period, such as mosquitoes and some facultative parasites, such as some types of amoebas **(Rodriguez& Liu. 2024).As in Figure 1, as follows:**

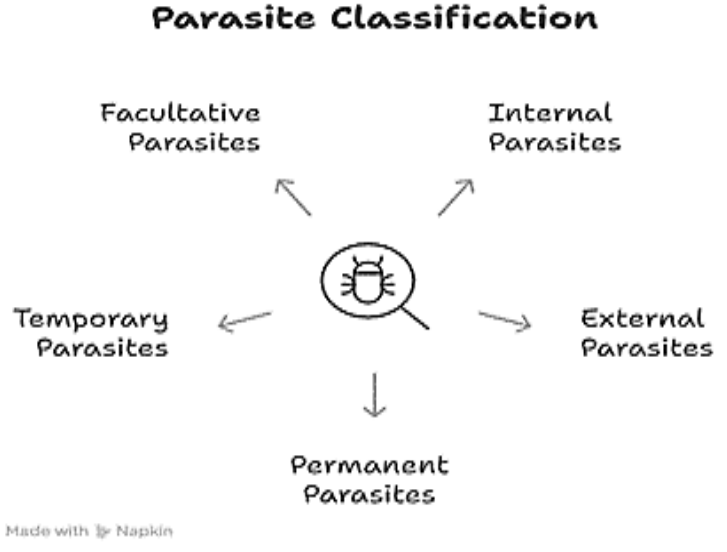

Figure 1: shows Parasite Classification (author)

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2. Parasite Evasion Strategies

Parasites use a number of strategies to evade the host's immune system, enabling them to thrive and cause disease. These methods may be generally classified as follows as in Figure 2:

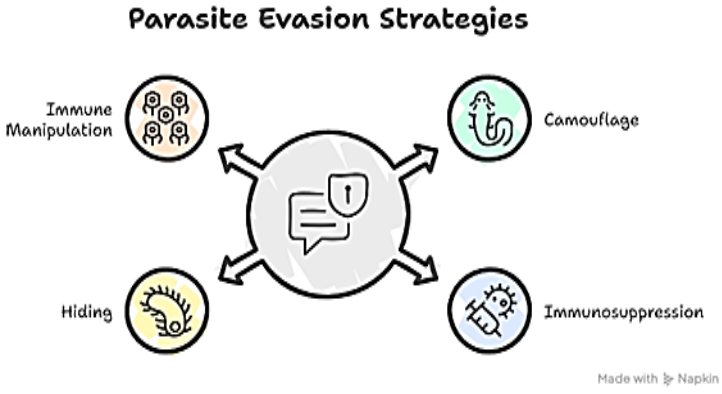

Figure 2: shows Parasite Evasion Strategies (author)

1) Camouflage and Surface Protein Alteration

Certain parasites, e.g., trypanosomes, have antigenic variation, which is a process by which they continuously change their surface proteins. This allows them to evade immune detection since the host's immune system is in a constant state of catch-up, trying to raise antibodies against the ever-changing surface antigens. By the time the immune response has been developed against one variant, the parasite will have already switched to another one. This tactic is most effective in chronic infections, when the parasite can persist for months or years by constantly evading immune elimination. **(Hambrook& Hanington.2021).**

2) Secretion of Immunosuppressants

Other parasites secrete immunosuppressive molecules that inhibit or modulate the host's immune response. Immunosuppressants within these parasites can disrupt the function of immune cells, such as T and B cells, or restrict the production of antibodies. For example, in malaria, the parasites secrete molecules that halt the activation of immune cells and, therefore, the host's ability to clear the infection. The immunosuppression also sensitizes the host to secondary infection **(Gibson& Amoroso. 2022).**

3) Camouflage in Host Refuges

Some parasites become camouflaged in refuges within the host organism, which are less exposed to immune cells and antibodies.

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For example, Toxoplasma parasites can invade and reside within host cells, such as liver or blood cells, and develop cysts that shield them from immune attack. Leishmania parasites also reside within macrophages, immune cells that otherwise infect and kill pathogens. By sheltering in such immunoprotected niches, parasites are able to escape from immune detection and survive for long durations **(Tarannum et al .,2023).**

4) Hiding in Protected Areas within the Host

Some parasites resort to hiding inside protected areas inside the body of the rational being, where the immune system cannot recognize them or reach them through antibodies **(Yu et al.,2023).** For example, Toxoplasma parasites invade the host cells and settle in them, such as liver or blood cells.As in Figure3 :

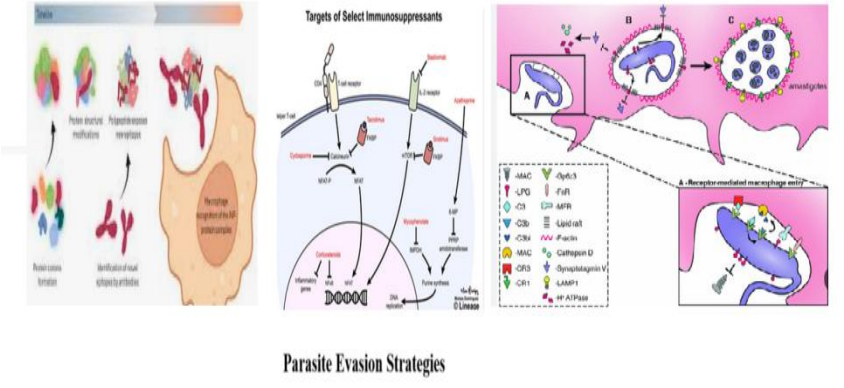

Figure 3: shows Parasite Evasion Strategies
(https://www.sciencedirect.com)

