German Journal of Veterinary Research

eISSN:2703-1322

Review

Turkey production and health: current challenges

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Article History:
Received: 12-Dec-2020
Accepted: 23-Jan-2021
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Abstract

Several factors and problems are influencing turkey production and health. These include intense global competition between producing countries, permanent changes in social, political and consumer perceptions regarding food safety, animal welfare and environmental protection. Several human food-borne infections are linked to poultry and poultry products, causing a serious challenge because it is difficult to control. Moreover, contamination of the turkey meat and product with antibiotic-resistant bacteria is a constant public health hazard. The loss of consumer confidence and trust in turkey meat product safety and quality will also be a major concern. The current and future turkey health concepts should cover the control of diseases in birds and the relationship between bird's health, welfare and environmental protection. Additionally, infectious turkey diseases' emergence and re-emergence will remain an important and never-ending challenge. Only a few authorized pharmaceutical veterinary products are available to treat turkeys. The development of efficient vaccines and natural antimicrobials against bacterial infections will reduce antibiotic use and reduce resistant bacteria's development. Genetic selective breeding to improve production traits and health is a long-standing goal of the turkey industry. Furthermore, rearing technology, management, and feeding will help maintain the birds healthy and comfortable. Finally, all other partners involved in the production chain, including farmers, veterinarians, stockholders, need to collaborate to meet the consumer expectations for high quality and safe products.

Keywords: Turkey production, Consumer expectations, Diseases prevention and control, Legislations, SARS-CoV-2

Citation: Hafez, H. M. and Shehata, A. A. 2021. Turkey production and health: current challenges. Ger. J. Vet. Res. 1 (1): 3-14. https://doi.org/10.51585/gjvr.2021.0002

Introduction

The modern worldwide turkey industry aims a high production and better quality at a low cost. These, in addition to an increase in the demand for poultry meat, necessitates constant, efficient, and goal-oriented healthcare to prevent the development and spread of diseases. In addition to the already existing, several challenges and problems will face everybody involved in the turkey productions chain. Namely, the intense global competition, changes in social, political and consumer perceptions regarding food safety and animal welfare; environmental protection issues; the emergence of new and unforeseen diseases, and new legislation. Few authorized pharmaceutical veterinary products are currently available to treat turkeys as food-producing animals. The steady increase in the cost of feed will accelerate global trade. The increase in biofuel and biogas productions will reduce the available land for food grains and feed production, leading to a considerable increase in animal production feed costs. In the future, the feed industry will be forced to take more responsibility for the feed ingredients quality and ensure that no avian pathogens and unwanted contaminants or residues are present in the feed.

Turkey diseases will remain the major challenge. Once an outbreak of a given disease occurs, it can explode into an epidemic and significantly negatively affect trade in a specific country, a continent or even globally. Also, climatic changes and limited water resources should be considered to influence production costs (Hafez et al., 2010; Hafez and El-Adawy, 2019).

Strong global competition

Intense global competition and varying production costs in various regions will increase turkeys and turkey product's global movement. The top 10 countries in turkey meat production in 2019 (Metric Tons) are shown in Table 1 (Anonymus, 2019).

Changes in consumer perceptions

There is a higher interest from the consumer in organic poultry production and a great demand for natural and healthier products. The loss of consumer trust and confidence in poultry meat's quality and safety is a significant challenge. Turkey meat can harbor different foodborne pathogens such as Salmonella serovars and Campylobacter spp., which are the most common causes of human foodborne infections linked to poultry.

Salmonella infections in turkeys

Despite significant improvement in technology and hygienic practices in all poultry production stages, Salmonellosis and *Salmonella* infections remains a persistent threat to human and animal health. *Salmonella* infections in turkey are distributed worldwide and result in severe economic losses when no effort is made to control them. The enormous economic losses are caused by high poults mortality during the first weeks of age, high medication costs, reductions in egg production in breeder flocks, poor poults quality and high costs for eradication and control measures. Transmission and spread of *Salmonella* occur by vertical and horizontal routes. However, the most crucial aspect is the continuing risk on public health of Salmonella contaminated turkey meat and meat-products (Hafez, 2013).

