Poultry Litter in Agricultural Areas

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The poultry farming industry has assumed a pivotal role in meeting the global demand for affordable animal proteins. While poultry farming makes a substantial contribution to food security and nutrition, it also presents environmental and public health challenges. The use of poultry litter as fertilizer for agricultural soils raises concerns about the transfer of pathogens and drug-resistant microorganisms from poultry farms to crop production areas.

Keywords: poultry farming ; poultry litter ; fungi

1. Introduction

Poultry farming plays a pivotal role in meeting the rising demand for affordable animal proteins, particularly in developing nations. Its historical significance in providing consistent protein supplies, contributing to food security, and improving nutrition, especially in rural areas, cannot be overstated. However, this practice is not without its challenges, most notably the environmental and public health concerns it raises [1].

Over the past two decades, global poultry production has witnessed steady growth, and poultry imports are expected to rise even further. In comparison, pork and beef imports are also projected to increase, but poultry remains the preferred choice among consumers [2]. This intensification in poultry production, which often involves large flocks confined in automated systems, gives rise to concerns regarding parasitic infections and zoonotic diseases due to the densely populated living conditions for birds. One notable aspect discussed is the management of poultry litter, which comprises feces, waste, and bedding materials, and its importance in maintaining bird health and crop quality when used as organic soil fertilizer [3].

However, poultry litter can contain pathogens and contaminants, including resistant microorganisms, veterinary drugs, and potential toxic elements. This leads to concerns regarding its safety when used as an organic fertilizer, especially in developing countries with limited data [3][4].

The fungi kingdom is incredibly diverse, estimated to comprise 1.5 to 5 million species. Fungi are vital participants in various ecosystems, contributing to the decomposition of organic matter, forming mutualistic associations with plants, and acting as biocontrol agents. While most fungi play beneficial roles, some are pathogenic to humans, causing diseases that affect millions [5].

The adaptability of fungi to various environmental pressures, including climate change and increased pesticide resistance in agriculture, is noted as a significant area of study. Understanding these adaptations is crucial for developing strategies to manage fungal diseases and preserve ecosystems [2].

In the context of poultry farming, fungi play essential roles in decomposing organic matter in poultry waste, recycling nutrients, and maintaining ecological balance. However, there are certain fungi that can produce mycotoxins, posing health risks when they contaminate poultry feed and food products [6].

Fungal presence in poultry farms generates organic dust composed of various particles, including fungal spores, some of which can cause allergies, posing health risks to workers [7].

The adverse environmental consequences brought about by fungi, obstructing both soil utilization and animal husbandry for consumption, have driven substantial shifts in the interaction between fungi and their developmental environment [4]. The escalating use of fungicides in poultry farming is a mounting concern, raising the prospect of pathogenic fungi developing resistance due to heightened fungicide consumption. This underscores the critical need for diligent monitoring and effective management of antifungal resistance, including susceptibility testing [8].

In poultry production systems, fungal disease control often focuses on management, hygiene, and prevention practices rather than relying extensively on fungicides. Some typical prevention measures include maintaining a clean, dry environment for birds, rotating grazing areas, and properly disposing of poultry litter [9]. However, it is important to highlight that, even if the use of fungicides in poultry farming is limited, the soils on which poultry litter is applied can receive contamination from pesticides for agricultural use and fungi that have proliferated in the litter. This is because the bedding, which is often made from organic material such as straw, sawdust or rice husks, can contain fungi and pesticide residues that were applied to the growing areas of the litter ingredients. Fungicides are an important class of agrochemicals used to control fungal diseases in crops [10].

The Food and Agriculture Organization of the United Nations (FAO) provides data and information on the use of agrochemicals, including fungicides, in agriculture. These chemicals play a significant role in protecting crops from fungal infections that can cause significant losses in food production. Raising awareness about the responsible use of agrochemicals, including fungicides, is essential to ensure food safety and minimize adverse environmental impacts. Furthermore, strict regulation and monitoring of the use of fungicides in agriculture are essential to ensure that these products are applied safely and effectively, minimizing risks to human health and the environment [11].