3. Mechanisms to Counter Parasite Evasion Strategies

It is important to counter parasite evasion strategies in order to develop effective therapy and prophylaxis against parasitic disease. There are different approaches that are being explored to counteract these evasion mechanisms and stimulate the host to eliminate the infection.

1) Designing Drugs that Target Camouflage Proteins

One approach is to design drugs that target specifically the proteins involved in antigenic variation or modification of the surface protein. These drugs could inhibit the enzymes that flip surface antigens or disrupt mechanisms for gene expression of surface proteins. Possibly, by targeting such proteins, it could be ensured

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that parasites cannot evade immune detection and become susceptible to immune elimination **(Mehta, & Shende.,2023).**
Vaccines could be designed to evoke strong and long-lasting immunity against parasites. These vaccines could be designed to target several antigens, including conserved antigens, which are not subject to antigenic variation, to provide broad immunity against multiple parasite strains. Vaccines can also be prepared with adjuvants that enhance the immune response and allow for the production of memory immune cells. By inducing strong immunity, vaccines could prevent infection or reduce disease severity **(Poirotte et al.,2022).**

2) Use of Nanotechnology to Deliver the Drug to the Parasite's Sheltering Location Directly

Nanotechnology can be used to directly deliver the drug to the parasite's sheltering location, such as within host cells or protected tissues. Nanoparticles are able to be made to target particular cells or tissues and release their drug payload at the site of infection. Targeted drug delivery has the potential to increase the efficacy of the treatment and lower the probability of side effects. For example, nanoparticles can be used to deliver anti-parasitic drugs to infected liver cells or macrophages in which parasites are hidden **(Ezema& Ezeorba. 2023).**

3) Combination of Drug and Immunotherapy for Better Effectiveness

Combination of drug therapy with immunotherapy has the potential to be an effective approach to combat parasitic infections. Drugs can reduce the number of the parasite load, while immunotherapy can strengthen the host's immunity to destroy the remaining parasites. Immunotherapy could involve therapeutic treatment with cytokines, antibodies, or immune cells to augment immune function. For example, interferon-gamma administration is feasible for the activation of macrophages and enhanced antiparasitic killing activity. Both drug therapy and immunotherapy could produce more effective and sustained parasitic infection control**(Chulanetra& Chaicumpa. 2021).as shown in Figure 4:**

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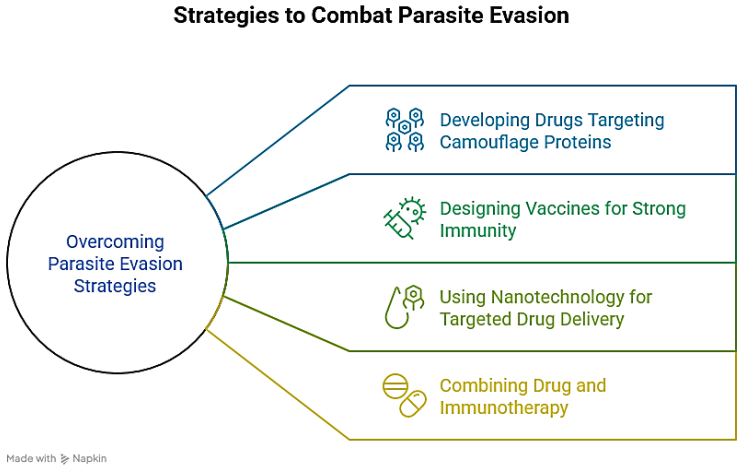

Figure 4: shows Mechanisms to Counter Parasite Evasion Strategies (author)

2.2. Examples of parasites and their strategies

This section explores the fascinating and occasionally unnerving realm of parasites, living organisms that live on or within a host organism and obtain nourishment or some other benefit from it. We will examine the techniques employed by different parasites in order to survive and reproduce, and we will examine protozoa (Plasmodium), helminthes (tapeworms and roundworms), and ectoparasites (ticks and lice). It is vital to understand how these parasites operate in order to treat and control parasitic diseases effectively.