In June 2008, the commission regulation (EC) No 584/2008 of implementing Regulation No. 2160/2003 of the European Parliament and of the Council as regards a community target for the reduction of the prevalence of *S.* Enteritidis and *S.* Typhimurium in turkeys was put into force. The community target is reducing *Salmonella* serovars to the lowest percentages in fattening and breeder flocks remaining positive to 1% or less by December 31, 2012 (EC, 2008).The testing scheme necessary to verify progress in the achievement of the community target is set out in the Annex of this regulation and shall apply from January 1, 2010. The minimum sampling requirements (Table 2). At least two pairs of boot/sock swabs shall be taken. All boot/sock swabs must be pooled into one sample. Alternatively, the competent authority may decide that one pair of boot swabs shall be taken, covering 100% of the house area if combined with a dust sample, collected from multiple places throughout the house from surfaces with the visible presence of dust.

Sampling by the competent authority in holdings with at least 500 fattening turkeys should be carried as mentioned by breeding flocks. From 2010 fresh poultry meat may not be placed on the market for human consumption when Salmonella was detected. The criterion laid down does not apply to fresh poultry meat destined for industrial heat treatment or another treatment to eliminate Salmonella in accordance with community legislation on food hygiene (EC, 2003).

Campylobacter infections

Infections with thermophilic *Campylobacter* in humans can cause diarrhea, abdominal pain, vomiting and fever. They further play an indirect role in acute neuromuscular paralysis (Guillain- Barré syndrome). *Campylobacter* spp., especially *C. jejuni*, are the most frequent cause of bacterial gastroenteritis in Europe. Campylobacteriosis is steadily increasing in humans and has already exceeded the number of Salmonellosis cases in some EU countries. While food derived from other animals, especially cattle, or even vegetables or fruits, can be a source of foodborne human Campylobacteriosis.

Contaminated and undercooked poultry and poultry products remain the most important source. Horizontal transmission is the most common mode of introducing *Campylobacter* into poultry flocks. However, the ability of *Campylobacter* to spread is limited by their relatively low tenacity, especially in dry environments, which can vary between strains (Evans and Sayers, 2000). Drinking water was found to be the primary source of flock contamination (Bull et al., 2006; Sasaki et al., 2011). It is not uncommon to detect several *Campylobacter* genotypes in the same flock, at the same time or different ages. The same strains are often encountered in several houses on the farm or consecutive flocks. Both facts indicate the relative ease of horizontal introduction of *Campylobacter* into flocks as well as the existence of reservoirs on the farm or nearby (Sahin et al., 2015).

Since farm visitors and other animals on the farm are the major risk factors for introducing *Campylobacter* to a farm, prevention by improving biosecurity should emphasize these aspects. Flyscreens were also highly efficient to decrease the prevalence of *Campylobacter*-positive flocks. Water pipes and drinkers need to be kept clean. Chlorinating the drinking water or adding organic acids in the feed can reduce colonization of the birds by *Campylobacter* (Chaveerach et al., 2004; Heres et al., 2004). The use of competitive exclusion or probiotics has yielded inconsistent results (Sahin et al., 2015).

Dry bedding in poultry houses will limit the spread of the bacteria within a flock. Feed, good gut health, litter material, heating and ventilation are factors to keep litter drier. Additionally, under experimental conditions acidifying the litter with aluminum sulfate or sodium bisulfate reduced *Campylobacter* colonization frequency and populations in the ceca, but the effect wears off as the litter pH increases again (Line, 2002; Line and Bailey, 2006).

There are no commercial vaccines available. Experimentally, attenuated *C. jejuni* strains used as vaccines did not colonize the birds long enough to induce protection. On the other hand, vaccination with recombinant Salmonella expressing *Campylobacter* antigen can reduce colonization (Sahin et al., 2015). Finally, treatment of birds with bacteriophages can reduce *Campylobacter* counts in the intestines. However, even if mixtures containing several phages are used, resistance rates of the bacteria are high and quickly develop (Fischer et al., 2013).