2. Global Poultry Farming

Poultry farming plays an essential role in global food production and has been accompanied by steady growth in poultry production in recent years. This increase is directly associated with the growing demand for affordable animal proteins, particularly in developing countries, where the search for a diversified diet is on the rise [1]. Raising domesticated birds to obtain meat, eggs, and feathers is an ingrained practice in food production, dating back to the beginnings of agriculture. Avian farming stands out for its remarkable efficiency in using a wide range of raw materials, ranging from agricultural and domestic waste to food processing by-products [3]. This approach establishes fowl farming as one of the most effective methods of animal husbandry, ensuring a consistent supply of protein and playing a key role in food and nutrition security, especially in rural areas around the world, with an emphasis on developing countries [1].

Over the two-decade period spanning from 2001 to 2021, there was a consistent annual growth rate of 4 percent in global poultry imports, culminating in a total of 14.2 million metric tons imported by 2021. The United States Department of Agriculture (USDA) anticipates a significant upswing in poultry imports, projecting them to reach 17.5 million metric tons by the year 2031. In contrast, pork imports are also on an upward trajectory, with projections indicating an increase to 14.8 million metric tons by 2031, while beef imports are expected to reach 14.3 million metric tons during the same period [12].

In the FAO's Food Outlook 2023, the global production of poultry, including chicken, turkey, duck, and goose meats, is expected to increase by approximately 1.35%, reaching a total of 142.6 million tons this year. China is predicted to become the world's largest producer, surpassing the United States by around 5%, with Brazil ranking third at 11% of the global production. While China and the United States are projected to see modest growth (below half a percent and less than 2%, respectively), Brazil is expected to experience the highest growth rate among the top ten global producers, at 2.74%. Japan is the sole country in this group with a negative outlook, though it signifies a state of relative stability. Approximately 60% of the top ten countries are expected to lose their share of global production, while Brazil stands out with the most significant increase (1.37%) compared to 2022. On a continental scale, Africa is the only region with a potential reduction, and both Asian and European countries are also anticipated to lose their share. Notably, the production of the 27 European Union (EU) member states accounts for approximately 60% of the continent's total production, with non-member countries, including Russia, Ukraine, and the United Kingdom, responsible for the remaining 40% [13].

Most of the industrial-scale poultry production, chiefly encompassing broilers for meat production and layers for egg production, is carried out on intensive production farms. In this context, flocks ranging from several thousand to hundreds of thousands of birds are maintained, primarily raised in open indoor housing or battery cages equipped with automatic feeding and drinking systems [14]. Recent years have witnessed an intensification of livestock production systems due to an increased demand for animal-derived foods, along with changes in management practices, which have impacted the distribution and intensity of parasitic infections, frequently associated with zoonotic diseases [2][15].

Poultry production is predominantly characterized by densely populated confinement structures for birds. Consequently, maintaining the ideal microclimate and animal hygiene conditions can pose significant challenges. Despite the utilization of mechanical ventilation systems to safeguard bird health, microorganisms found in animal bedding can readily accumulate and disperse in the air. Poultry litter, composed of feces, food waste, bedding materials, and feathers, is highly regarded as a cost-effective, high-quality organic soil fertilizer that contributes to enhancing crop quality and productivity, justifying its extensive global use [16].

Ensuring efficient poultry production requires adequate litter material with appropriate chemical and physical characteristics, along with controlled microbial counts. Wood-based bedding has been associated with improvements in bird performance. Besides its organic composition, the material used as animal bedding can harbor various pathogens, including viruses, bacteria, parasites, and fungi. Furthermore, the combination of bedding materials with chicken droppings and feathers appears to influence pathogen development [6][15].

Microbiological air contamination in poultry facilities, including an analysis of microbial composition, has been the subject of comprehensive studies [2]. Concerns about rising foodborne outbreaks have led to the identification of bacteria in animal bedding, with certain *Salmonella* strains exhibiting antimicrobial resistance [17]. The presence of microbial pathogens is a matter of utmost importance in the food industry; thus, the quality of litter material can directly impact food safety [10].

Brazil and the United States are the primary producers and exporters of poultry meat, with substantial growth expected in the coming years. In the case of Brazil, a 29% increase in production is anticipated by 2028. Concerning egg production, the domestic market constitutes the primary destination, representing nearly 100% of consumption [16]. Despite playing a limited role in exports, Brazil ranks among the largest egg producers globally, with consumption steadily rising over the years. The impacts associated with the growth of the poultry production chain extend beyond production areas and may have regional and global ramifications [16].