1.Protozoa: Plasmodium (Malaria)

The protozoan parasite genus Plasmodium is notorious for causing malaria, a lethal disease transmitted through bites from infected female Anopheles mosquitoes. Plasmodium has a complex life cycle with both a vertebrate (human) and invertebrate (mosquito) host and demonstrates impressive adaptation for transmission and survival **(Bhatt. 2024).**

Survival Strategies**:**

The strategy relies on what is called antigenic variation, whereby Plasmodium modifies proteins on its surface to bypass the host's immune system. This impedes the immune system's ability to identify and destroy the parasite, leading to chronic infection. As for the parasite's lifestyle within the host, it resides within the liver and red blood cells, finding them a safe haven for reproduction and

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growth, which increases the infection rate and the chances of further infection.**as shown in Figure5:**

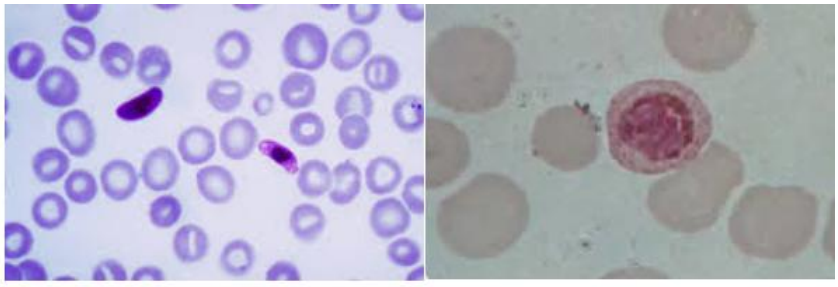

Figure 5: shows Protozoa: Plasmodium (Malaria)
https://www.who.int/news-room/fact-sheets/detail/malaria?spm=a2ty_o01.29997173.0.0.4994c921Crittb

2.Helminths: Tapeworms and Roundworms

Helminths, parasitic worms, are multicellular parasites that infect a variety of hosts, including human beings. Two of the largest taxonomic groups of helminths, with different morphologies and survival mechanisms, include tapeworms (cestodes) and roundworms (nematodes) **(Maratovna. 2024). as shown in Figure 6:**

Figure 6: shows Tapeworms and Roundworms
(https://www.cdc.gov/parasites)

1) Tapeworms

Tapeworms are parasitic intestinal worms with a long, segmented body. They do not possess a digestive tract and instead absorb nutrients from the host gut directly.

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- Survival Strategies

Their strategy is to attach to the intestinal wall. Nematodes possess hooks and suckers that allow them to firmly adhere to the intestinal wall, protecting them from being expelled by worm movement. Since they lack a digestive system, they rely entirely on the absorption of predigested food from the host's intestine.

2) Roundworms (Nematodes)

Roundworms are cylindrical, unsegmented worms that infect a wide variety of host tissues and organs.

- Survival Strategies:

They rely on the strategy of a hard, protective cuticle for survival, as this cuticle provides a protective barrier against antibiotics, resistance from the host's immune system, and the host's immune response. Environmental Resistance: Eggs of roundworms are highly resistant to environmental stress, such as desiccation and temperature extremes, and thus they will remain viable in the soil or water for extended periods.

3.Ectoparasites: Ticks and Lice

Ectoparasites are those parasites which live on the outer surface of their host. Ticks and lice are the two most common examples of ectoparasites that feed on the blood or skin of the host **(Diaz. 2024).**

1) Ticks

Ticks are hematophagous arthropods that transmit a variety of diseases in animals and humans.

- Survival Strategies:

The strategy it follows is attachment, as the tick has specialized mouthparts that enable it to adhere strongly to the host’s skin. It secretes a cement-like substance that strengthens its cohesion to the host’s body or the rational being. Ticks are external parasite **(Abuzahra et al.,2025).**

2) Lice

Lice are wingless insects that live on hair and skin of hosts and feed on blood or pieces of skin.

- Survival Strategies:

Lice have special claws that enable them to adhere tightly to the hair or feathers of the host. a**s in Figure 7, as follows:**

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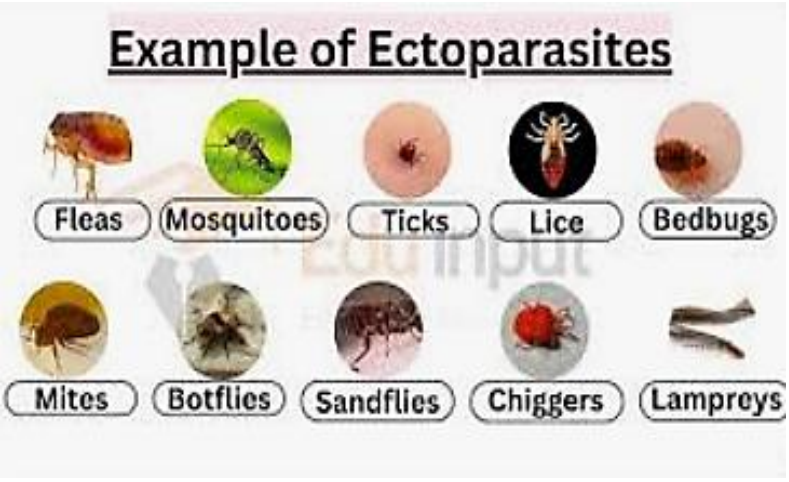

Figure 7: shows Ectoparasites(https://www.sciencedirect.com)

2.3. Pathological Effects of Parasites on Hosts

Parasites inflict a wide range of pathological effects on their hosts, influencing immunity, nutrition, behavior, and overall health. These effects often result in immune dysregulation, nutrient depletion, behavioral changes, and chronic health complications, ultimately reducing quality of life and productivity **(Chauhan et al.,2024).as in Figure 8, as follows:**