Campylobacter infections in humans are mainly transmitted by contaminated food. No evidence has been found either for vertical transmission or horizontal transmission from one flock to the next via persistent house-contamination. However, since the organism has been detected in most slaughtered poultry intestines, the primary route for *Campylobacter* contamination of poultry appears to be the horizon-

Table 1: Top ten countries of turkey meat production in 2019

Rank	Countries	Metric Tons
1	United States	2,692,241.00
2	Brazil	588,051.00
3	Germany	475,553.00
4	France	363,828.00
5	Italy	304,253.00
6	Spain	219,025.00
7	Poland	191,162.00
8	Canada	171,469.00
9	United Kingdom	152,005.00
10	Israel	99,969.00

Table 2: The minimum sampling requirements on the initiative of the food business operator

Zoonotic agent	Animal population	Time of sampling by food business operators
	Breeding turkeys (EC, 2008)	
S. Enteritidis *S.* Typhimurium	Rearing flocks	- Day-old birds - Four-week-old birds - Two weeks before moving to lay phase or laying unit
	Adult flocks	- At least every third week during the laying period at the holding or the hatchery
	Fattening turkeys (EC, 2008)	
S. Enteritidis *S.* Typhimurium	Fattening turkeys	- Within three weeks before moving birds to the slaughterhouse

tal transmission from the environment. Investigations indicated that the external *Campylobacter* load per chicken increases during transport, defeathering and evisceration, and decreasing at the other processing steps studied, with an overall reduction of the mean load from production-to-consumption of about 4 to 5 logs. Suitable hygienic practice protocols should be prepared and strictly followed in all production stages. Biosecurity should be improved throughout the production chain. Since *Campylobacter* is found in the environment, hygienic barriers should be constructed to keep them outside the house (Hartnett et al., 2009; EFSA, 2015).

In general, controlling zoonotic diseases and foodborne pathogens requires a deep understanding of how microbial pathogens invade and colonize and the circumstances that encourage or stop growth for the microorganism (Hafez, 2005). Adequate hygienic protocols should be used and strictly implemented in all production phases. Biosecurity should be enhanced throughout the chain of production. Given that *Campylobacter* spp can be observed in hygienic barriers, an environment should be built to maintain them far away from the poultry house (EFSA, 2015). To guard consumers, the EU approved a unified methodology for food safety from the farm to the fork. The four steps of risk assessment namely: 1) documentations of a hazard; 2) assessment of exposure; 3) hazard characterization; and 4) risk characterization.

The aims of the several pieces of EU legislation toward food safety were: firstly, consumer health safety is ensured by decreasing the use of medicines/antibiotics, improving resistance to disease, controlling zoonotic pathogens, and ensuring the traceability of animals and their products. Secondly, product safety is ensured by controlling the processing steps, hygiene, and tracing products or materials anticipated to contact the food. Third, animals should be reared and kept according to existing governmental regulations. Fourth, products and contents are improved via quality and food chain control systems and poultry and poultry-product traceability, and fifth, the tasks serve to reduce environmental contamination. Finally, rural impact, economic effects, and bio-diversity are also considered. Other important issues are consumer failure to apply proper, hygienic, and proper handling and cooking of food and the limited ability of the processing plants to decrease pathogenic microorganisms concentration in animal products.

Changes in social, political and consumer perceptions

Problems associated ban antibiotic growth promoters and the use of antibiotic in food-producing animals

It is generally known that poultry feed supplementation with antibiotic growth promoters (AGPs) improves livestock performance. AGP's effect on gut flora results in improved digestion, better absorption of nutrients, and a more stable microbial population balance. As a consequence, the prevalence and severity of intestinal disorders are reduced. However, AGPs also can increase the prevalence of drug-resistant bacteria. However, the development of antibiotic resistance in bacteria, which is common in both animals and humans, will also be a continuous public health hazard. Based on the "Precautionary Principle" and experiences made in some European countries, the EU completely banned the use of growth-promoting antibiotics in the feed of food-producing animals by January 2006 (EC, 2005).

Field observations in Europe showed that the poultry industry faced several problems after the AGPs ban. The impact of the ban has been seen on the performances (reduced body weight and low feed conversion rate) as well as on the rearing husbandry (wet litter and high ammonia level), animal welfare problem (increases footpad dermatitis) and general health issues on the birds (enteric disorders due to dysbacteriosis and high clostridial infections). Investigations indicate that competitive exclusion, prebiotics, probiotics, enzymes, and acids can impact the incidence and severity of clostridial infections in poultry. Combinations of different approaches are necessary to enhance the performance and health status of the birds, such as: using highly digestible feed ingredients, using a special pre-starter diet, improving climate conditions in the poultry house and keeping litter quality in optimal condition (Hafez, 2008).

Furthermore, histomoniasis was the most important cause of mortality in turkey flocks until several highly effective drugs against the disease were discovered. Also, improved management practices like separation of turkey and chicken flocks and the trend toward confinement rearing substantially decreased histomoniasis incidence. Starting in 1995, the EU and the USA successively banned all drugs used to prevent or treat histomoniasis due to food safety concerns.