It is vital to emphasize that, in addition to export and increased domestic consumption concerns, there are significant challenges pertaining to environmental and public health impacts arising from large-scale production systems. Nonetheless, in Brazil, the discussion of these impacts is still in its early stages, and there is a scarcity of available information, despite the importance of these issues for food security, environmental quality, and public health [17][18][19].

The significant growth seen in global poultry production in recent years has not only boosted the industry but has also raised serious concerns about the environmental impacts associated with this expansion.

Poultry Litter

Poultry litter comprises any material placed on the ground to serve as a bed for birds, receiving excrement, feed remains, feathers, spilled food, medicines, and water. Its primary function is to prevent birds from direct contact with the ground, while absorbing moisture, incorporating waste, promoting the birds' well-being, and improving their comfort [8]. There are several materials that can be used in the composition of these beds, from the most common, such as rice husks, wood shavings or sawdust, to alternatives such as sugarcane bagasse [3]. The use of chicken litter in the soil as an organic fertilizer represents the most economical and environmentally friendly approach to disposing of this material from the rapidly expanding poultry industry around the world [3].

Nonetheless, a key challenge lies in optimizing the advantages of chicken litter as an organic fertilizer while concurrently mitigating its potential adverse impacts on the environment [8]. Among the foremost concerns related to the safety of poultry litter is its high nutrient content, being notably rich in nitrogen and phosphorus, which has the potential to lead to the contamination of freshwater bodies [3]. Chicken litter carries pathogenic microorganisms, encompassing bacteria, fungi, viruses, parasitic protozoa, and helminths. Additionally, it may contain antibiotics, along with pathogenic microorganisms that harbor antibiotic-resistant genes, heavy metals, sex hormones like estrogen (17β-estradiol and testosterone), polycyclic aromatic hydrocarbons, and persistent organic pollutants such as dioxins, furans, and polychlorinated biphenyls [3].

It is essential to highlight that the presence of contaminants poses a threat to the natural environment and has the potential to undermine the environment's usability by humans [19]. Furthermore, poultry litter can serve as a reservoir for pathogens, which are organisms capable of inducing diseases in susceptible hosts, encompassing humans, animals, or plants [1]. This regulatory diversity poses challenges in providing farmers with clear guidance on the appropriate and safe application of chicken litter to the soil, particularly for the purpose of restoring productivity to degraded soils [10].

Consequently, it is imperative to conduct more comprehensive studies to evaluate the degree of contamination in poultry litter, both from broilers and layers, with a particular focus on developing countries, where data is limited. Moreover, there is a need to establish standardized guidelines encompassing all contaminants present in chicken litter, with the aim of ensuring consistent practices across all regulatory agencies to facilitate the safe disposal of this material into the soil [2] [15].

3. Fungi and Poultry Farming

3.1. Fungi Kingdom

The “Fungi” kingdom encompasses a remarkable diversity of species, estimated to range from 1.5 to 5 million, with approximately 600,000 of them having already been documented [5]. Fungi play a fundamental role in the ecosystem functions of terrestrial and aquatic ecosystems, performing several essential functions. Fungi play a crucial role in the decomposition of organic matter, an essential process for the recycling of nutrients in ecosystems. They decompose complex organic materials, such as fallen leaves, twigs, and plant debris, transforming them into simpler components. This contributes to nutrient cycling, releasing essential elements back into the soil, making them available to plants [20].

Many fungi establish mutualistic associations with plant roots, known as mycorrhizal symbiosis. In this symbiotic relationship, mycorrhizal fungi help plants absorb nutrients, such as phosphorus and nitrogen, in exchange for carbohydrates and organic compounds provided by plants. This symbiosis benefits both fungi and plants, improving plant nutrition and fungal survival [5]. Some fungi act as biocontrol agents, fighting pests and pathogens that affect plants and animals. These fungi can parasitize or compete with harmful organisms, contributing to the regulation of pest populations and the maintenance of ecological balance [5].

Fungi play an essential role in the production of food and beverages. Yeasts are used in the fermentation of bread, beer, wine, and cheese, while edible mushrooms are cultivated and consumed around the world [20]. Certain fungi could degrade organic pollutants, such as hydrocarbons and toxic compounds. They are used in bioremediation processes to clean up contaminated environments, helping to restore damaged ecosystems [5]. Fungi play an important role in the formation and stabilization of soil. They assist in the decomposition of organic matter, releasing organic acids that contribute to the chemical alteration of soil particles. This influences the texture and water-holding capacity of the soil, impacting plant growth and soil quality [5]. Fungi serve as a food source for various organisms, including insects, nematodes, and vertebrate animals. Furthermore, the process of decomposition of fungi provides food for a variety of invertebrates, contributing to the food chain of ecosystems [5].