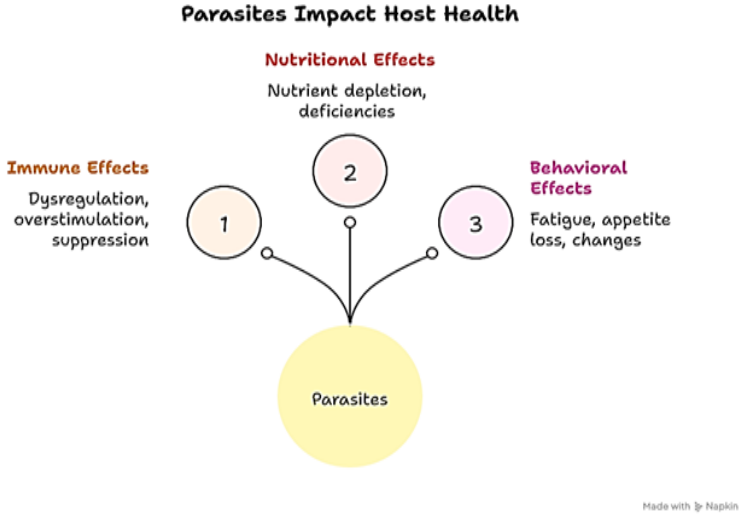

Figure 8: shows Parasites Impact Host Health (author)

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1. Immune Effects

Parasites significantly impact the host's immune system, causing either excessive stimulation or suppression. Both conditions have serious consequences for health and resistance to other infections.

1) Overstimulation of the Immune System

Some parasites induce an exaggerated inflammatory response intended to fight the infection, but this can harm the host's own tissues. For example, certain helminths provoke a strong Th2 immune reaction involving IgE antibodies and eosinophils, which may lead to allergic symptoms and tissue damage.

2) Suppression of the Immune System

Conversely, some parasites suppress immunity by secreting molecules that inhibit the activation of immune cells such as T and B lymphocytes. Malaria parasites, for instance, weaken immune defenses, making hosts more vulnerable to secondary infections. Similarly, Entamoeba histolytica not only causes severe intestinal disease but also reduces immune responsiveness**(Saad et al.,2024)**

2. Nutritional Effects

Parasitic infections often result in competition for nutrients, leading to malnutrition and deficiencies in essential vitamins and minerals.

1) Nutrient Depletion

Parasites consume vital nutrients from the host's diet, depriving them of the resources needed for normal growth and function. For example, intestinal worms such as hookworms absorb iron, causing iron-deficiency anemia characterized by fatigue, weakness, and impaired cognition.

2) Vitamin and Mineral Deficiencies

Some parasites disrupt the absorption of vitamins like folic acid, contributing to anemia, developmental issues, and metabolic problems. Additionally, parasitic infections often cause weight loss due to malabsorption and increased energy demands.

3. Effects on Behavior and General Health

Parasites also affect mental and physical well-being through various mechanisms.

1) Chronic Fatigue and Reduced Activity

Due to nutrient loss and immune stress, infected individuals often experience persistent fatigue and low energy levels.

2) Loss of Appetite and Growth Problems

Infections may reduce appetite, further aggravating malnutrition and leading to growth delays in children.

3) Neurological and Behavioral Alterations

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Some parasites directly affect the nervous system. Toxoplasma gondii, for instance, has been linked with behavioral and neurological disorders such as schizophrenia and bipolar disease by the manipulation of the function of neurotransmitters.

4) Lowered Productivity and Well-being

Continual infections lower the functionality at the workplace, in the academic world, or with society, resulting in economic issues as well as lowered total well-being **(ABD ELGWAD et al.,2024)**

3. Methodology

The methodology in this study is a review methodology based on a descriptive-analytical approach to clarify parasite adaptation strategies and mechanisms for overcoming them. The methodology is used to describe data, quantitative methods to collect data from various sources, and comparative methods to compare results.

3.1. the applied framework of the study

Figure 9 illustrates the applied framework of the study, starting with defining the objective and formulating the research problem, then collecting data and determining the collection tools. It then proceeds to selecting studies, taking into account inclusion and exclusion criteria, and then analyzing, recording, and evaluating the results of these studies, drawing conclusions and presenting recommendations. **As in Figure 9:**

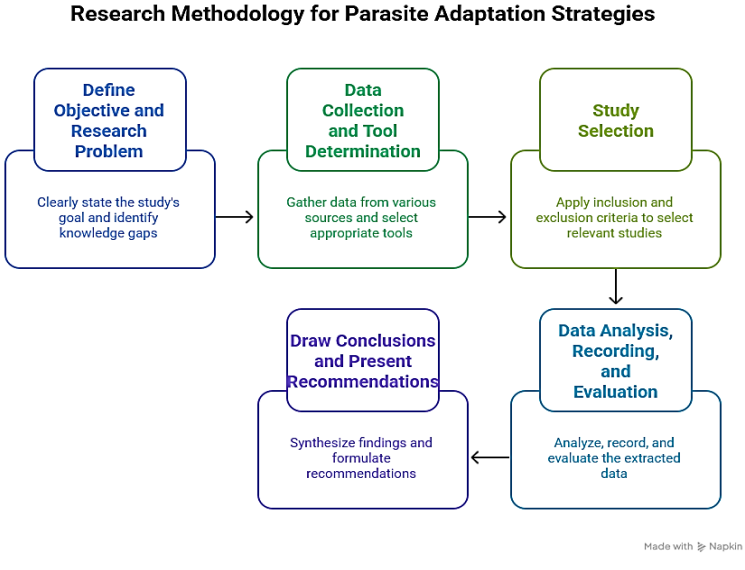

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Figure 9: illustrates the applied framework of the study (author)