In Europe, the Commission regulations 1798/1995 and 2205/2001 have stopped the usage of dimitridazoles as therapeutic or prophylactic drugs in food-producing animals (EC, 1995, 2001), and council regulation 1756/2002 banned the application of Nifursol from March 31, 2003 (EC, 2002). Consequently, histomoniasis is increasingly responsible for considerable economic problems to the poultry industry, causing sometimes disastrous economic losses in chickens, turkeys and game birds. Since 2015, paromomycin sulfate is registered in some EU member states for turkeys to prevent histomoniasis. However, its efficacy is too low for therapy of ongoing infections, so the success of the application of paromomycin is highly dependent on early diagnosis and start of metaphylactic treatment (Bleyen et al., 2009; Hafez et al., 2010).

Multi-resistant bacteria are increasingly posing a hazard to human and animal health worldwide, impeding successful antibacterial treatment (Arias et al., 2010). Also, novel antibiotics development does not keep in step with the emergence of antimicrobial resistance in bacteria (García-Rey, 2010). Increasing application of antibiotics for the treatment of humans and animals and the use of the glycopeptide avoparcin in subtherapeutic levels as a growth promoter in the past have been generally held responsible for progressive deterioration of the resistance situation in bacteria (Aarestrup, 2005; Alanis, 2005). Among multi-resistant bacteria, vancomycin-resistant enterococci (VRE) have been estimated as one of the most common bacteria causing a rise in cases of nosocomial infections in humans in the last few years (Arias et al., 2010).

The prevalence of vancomycin-resistant VRE in 20 turkey flocks reared in southwest Germany was investigated. The VRE were detected in 15 (75%) of the 20 investigated turkey flocks. In 5 flocks, all animal samples and environmental dust samples taken were VRE-negative. In a total of cultivated 68 isolates from birds and dust samples, enterococci bearing van-genes were detected. Of these, 12 isolates carried the vanA gene (17.6%), and 56 isolates carried the vanC1 gene (82.6%). Neither vanB (B1, B2, B3) genes nor the vanC2 or vanC3 genes could be detected (Sting et al., 2013).

Additionally, livestock-associated methicillin-resistant *Staphylococcus aureus* (LA-MRSA) has been isolated from several livestock species and animal production workers. Infections with MRSA often prove difficult and expensive to treat. Turkey meat was shown to be contaminated with MRSA (de Boer et al., 2009). Richter et al. (2012), investigated the prevalence of LA-MRSA in fattening turkeys and people living on fattening turkeys farms. Eighteen out of 20 investigated flocks (90%) were positive for MRSA. All female flocks were positive, while eight male flocks were positive. On 12 of the farms, 22 (37.3%) of 59 sampled persons were positive for MRSA. None of them showed clinical symptoms indicative of an MRSA infection.

People with frequent access to the stables were more likely to be positive for MRSA. MRSA assigned to clonal complex (CC) 398 were detected in most flocks. In five flocks MRSA of spa-type t002 that is not related to CC398 were identified. Moreover, other methicillin-resistant *Staphylococcus* spp. were detected on 11 farms and eight people working on the farms.

Animal welfare

In the published European Union report on the new Animal Health Strategy (2007- 2013), the concept of animal health covers the absence of disease in animals and the relationship between animals' health and their welfare. It will also consider social, economic and ethical considerations and support achieving a high environmental protection level (EC, 2007). There is great concern that serious animal welfare and health problems might have been caused already due to genetic selection practices within the turkey production.

Additionally, pharmaceutical companies are being encouraged to develop natural antimicrobials. With the recent technological advances, a new golden age of natural products drug discovery is dawning. Phytochemicals have exerted potential antibacterial activities against sensitive and resistant pathogens (Khameneh et al., 2016; Shakeri et al., 2018; Basiouni et al., 2020), highlighting the urgency for the development of natural antimicrobials to reduce the antibiotics in turkey farms, which in turn reduce the risk of multidrug-resistant microorganisms.

Genetic selection in turkeys and their impact on health conditions

Genetic selection practices within the turkey industry have achieved significant progress in terms of high growth rate, better feed conversion, better meat yield and low production cost accompanied by continuous improvement in husbandry practices, nutrition, and disease control. However, there is a big concern that serious animal welfare and health problems might have already been caused due to the selection mentioned above directions.