Among these species, a few hundred could cause disease in humans. Fungal diseases can be clinically classified as superficial, cutaneous, subcutaneous, and systemic [21]. In recent years, fungal diseases are estimated to have resulted in more than 1.6 million deaths annually, affecting more than a billion people with serious fungal diseases [21]. However, it is important to note that many cases go unreported, which raises doubts about the precision of available estimates [22].

In recent decades, there has been an exponential growth in the knowledge of pathogenic fungi that affect humans, driven by the development and improvement of genetic, genomic, and molecular tools specific to these microorganisms. On the other hand, the development of new medicines has been slow, and technical limitations persist in the clinical diagnosis of fungal diseases. In general, fungal diseases are not notifiable, which raises questions about the reliability of most estimates [22]. Fungal pathogens probably faced environmental pressures over time and, in their evolution, adapted their pathogenic mechanisms mainly to interact with less complex organisms, such as plants, environmental predators, invertebrates, and less complex mammals, such as amphibians and reptiles, before interactions with human beings arose [23]. These interactions often involve accidental hosts. On the other hand, there are several commensal fungi that can cause disease in humans when there is an imbalance in the immune system. For a fungus to cause damage to a human being and thus cause a disease, this microorganism must possess at least a triad of mechanisms: (I) the ability to obtain nutrients to sustain its metabolism, (II) ability to grow at temperatures close to 37 °C and (III) the ability to avoid, escape, or evade the human immune system [24].

Fungi have demonstrated a remarkable ability to adapt to diverse environmental pressures, including climate change, increased atmospheric temperature and changes in the water cycle in different regions of the planet. Furthermore, they face the challenge of increasing resistance to pesticides in agricultural environments. This adaptive flexibility is crucial to the survival of these organisms, allowing them to thrive in challenging environments [25]. Understanding these adaptative mechanisms can be fundamental for the development of effective strategies for controlling and preventing fungal diseases. Additionally, this knowledge also contributes to the preservation of ecosystems where these organisms play vital roles [26].

3.2. Fungi in Poultry Farms

In poultry farming, fungi play an important role in the decomposition of organic matter present in poultry waste, such as food remains and bird excrement. They help in recycling nutrients and maintaining ecological balance [7]. However, some species of fungi can produce mycotoxins, substances that are toxic to animals when feed and food are contaminated. Furthermore, these fungi can also be pathogenic and cause fungal infections [27]. On the other hand, yeasts can be used as probiotics, as is the case with *Saccharomyces cerevisiae*, to improve the intestinal health of birds, promoting digestion, increasing nutrient absorption, and improving resistance to infections [28]. The gastrointestinal and reproductive microbiota of birds are composed of bacteria, fungi, viruses, and protists, and are characterized by commensal, symbiotic, and pathogenic relationships with the host [27].

Differences between host and microbiota have been characterized by nutrient exchange, modulation of the immune system, exclusion of pathogens, and gastrointestinal tract and reproductive physiology [3]. The composition and function of the microbiota can be affected by many factors, including host age, genotype and sex, diet composition and form, food additives such as antibiotics, probiotics, prebiotics, postbiotics, symbiotics, phytobiotics, bacteriophages, stress, and the location in the reproductive tract [29]. Although birds are known to harbor pathogens with zoonotic potential, the yeast microbiota of these birds' gut biomes is still poorly understood [29].

There is growing concern that poultry products may be underappreciated sources of pathogenic microorganisms, especially certain yeast species that may be pathogenic to other species, including humans. These yeasts can behave as pathogens when they find a suitable and conducive host, in addition to developing antimicrobial resistance when moving between different niches [30]. Previous studies have documented the occurrence of different yeast species as natural residents of the avian gut, but the behavior and ecological factors that contribute to the conversion of these organisms from harmless commensals to pathogens are still poorly understood [29].