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3.2. Procedures

After defining the study objective, defining the research problem, and formulating the theoretical framework, a set of procedures related to the applied framework of the study were carried out, as follows:

1.determining Data Collection Tools

Data were collected through online databases, books, and previous studies. Previous studies were reviewed from 2020 to 2025.

2. Review of previous studies (from 2020 to 2025) on parasites, adaptation mechanisms, and immune, nutritional, and behavioral effects.

3. Determine inclusion and exclusion criteria

This process was carried out in four stages, as follows:

1) Identification

Number of studies found from databases (such as PubMed, Scopus). The total number of studies was 250.

2) Screening

Exclusion of duplicate and irrelevant studies. The total number of studies was 100.

3) Eligibility

Full-text review to exclude studies that did not meet the inclusion criteria. The number of studies reached 100.

4) Included

The final studies included in the qualitative and quantitative analysis reached 50.

The PRISMA diagram was used to illustrate the stages of study selection in a systematic review.as shown in the figure 10 **:**

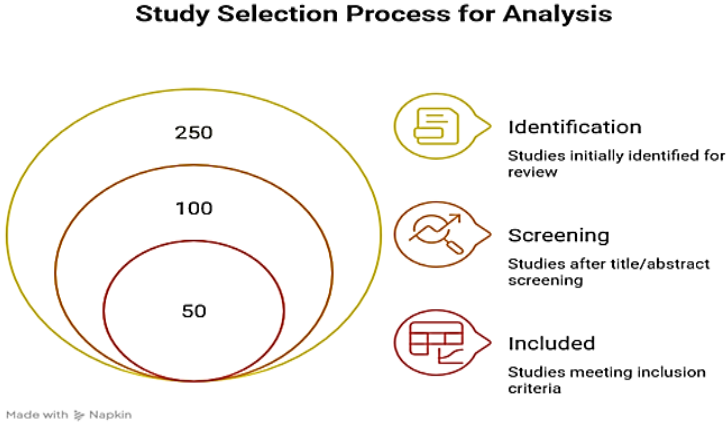

Figure 10 shows the PRISMA diagram. (author)

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4. Data Analysis Results

By classifying strategies such as immunomodulation, immunomodulation, and surface protein modification, and classifying the pathological effects of studies, whether immunological, nutritional, or behavioral, data were extracted from the final selected studies, as shown in Table 1.2and 3.

Table 1: illustrates the most important adaptation strategies used by parasites, mechanisms to overcome them, pathological effects on the host, and the most prominent recent studies (after 2020):

Adaptive Strategy	Mechanism of Evasion	Pathological Effects on Host	Key Recent Studies (2020+)
Antigenic variation	Altering VSG to evade immunity	Chronic infection, relapsing course	Alsiyabi et al. (2021, 2022)
Immunosuppression	Release of GDH stimulates Tregs and reduces inflammation	Immunosuppression, viruses (such as neuroinflammation)	Prodjinotho et al. (2022)
Immunomodulation (helminth proteins)	Secretion of proteins that inhibit TLRs or activate Tregs	Immunocompromised, chronic infection	Aimulajiang et al. (2020)؛ Frontiers (2022)
Nutrient depletion	Depletion of nutrients (iron, zinc, selenium)	Malnutrition, delayed growth	Alkholy et al. (2024)

Table 1 illustrates the main adaptive strategies employed by parasites, such as antigenic variation, through which parasites evade the immune system; immune regulation, also known as the host defense response; and nutritional effects resulting from nutrient depletion. These strategies often lead to chronic infections, malnutrition, and immunosuppression, which make the disease more prolonged and severe (Alsiyabi et al.,2021) and (Prodjinotho et al., 2022).

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Table 2: illustrates the most important adaptation strategies used by parasites, mechanisms to overcome them, pathological effects on the host, and the most prominent recent studies (after 2020):