Consequently, it is essential to understand the relationship between genetic selection pressures and other factors that may impact the health conditions, including the effects on the growth and development of supporting structures such as blood supply and bones.

Compared to traditional lines, the genetically selected birds have reduced cardiopulmonary capacity with their muscle mass, as the ratio of development of the heart and lungs has strongly decreased in modern turkey. Besides, traditional turkey's blood pressure is known to be almost half of that of the modern one (Norci and Montella, 2003; Havenstein et al., 2007). This physiological unbalance causes problems such as sudden death syndrome, deep pectoral myopathy and aortic rupture. Furthermore, genetic selection is mostly incriminated as the major cause of skeletal disorders, which currently receive much attention as a cause of concern from an animal welfare point of view. All these relevant health problems are primeval known ones and were described many years ago; however, the current issues are fundamental since the European citizens are increasingly concerned about the health and welfare of chickens and turkeys reared for meat production. In particular, several animal welfare organizations have initiated campaigns calling for improved welfare standards. The most common musculoskeletal system problems related to fast growth comprise dyschondroplasia and footpad dermatitis. The incidence and severity of both can be influenced by nutrition and genetic selection (Farquharson and Jefferies, 2000; Mayne, 2005). The most relevant health problems, which might be related to genetic selection, are summarized in Table 3 & 4 and Figure 1 &2.

Sudden death in turkeys associated with perirenal hemorrhage

Sudden death in turkeys associated with perirenal hemorrhage (SDPH) has been recognized as a significant cause of mortality in male turkeys between 8 and 14 weeks of age. The turkeys are mostly in good condition and die suddenly. They have congested and oedematous lungs and clotted blood surrounding a portion of the whole kidney (Figure 1). It is often associated with cardiomyopathy, rapid growth gain, continuous lighting programs, high stocking density, and hyperactivity have been suggested as factors that may influence this condition's incidence.Vitamin E supplementation, the elevation of room temperature, and step up/step down-lighting can reduce the incidence. On long term genetic selection for lines with low blood pressure is essential.

Aortic rupture

Aortic rupture is firstly described in 1945 (Mcsherry et al., 1954). It is characterized by sudden death in growing turkeys due to internal hemorrhage. Mortality has been reported to reach 50% in the past, but losses in affected flocks at present usually reach only 1-2%. The condition occurs in male turkeys with a peak between 12 and 16 weeks of age. Affected birds die suddenly. The abdominal aorta is affected (Figure 1), where a longitudinal slit can be seen. Blood clots are present in the body cavity, and the birds may bleed from the mouth.

Several causes are suspected. Among the possible causes of high blood pressure, as in today's large white turkeys, the systemic blood pressure is double the wild turkeys that might predispose to aortic rupture. Also, copper deficiency is a further contributing factor, but paradoxically administration of diethylstilbestrol, which decreased blood pressure, caused an increase in incidences. Diets containing high protein and fat levels might also increase aortic rupture incidence (Crespo and Shivaprasad, 2013). Optimizing the feed protein- and fat contents and the copper supplement can improve the situation. Management procedures to keep the birds quiet and genetic selection for a line with low blood pressure are additional options.

Diseases of the musculoskeletal system and leg disorders

Diseases of the musculoskeletal system and leg disorders receive much attention currently as a cause of concern from the animal welfare point of view. They are mostly accompanied by economic losses for turkey meat producers due to mortality, predisposition to cannibalism, retardation of growth, increased condemnation rate and downgrading at the processing plant. Leg weakness can impair the birds' welfare by reducing walking ability, in severe cases linked with pain and discomfort. Bone weakness and deformations may result in bone fractures during catching and the slaughtering process. The causes of leg disorders can be noninfectious and/or infectious (Table 4).