The state of the host immune system and putative yeast virulence factors play important roles in triggering infections and invasion of host tissues [3]. Studies have reported the presence of medically important yeasts in pigeon feces, confirming that these birds can serve as reservoirs and disseminators of *Cryptococcus* spp. and other yeasts for humans [31]. Furthermore, birds such as parrots have been identified as sources of dissemination of *Trichosporon* spp., *Candida* spp., and other yeasts in the environment [32]. The contact of these birds with humans, especially in urban environments, represents a risk to public health. The detection of multidrug-resistant yeasts in the gastrointestinal tract of synanthropic birds is also concerning, as these birds may be reservoirs for the transmission of drug-resistant fungal infections to humans [29].

Previous studies have reported direct transmission of fungal infections to poultry farmers and poultry keepers through contact with bird bodies and excreta. Additionally, the dimorphic fungus *Histoplasma capsulatum*, which can cause serious illness in immunocompromised people, has been found in the droppings and body parts of certain species of birds, including chickens [33][34]. However, the role of the yeast microbiota in birds and their propensity for pathogenicity and infection is not yet well established. Although it is known that birds can act as carriers of pathogenic fungi for humans, there is still a lack of clear evidence to indicate that domestic birds are reservoirs of yeast [2][35].

Blood infections caused by non-albicans *Candida* species have become increasingly common. Additionally, invasive infections with other rare yeasts, such as *Trichosporon* spp., *Geotrichum* spp., *Cryptococcus* spp. and *Rhodotorula* spp., have also been recently reported. Studies have suggested that gastrointestinal colonization may be a potential source of more serious fungal infections [29]. Laying hens carry yeasts, mainly *Candida* spp., in their cloaca and can contaminate the environment through their feces and eggs. The prevalence of yeast in samples of cloacal swabs and feces from chickens was higher than that found in other birds, indicating the role of laying hens as potential transporters and disseminators of these microorganisms. Feces showed a greater occurrence and population size of yeast compared to cloacal swab or egg samples, suggesting that feces are a suitable enrichment medium for yeast growth [30].

The presence of species such as *C. parapsilosis* and *R. rubra* in fecal and egg samples, in addition to the cloaca, suggests that laying hens can disseminate yeasts in the environment through their feces and eggs. Yeasts were also found on eggshells and in their yolks and whites, indicating that these microorganisms can contaminate the entire egg during passage through the cloaca or after oviposition [30]. Egg storage temperature has been shown to have a significant effect on the yeast population on the shell. Eggs stored at higher temperatures showed an increase in yeast prevalence and population size compared to those stored at lower temperatures. This suggests that egg protective factors lose their ability to inhibit the growth of microorganisms during storage at higher temperatures [30]. Eggs contaminated by pathogenic yeasts represent a potential risk to human health, especially for immunocompromised patients. In this sense, adequate management and sanitation measures must be implemented in poultry farms to reduce the contamination of eggs by pathogenic yeasts [30].

Also noteworthy is the organic dust present on poultry farms, which is formed by a complex mixture of particles that include feces, feed, feathers, mites, bacteria, fungi, and their spores, as well as biological toxins. Dust derived from poultry production systems can contain bacteria and fungi of plant and animal origin. Fungi such as *Acremonium*, *Alternaria*, *Aurobasidium*, *Aspergillus*, *Basidiospores*, *Cladosporium*, *Chrysosporium*, *Drechslera*, *Epicoccum*, *Eurotium*, *Fusarium*, *Geomyces*, *Mucor*, *Penicillium*, *Pithomyces*, *Rhizomucor*, *Scopulariopsis,* and *Ulocladium* have been reported as prevalent in bird dust. Many of these fungi are recognized as allergenic strains [27]. Furthermore, fungal secondary metabolites, such as aurofusarin, deoxynivalenol, zearalenone, and infectopiron, have been found, which may have cytotoxic effects [27].

Regarding worker health, the dust deposited, airborne microorganisms, fungal secondary metabolites, and odors present in the environment of poultry farms represent potential risks to the respiratory health of farm and poultry workers. Therefore, it is important to carry out respiratory medical assessments of workers and implement prevention measures, such as the appropriate use of respiratory protection devices [27]. Poultry litter, which is composed of a plant substrate, feces, feed waste, feathers, and agricultural inputs, has been widely used as an organic soil fertilizer throughout the world. This is due to its composition (organic matter, micro- and macronutrients for vegetable crops) and low cost, which contribute to increasing the quality and productivity of agricultural crops [3][30].