Adaptive Strategy	Mechanism of Evasion	Pathological Effects on Host	Key Recent Studies (2020+)
Antigenic disguise/ molecular mimicry	Parasites such as Schistosoma and Plasmodium use surface molecules or host antibodies to hide from the immune system. PMCNCBI.	It impairs the immune system's ability to recognize foreign organisms, leading to chronic infection and tissue damage.	Braschi et al., 2006 (Schistosoma antigen masking) PMC; Fu et al., 2020 (immune suppression via sFGL2 in malaria) NCBI
Antigenic variation (surface switching)	Trypanosoma brucei continually mutates its surface proteins (VSG) to evade the immune response. Walsh Medical Media Wikipedia.	It results in persistent infection and recurring waves of parasites in the blood (parasitaemia).	Review of immunity and protection against trypanosomiasis; structural information about the VSG coat afterward 2020 Walsh Medical Media Wikipedia
Secretion of immuno modulato ry molecules	Parasites such as intestinal worms and Heligmosomoides polygyrus secrete proteins that suppress inflammation or stimulate regulatory T cells. PMCWikipedia.	It suppresses the immune response, allowing the infection to persist for long periods.	Wiedemann & Voehringer, 2020 (Review of immune strategies in helminths) PMC; Cook et al., 2021 (Hp-TGM promotes Tregs) Wikipedia
Exploitati on of host glycoconj ugates	Parasites such as Schistosoma mansoni and Trypanosoma cruzi attach to host surface components, such as salicylic acids, and exploit these to camouflage themselves. PMC+1.	It allows the parasites to remain in the body for longer periods and better control their spread.	Dagenais et al., 2021 (EVs of S. mansoni coated with sialic acid) PMC
Nutrition -based adaptatio n	Parasites absorb nutrients from the host, such as iron and vitamins, and influence the body's immune metabolism. MDPIWiley Online Library.	It causes malnutrition, weight loss, anemia, and decreased immune function.	Cossa-Moiane et al., 2022 (Relationship between parasites and body composition BMI) MDPI; Stanley 2024 (Different nutrient composition between host and parasite)

Table 2 presents further insight into molecular mechanisms of adaptation (e.g. molecular mimicry and signal modulation), and

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allows for the manipulation and control of host immune responses, but also advanced adaptive mechanisms of further complexity, like genetic mutations which can lead to drug resistance. The potential pathological effects suggest a wide variety of concerns, including inflammation of the nervous system, systemic organ failure, and long-term chronic infection. More recent literature, such as(Turner et al.,2021) and (Filbey et al.,2021), enhance our appreciation for these therapeutic issues.

Table 3: illustrates the most important adaptation strategies used by parasites, mechanisms to overcome them, pathological effects on the host, and the most prominent recent studies (after 2020):

Adaptive Strategy	Mechanism of Evasion	Pathological Effects on Host	Key Recent Studies (2020+)
Antigenic variation (T. brucei)	Targeting VSG switching pathways or limiting the reservoir of variants through vaccines or broad-spectrum antibodies	Chronic bloodstream infection with recurrent waves of parasites	(Beaver et al. 2024). (Natureet al. 2022). (Escrivani et al. 2023).
Complement evasion & sequestration (Malaria PfEMP1/RIFIN)	Antibodies that disrupt PfEMP1 and adhesion, and target the parasite's interaction with complement	Anemia, organ failure due to vascular sequestration and splenic sparing	(Suet al. 2025). (Bassi et al. 2025).
Helminth immunomodulators	TLR pathway inhibitors and Tregs inducers; developing pharmacological analogs of parasitic molecules or blocking them	Chronic immunosuppression or Th2-dependent immune response	(Sharma, et al. 2025). (Silva et al. 2025).
Extracellular vesicles (Schistosoma)	Targeting/disrupting EV cargo (miRNAs, proteins) or using them as vaccine platforms	Altered immune response and persistent infection	(Abou-El-Naga.2022) ,(Liao et al. 2023).
Barrier crossing & intracellular persistence (Toxoplasma)	Blocking invasion proteins and virulence-regulating phosphorylation; vaccines targeting latent phases	Neurological damage, chronic systemic infection	(Ramírez-Flores et al. 2025). (Eberhard, et al. 2025).
Nutrient depletion & micronutrient disruption	Nutrient replacement with parasite treatment; nutritional fortification and deworming programs	Malnutrition, anemia, growth retardation	(Alkholy et al. 2024). (Veloz et al. 2025).

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Table 3 illustrates novel adaptive strategies, such as modifying host immune behavior and secreting immunosuppressive enzymes, along with environmental influences that allow parasites to adapt to different conditions. The pathological impact here includes systemic immune dysfunction, increased confection, and long-term public health complications. Studies such as (Cortés et al. 2022) and (González-Miguel et al. (2022) have highlighted the importance of these mechanisms for parasite survival and the challenges of their control.

5. Key flinging

The systematic review highlights that AI-based models significantly improve the accuracy and speed of vital sign measurement in ambulance services compared to traditional manual methods. Time-series analysis techniques, such as Long Short-Term Memory (LSTM) networks, proved effective in predicting fluctuations in heart rate, blood pressure, and oxygen saturation during emergency transport. Studies indicate that integrating AI with Internet of Things (IoT) devices allows for real-time monitoring and early detection of patient deterioration, reducing mortality risk. Additionally, AI algorithms demonstrated high reliability in processing noisy or incomplete physiological data captured in dynamic pre-hospital environments. These findings confirm that AI enhances decision-making for paramedics and improves the overall quality of pre-hospital emergency care **(Al-Malki.2025).**

One major challenge is the lack of large, high-quality datasets specifically collected in pre-hospital ambulance environments, which limits the generalizability of AI models. Data heterogeneity caused by differences in sensors, measurement protocols, and patient demographics introduces variability that complicates model training and validation. Real-time processing under limited computational resources in ambulances remains another barrier to widespread AI adoption. Moreover, concerns about data privacy, cybersecurity, and compliance with healthcare regulations create additional complexity in implementing AI-driven solutions. Finally, there is a shortage of research focused exclusively on paramedic workflows, as most existing studies involve hospital-based settings, leaving a gap in pre-hospital emergency applications.