Dyschondroplasia

It is a common defect associated with the growth plates of meat-type poultry. It is characterized by an avas-

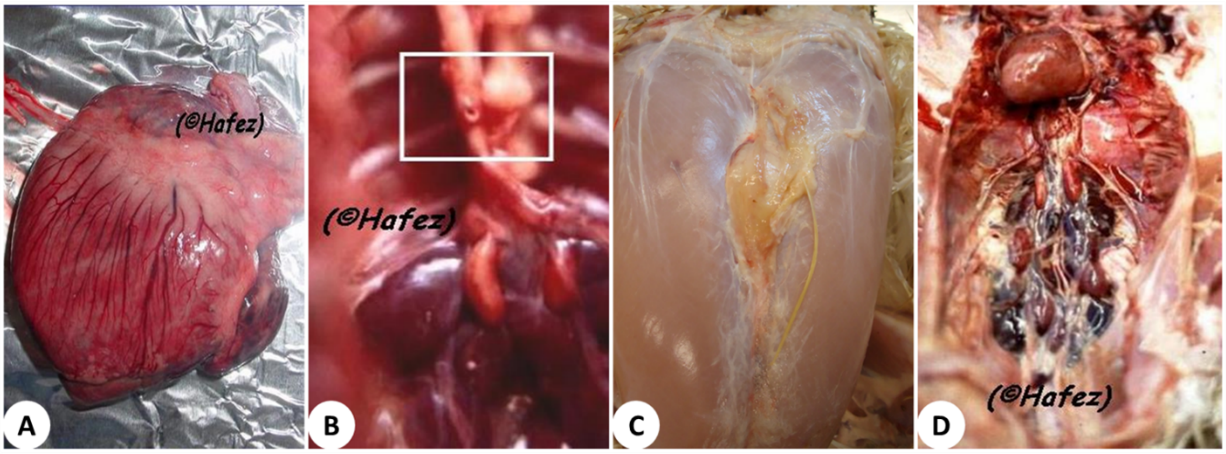

Figure 1: Lesions of the most relevant health problems might be related to genetic selection. A) Sudden death ascites, B) Aortic rupture, C) Deep pectoral myopathy, and E) Peri-renal hemorrhage.

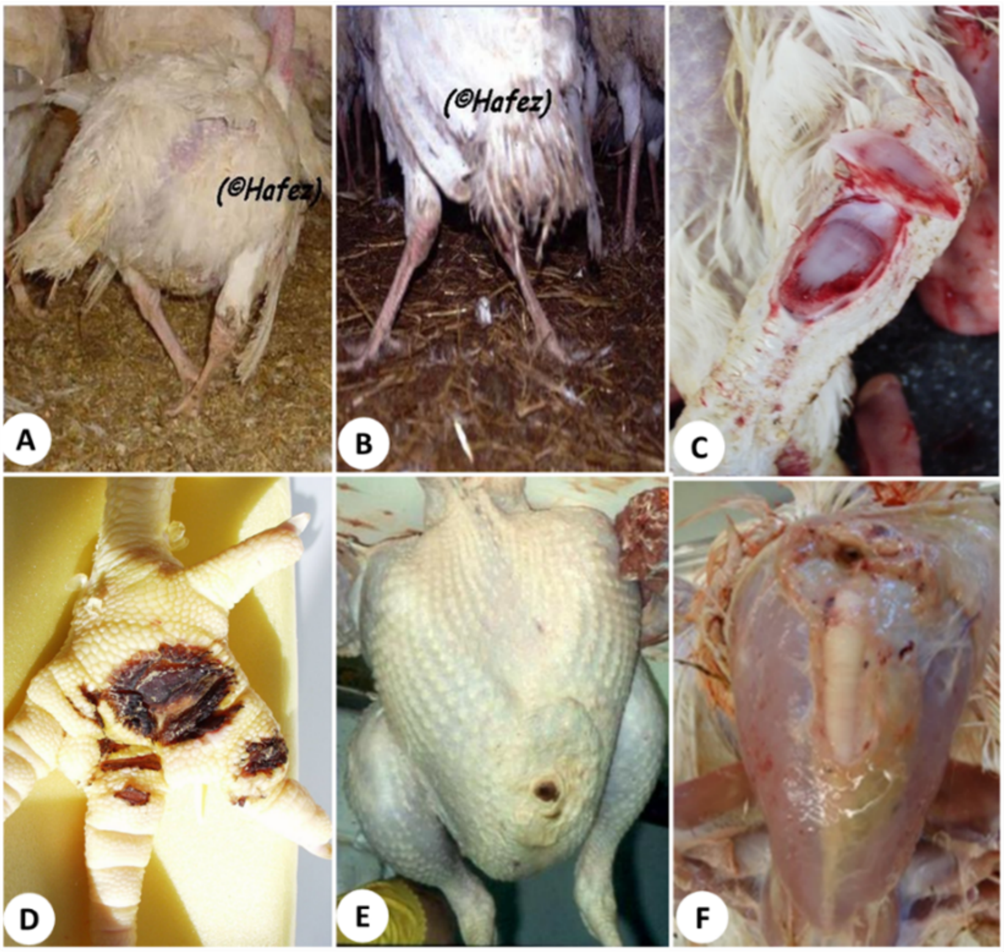

Figure 2: Lesions of leg disorders that might be related to genetic selection. A&B), Leg disorders, C) Dyschondroplasi, D) Pododermatitis, E&F) Breast blister.