To ensure efficient production of broiler chickens, it is necessary to use an appropriate litter material that meets the requirements for chemical, physical, and microbiological characteristics [36]. Studies have shown that wood sawdust bedding is associated with improvements in bird performance. However, it is necessary to keep in mind that the bedding material used can harbor various pathogens, such as viruses, bacteria, parasites, and fungi [2][36]. The combination of different bedding materials, along with chicken droppings, feathers, and chemicals used during the production cycle, can influence the development of these pathogens [36].

Assessing microbiological contamination in poultry litter and poultry facility environments is crucial for ensuring the well-being of animals, workers, and consumers. Conducting studies to examine microbial growth and the presence of pathogens in these areas is essential to identify health risks and implement appropriate mitigation measures. Notably, poultry litter significantly contributes to the spread of fungal contamination in poultry facilities [9]. Moreover, the activity of spreading litter often exposes poultry workers to elevated levels of dust, along with fungi and their byproducts, including volatile organic compounds (VOCs) and mycotoxins [37]. After it is used and removed from poultry facilities, the litter, containing keratinous materials, is incorporated into agricultural soils. However, this practice may pose potential threats to the soil environment and the health of both humans and animals [38]. The annual disposal of millions of tons of feathers, common in poultry production, can negatively affect soil and human health. Recent studies have investigated the presence of these fungi in soils globally, due to their potential to infect humans and animals, awakening interest in dermatologists and mycologists [39].

3.3. Fungi in Poultry Feed

Fungi, known as mycoflora or molds, can be present in animal feed and pose a threat to the quality of the feed. They can cause several problems, such as decreased seed germination, unpleasant or musty odors, loss of dry matter and nutrients, clumping, formation of mycotoxins and, consequently, a reduction in the economic value of the feed [40]. There are two main groups of fungi that can be found on grains: field fungi, such as *Absidia* spp., *Alternaria* spp., *Chaetomium* spp., *Cladosporium* spp., *Diplodia* spp., *Phaeoramularia* spp., and *Rhizopus* spp., and storage fungi, such as *Drechslera* spp. (Helminthosporium) and *Fusarium* spp., which attack the grains or seeds of plants while they are still growing [7].

The presence of these fungi is influenced by climatic factors, including precipitation and temperature. Some, like *Aspergillus flavus*, can act as plant pathogens and storage fungi [7]. Mycoflora growth in crops is highly dependent on weather conditions, with fungal invasion intensifying when crops are stressed, such as during droughts or insect infestations. Field fungi require high moisture content and are susceptible to drying out after harvest. Although some mycelium may remain dormant in food after harvest, most die during storage or transport. These xerophilic fungi, rarely found in growing grains, include *Candida* spp., *Hansenula* spp., and *Penicillium* spp. These fungi can be disseminated by insects and mites that feed on cereals [7][40].

The same fungi responsible for contaminating grown and stored grains have also been identified in commercial pet foods and feed ingredients. Some studies have detected these fungi in poultry feed, fishmeal, and rabbit feed. Insect droppings, exuviates, and the ability of insects to penetrate the protective waxy layer of grains can alter the grain environment and promote fungal infestation. Fungi, such as *Aspergillus* spp., *Fusarium* spp., *Mucor* spp., and *Penicillium* spp. have also been isolated from poultry litter, although the exact source of exposure to these fungi is uncertain and may occur through spilled feed, insect vectors, or fungal spores surviving in the birds' intestinal tract [7][8].

4. Poultry Litter as a Source of Fungi for Agricultural Soils

The growing demand for animal products has led to a significant increase in intensive livestock farming, creating an imbalance between the number of animals and the environment's carrying capacity. Intensive production of poultry, swine, and dairy results in the generation and concentration of large volumes of animal waste [14]. Due to the macro and micronutrient content in these waste materials, they can be repurposed as organic fertilizers in agricultural crops. This contributes to reducing environmental impacts, such as waste accumulation in ponds and piles, which can harm soil, surface, and groundwater quality. This approach aligns with the growing need for environmental sustainability and natural resource conservation [7].

The use of animal waste represents an alternative fertilization method for agricultural crops, primarily due to its organic matter and nutrient content, especially nitrogen (N) and phosphorus (P) [8]. This allows for the recycling of nutrients within ecosystems, improving soil properties and promoting the growth of beneficial microorganisms. Additionally, this practice replaces mineral fertilizers, which are finite and non-renewable nutrient sources, resulting in reduced production costs and a more sustainable system. However, it is important to note that the application of these wastes is often done empirically, with producers applying doses without proper evaluation of their impact on soil fertility, as these wastes contain nutrients in disproportionate amounts compared to plant requirements [8].