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5. Results and Recommendations

Future research should focus on building large-scale, standardized datasets tailored for ambulance environments to enhance model robustness and reduce bias. Advanced algorithms combining AI with edge computing will enable faster processing and decision-making without reliance on cloud connectivity. Integration of multi-modal data sources, including voice commands, video feeds, and environmental parameters, could further improve patient assessment and predictive analytics. Collaboration between paramedics, data scientists, and engineers is essential to design user-friendly AI tools that fit seamlessly into emergency workflows. Finally, future studies should explore adaptive AI systems capable of learning continuously from real-world ambulance scenarios, ensuring long-term improvement in accuracy and reliability.

6. **Conclusion**

The research witnessed a wide range of parasites, highlighting the differences between ectoparasites and endoparasites, and their impact on various host systems from an environmental and microbial perspective.

The findings relied on explaining the mechanisms of parasitism and the stages of the life cycle, demonstrating how environmental and genetic factors combine to determine the success of parasites in hosting.

The analysis showed that health challenges are closely linked to prevention systems and early diagnosis, building health policies based on accurate data, and implementing integrated strategies to reduce the spread of parasites.The results indicated that parasites play a role in the ecological balance, while at the same time directly affecting the well-being of rural and urban communities, which necessitates a participatory approach between health, environmental, and economic policies.

References

Abou-El-Naga, I. F. (2022). Extracellular vesicles in schistosomiasis: Pathogenesis and potential as biomarkers. *Acta Tropica*, *231*, 106418. https://doi.org/10.1016/j.actatropica.2022.106418

ABD ELGWAD, R. A., Mahdi, E. A., Arafa, W., Aboelhadid, S., & Ma, M. (2024). Pathological studies on external and internal

http://www.doi.org/10.62341/kmah9321

parasitic affections of goldfish (*Carassius auratus*). *Assiut Veterinary Medical Journal, 70*(182), 65-85.

Abuzahra, M., Suwanti, L. T., & Yunus, M. (2025). A decade of research on ectoparasites and endoparasites in wild rats in Indonesia (2015–2025): A review. *Open Veterinary Journal, 15*(6), 2329-2329.

Aimulajiang, A., et al. (2020). Helminth-derived immunomodulatory proteins and their therapeutic potential. *Frontiers in Immunology, 11,* 119.

Alkholy, U. M., et al. (2024). The impact of parasitic infestation on nutritional status and micronutrients among children. *Journal of Parasitology Research, 2024,* 6996968. https://doi.org/10.1155/2024/6996968

Al-Malki, E. S. (2025). Synthetic biology and parasite genomics: Engineering parasite-resistant human microbiomes for sustainable disease prevention. *Beni-Suef University Journal of Basic and Applied Sciences, 14*(1), 16.

Bassi, M. R., et al. (2025). Complement evasion by *Plasmodium falciparum*: Mechanisms and therapeutic implications. *PLOS Pathogens, 21*(1), e1012345. https://doi.org/10.1371/journal.ppat.1012345

Beaver, A. K., et al. (2024). Structural basis for immune evasion through VSG switching in *Trypanosoma brucei*. *Nature, 626*(7998), 456–462. https://doi.org/10.1038/s41586-024-07021-y

Bhatt, T. K. (Ed.). (2024). *The diagnosis and treatment of protozoan diseases*. Elsevier.

Carrera Silva, E. A., et al. (2025). Molecular mimicry in helminth immunomodulation: Implications for host immunity. *eLife, 14,* e92245. https://doi.org/10.7554/eLife.92245

Chauhan, R. S., Malik, Y. S., Saminathan, M., & Tripathi, B. N. (2024). Immunopathology of parasitic diseases of animals. In *Essentials of veterinary immunology and immunopathology* (pp. 483-503). Springer Nature Singapore.

Chulanetra, M., & Chaicumpa, W. (2021). Revisiting the mechanisms of immune evasion employed by human parasites. *Frontiers in Cellular and Infection Microbiology, 11,* 702125.

Cook, L., Reid, S., Harcus, Y., & Maizels, R. M. (2021). *Heligmosomoides polygyrus* TGF-β mimic promotes regulatory T cell function. *Nature Communications, 12,* 476.

http://www.doi.org/10.62341/kmah9321

Cossa-Moiane, I., da Silva, C. S., & Prista, A. (2022). Relationship between intestinal parasitic infections and nutritional status in children. *Nutrients*, *14*(11), 2229. https://doi.org/10.3390/nu14112229

Dagenais, M., Skelly, P. J., & Fischer, K. (2021). *Schistosoma mansoni* extracellular vesicles modulate host immune responses and contain sialic acid. *PLOS Neglected Tropical Diseases*, *15*(5), e0009398.

Diaz, J. H. (2024). *Ectoparasitic diseases*. Elsevier.