Table 3: Some possible causes sudden death, aortic rupture and perirenal hemorrhage and deep pectoral myopathy

Disease conditions	Possible causes	
	Noninfectious	Infectious
Sudden death, Ascites	Genetic: rapid growth, reduced oxygen (hypoxia) Management: stress, excitement	Unknown
Aortic rupture	Genetic: rapid growth, high blood pressure of some birds Nutrition: copper deficiency, high fat and/or protein content Management: stress, stocking density, disquietness	Unknown
Deep pectoral myopathy	Genetic: rapid growth, inadequate muscular vasculature in meet-type birds Management: traumatic, multiple wing flapping and excitement	Unknown
Peri-renal hemorrhage	Genetic: rapid growth, high blood pressure of some birds Management: stress, continuous lighting programs, hyperactivity	Unknown

Table 4: Some possible causes of leg disorders

Disease conditions	Possible causes	
	Noninfectious	Infectious
Dyschondroplasia	Genetic: rapid growth, high body weight	Unknown
Leg disorders	Genetic: rapid growth Management: litter quality, stocking density, lighting program, deviation in hatching	Reovirus, *Mycoplasma*, *E. coli*, *Pasteurella*, *Ornithobacterium rhinotracheale*, *Streptococcus*, *S. aureus*, and *Aspergillus*
Pododermatitis	Management: stocking density, litter material, quality, and management, humidity	Unknown
Breast blister	Genetic: rapid growth, slow feather development Management: litter quality, stocking density, mechanical-traumatic	*Mycoplasma*, *S. aureus*

cular plug of abnormal cartilage in long bones growth plates. It is most commonly recognized in the proximal tibiotarsus, and, hence, the condition is often described as tibial dyschondroplasia (TD).

The incidence and severity of TD can be influenced by nutrition and genetic selection (Farquharson and Jefferies, 2000). TD is a specific form of growth plate abnormality with an abnormal mass of cartilage under the growth plate upon necropsy. Lameness only occurs if there is deformity or enlargement with loss of bone strength that results in leg weakness and bone fracture. Several investigations have shown that the occurrence of TD is related to genetic selection.

Pododermatitis

Footpad dermatitis is a condition characterized by lesions on the ventral footpad of poultry. The lesions vary from hyperkeratosis to severe erosions and ulceration. Several predisposing factors such as genetic line, rapid growth, feed, stocking density, and litter quality have been discussed as a cause of the plantar pododermatitis complex. It was also shown that the turnkey line] can influence the incidence and the severity of Pododermatitis. Hafez et al. investigated five commercial meat turkey lines (Kelly Bronze, Nicholas 300, BUT 9, Nicholas 700, and BUT-Big 6) regarding leg disorders (Hafez et al., 2004).

The obtained results showed that pododermatitis could be observed in all turkey lines regardless of body

Table 5: Absolute numbers of leg disorders in the investigated different meat turkey lines (n = 35/lines)

Leg disorders/turkey line	Turkey lines				
	Kelly	N300	BUT9	N700	Big6
Tibial dyschondroplasia	15	11	12	13	13
Pododermatitis	32	33	33	35	35
Fractures	3	1	6	2	4
Femoral head epiphysiolysis	2	6	2	1	1
Arthritis/periarthritis	2	1	0	2	2
Bowlegged	0	0	1	1	1
Toe deformation	0	0	0	1	0
Soft bone condition	0	0	0	0	1

Table 6: Prevalence of footpad lesions in organic farms reared turkeys at the processing plant

Turkey line and sex	Number tested	FPD score				
		0	1	2	3	4
Kelly BBB toms	540	25	61	286	161	7
Kelly BBB hens	540	10	66	316	120	28
BUT 6/TP7 hens	780	7	34	594	144	1
Total	1860	42	161	1196	425	36

weight; however, the severity of changes was evident in heavy turkey lines, and a correlation between body weight and the severity of the footpad dermatitis seems to exist. The results also revealed no correlation between turkey lines and the incidence of tibial dyschondroplasia, fractures, and arthritis (Table 5). Feed composition may also affect the feces and, as a result, the litter's moisture. Some investigations showed that supplemental biotin reduced the pododermatitis only in poults maintained on dry litter but not on the wet litter.