Furthermore, animal wastes are often applied to the soil surface, leading to nutrient accumulation in the top 10 cm of the soil. This results in the saturation of adsorption sites and a reduction in the soil colloid's nutrient retention capacity, particularly for phosphorus. The amount of organic waste to be applied in a specific area depends on various factors, such as waste composition, organic matter content, soil fertility, the nutritional needs of the cultivated crop, and regional climatic conditions [8]. Poultry litter consists of bird excrement, feathers, wasted feed, and the moisture-absorbing material used on the floor of poultry houses. It is a nutrient-rich waste, and its composition can vary based on the feed nature, the amount and type of floor covering material in the poultry house, the duration the birds spend on the material, the number of birds per area, and storage conditions. Nutrient levels can also fluctuate depending on the poultry litter's origin and the number of layers of absorbent material (e.g., wood shavings) used [41][42].

While the benefits of using animal waste for fertilizing agricultural areas are clear, excessive use can harm productivity, exceeding soil's carrying capacity and causing significant environmental contamination [36]. Therefore, continuous monitoring of soil quality, especially focusing on microbiological aspects, is essential to ensure the proper utilization of animal waste in agriculture. Poultry litter, commonly used as a substrate for poultry in agricultural systems, may contain fungal spores and microorganisms naturally present in poultry facilities. When this litter is disposed of in agricultural soils, it can release fungal spores into the environment, potentially introducing fungi into the soil [43].

This introduction of avian fungi into agricultural soil is a significant aspect with implications for biogeochemical cycles and soil microbiology [3]. Additionally, the extensive use of fungicides in agriculture to control fungal diseases in crops raises concerns about their entry and persistence in agricultural soils, which can have environmental impacts such as groundwater contamination and fungal resistance. Investigating the presence and effects of both poultry litter and fungicides in soils is crucial for sustainable agriculture management and mitigating adverse impacts [43].

Opportunistic fungal infections are a growing global health concern, and both domestic and wild birds may play a role as carriers of pathogenic fungi with potential impacts on human health [29]. Human exposure to pathogenic fungi like *Candida*, *Cryptococcus*, *Geotrichum*, *Rhodotorula*, *Saccharomyces*, and *Trichosporon* from avian sources poses significant health risks [29][44]. The potential transmission of zoonotic pathogens from synanthropic birds to humans is particularly alarming, given that these birds might harbor drug-resistant fungi [31].

Fungi, including *Aspergillus* spp., *Penicillium* spp., *Fusarium solani*, *Geotrichum candidum*, *Nannizzia gypsea*, *Rhizopus stolonifer*, *Trichoderma* spp., and *Trichophyton* mentagrophytes, are commonly found in soils fertilized with poultry litter. These fungi may present infection risks to humans, particularly in specific environmental conditions. Aspergillus species, abundant in such soils, can be pathogenic to humans when their spores are inhaled, leading to lung infections, especially in individuals with compromised immune systems. Fusarium solani, another prevalent fungus, can cause opportunistic infections affecting the skin, nails, eyes, and internal organs, notably in hospital settings. Although more common in the food industry, certain strains of *Geotrichum candidum* can infect humans, primarily in moist skin areas [38].

Dermatophytes like *Nannizzia gypsea* and *Trichophyton mentagrophytes* cause skin, hair, and nail infections, including ringworm. Some *Penicillium* species, although mostly harmless, can produce harmful mycotoxins, potentially impacting humans through spore inhalation or consumption of contaminated food. While *Rhizopus stolonifer* is not commonly linked to human infections, specific *Rhizopus* species can affect immunocompromised individuals, causing invasive fungal infections. *Trichoderma* spp., typically considered beneficial in agriculture and enzyme production, can become opportunistic pathogens in humans, particularly in those with weakened immune systems [38].

It is essential to consider the interaction between fungi introduced by poultry litter and the fungicides used in agriculture. Fungicides can affect the diversity and activity of fungi in the soil. Furthermore, it is crucial to investigate whether exposure to fungicides can result in fungal resistance in strains present in the litter or soil. This research can provide insights into the potential risks to the effectiveness of fungicides in agriculture.

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