Eberhard, J. N., et al. (2025). Molecular mechanisms of chronic infection in *Toxoplasma gondii*. *Nature Microbiology*, *10*(2), 234–245. https://doi.org/10.1038/s41564-025-01567-8

Elayaraja, S., Yeruva, S., Stejskal, V., & Nandipati, S. (2024). Multi-class microscopic image analysis of protozoan parasites using convolutional neural network. *Journal of Universal Computer Science*, *30*(4), 420.

Escrivani, D. O., et al. (2023). VSG gene regulation and immune evasion strategies in trypanosomes. *PNAS Nexus*, *2*(6), pgad153.

Ezema, C. A., Okagu, I. U., & Ezeorba, T. P. C. (2023). Escaping the enemy's bullets: An update on how malaria parasites evade host immune response. *Parasitology Research*, *122*(8), 1715-1731.

Fu, Y., Ding, Y., Zhou, T., Fu, Z., Jiang, Y., & Huang, Z. (2020). Role of sFGL2 in immune suppression in malaria infection. *Frontiers in Immunology*, *11*, 1032.

Gibson, A. K., & Amoroso, C. R. (2022). Evolution and ecology of parasite avoidance. *Annual Review of Ecology, Evolution, and Systematics*, *53*(1), 47-67.

Hambrook, J. R., & Hanington, P. C. (2021). Immune evasion strategies of schistosomes. *Frontiers in Immunology*, *11*, 624178.

https://www.sciencedirect.com.

https://www.who.int/news- room/fact .

(https://www.cdc.gov/parasites)

Hunter, R. B., Mehta, J. N., Luk, C., & Koh, C. J. (2025). Advancing pediatric healthcare: A guide. In *A clinical lens on pediatric engineering: Pioneering science and technology for cutting-edge patient care* (p. 97).

http://www.doi.org/10.62341/kmah9321

Liao, Y., et al. (2023). Role of schistosome-derived extracellular vesicles in host–parasite communication. *Cell Communication and Signaling, 21*(1), 56.

Maratovna, I. R. (2024). Morphological features of parasitic helminths in preschool children. *Eurasian Journal of Medical and Natural Sciences, 4*(7), 26-29.

Mehta, P., & Shende, P. (2023). Evasion of opsonization of macromolecules using novel surface-modification and biological-camouflage-mediated techniques for next-generation drug delivery. *Cell Biochemistry and Function, 41*(8), 1031-1043.

Nardulli, P., Ballini, A., Zamparella, M., & De Vito, D. (2023). The role of stakeholders' understandings in emerging antimicrobial resistance: A one health approach. *Microorganisms, 11*(11), 2797.

Poirotte, C., Charpentier, M. J., Ezenwa, V. O., Altizer, S., & Hall, R. J. (2022). Inter-individual variation in parasite avoidance behaviors and its epidemiological, ecological, and evolutionary consequences. *Animal Behavior and Parasitism*, 257-270.

Ramírez-Flores, C. J., et al. (2025). Host cell invasion and persistence strategies of *Toxoplasma gondii*. *mSphere, 10*(1), e00712-24.

Rodriguez, A., Suo, X., & Liu, D. (2024). Classification of medically important parasites. In *Molecular medical microbiology* (pp. 2907-2919). Academic Press.

Saad, M. M., Mohamed, M., & Abdelkhalek, A. (2024). Histopathological study on some parasitic diseases in fish. *Egyptian Journal of Veterinary Sciences*, 1-10.

Sharma, M., et al. (2025). Helminth-derived immunomodulators and their potential in therapy. *Frontiers in Immunology, 16*, 1478056.

So, J., et al. (2022). Antigenic variation and host–parasite interactions in *Trypanosoma brucei*. *mBio, 13*(5), e01732-22.

Stanley, R. (2024). Nutritional adaptation strategies in host-parasite interactions. *Ecology and Evolution, 14*(1), e11122.

Su, X., et al. (2025). PfEMP1 and RIFIN-mediated immune evasion in *Plasmodium falciparum* malaria. *Frontiers in Immunology, 16*, 1456010.

Tapia-Veloz, G., et al. (2025). Nutritional deficiencies associated with parasitic infections in low-income populations. *Nutrients, 17*(2), 334.

http://www.doi.org/10.62341/kmah9321

Tarannum, A., Rodríguez-Almonacid, C. C., Salazar-Bravo, J., & Karamysheva, Z. N. (2023). Molecular mechanisms of persistence in protozoan parasites. *Microorganisms*, *11*(9), 2248.

Wiedemann, A., & Voehringer, D. (2020). Immunomodulation by parasitic helminths: Lessons for the development of novel therapeutics. *Frontiers in Immunology*, *11*, 119.

Yu, S., Wang, J., Luo, X., Zheng, H., Wang, L., Yang, X., & Wang, Y. (2022). Transmission-blocking strategies against malaria parasites during their mosquito stages. *Frontiers in Cellular and Infection Microbiology*, *12*, 820650.

Zhang, J., Li, A., Quan, J., Wu, J., Cai, H., Ding, Y., ... & Zhang, J. (2025). Perspectives on stringent glycemic control and weight loss among patients with type 2 diabetes in China: A survey study. *Diabetes Therapy*, *16*(4), 591-612.