The influence of sex is controversial. While some studies showed no difference between hens and toms, other authors found a better footpad status in hens. Some investigations showed that the male turkeys had a better footpad condition than the female birds (Table 6) (Freihold et al., 2019). The hens and toms kept on wood-shavings had a significantly better footpad condition than those kept on straw. Another investigation's preliminary results show that the elevation of energy content in the feed and supplementation with biotin positively affects the footpad's health. Attempts to treat leg weakness are unrewarding. Affected birds should be separated from healthy animals (animal welfare). Addition of vitamin D3 in drinking water and/or calcium-phosphorus- preparation in the feed can improve the condition.

Stocking density

Hafez et al. investigated the effect of the stocking density on health condition, hematology, immune response, and medicament's application in male meat turkey flocks reared under field conditions. Three different stocking densities, namely 25, 48 and 58 kg/m2, were compared. The stocking density was calculated according to expected body weight at slaughter. The results revealed that the stocking density in all groups and farms didn't influence the treatments' frequencies and duration. The hematological results showed that there is no stocking density cause a significant difference in hematocrit, red blood cells count, hemoglobin, mean corpuscular volume (MCV), mean corpuscular hemoglobin amount (MCH), mean corpuscular hemoglobin concentration (MCHC), thrombocytes count, total leukocytes count and differential leukocytes. Also, no significant difference could be determined by calculating the Heterophils/Lymphocytes ratio, which is used as a stress indicator (Hafez et al., 2016). The immune responses to applied vaccines such as Newcastle disease (ND) and/or to field infections with avian metapneumovirus (AmPV) and *Ornithobacterium rhinotracheale* (ORT) were measured at several points using ELISA for ND, TRT, and ORT as well as haemagglutination inhibition test. The obtained results showed that there was no stocking density specific effect. On the other hand, the daily weight gain on both farms was slightly higher in the 25kg/m2-groups compared to other groups.

Emergence and re-emergence of turkey diseases

Besides several managements related and political issues, emerging and re-emerging diseases and/or turkeys' infections will remain a continuous challenge for poultry veterinarians and the turkey industry. In general, most emerging infections appear to be caused by pathogens already present in the environment that acquired a selective advantage or allowed to infect new host populations (Morse, 1995). Several factors can precipitate or predispose to disease emergence. These include changes in the turkey industry's structure and development, intense global competition and varying production costs in different continents and countries, leading to an increased global movement of poultry and poultry products. Hence, an increased risk of introducing infections to other areas considered free from such diseases also exists (Hafez et al., 2010). Re-emerging and resurging infections existed in the past but are rapidly increasing in incidence, geographical distribution, or host range.

Health disorders and infectious diseases of turkeys are mostly associated with severe economic losses. Several pathogens are incriminated as possible causes of many disease complexes of turkey poults alone (monocausal), in synergy with other microorganisms (multicausal), or accompanied by noninfectious factors. Noninfectious causes mean all factors that influence the bird's health and include house structure, climatic conditions (ventilation, temperature, and litter condition), stocking density, feed and water supply, hygienic condition, and the knowledge and qualification of the stockman. These factors affect each other and promote or inhibit the flock's health condition. To achieve desired performance results, managers of turkey flocks should integrate the right environment, husbandry, nutrition and disease control programs.

The rearing management must be directed to satisfy the bird's requirements, promote the production, and prevent diseases. Any disturbance will cause stress, which will reduce the birds' resistance, increase their susceptibility to infections and reduce their immune response to vaccines. Infectious diseases caused by several infectious agents such as viruses, bacteria, fungus and parasites are involved in many disease conditions. These infectious agents can be introduced and spread in turkey farms by different routes. It occurs by vertical and/or horizontal route. At early days of age, the primary disease problems are related to vertically transmitted infections and improper hatchery eggs sanitation (Yolk sac infection/ Omphalitis) with *Salmonella*, *E. coli*, *Mycoplasma*, *Aspergillus* spp., *Staphylococci*, *Streptococci*, *Pseudomonas* and avian encephalomyelitis. Those infectious agents can also be transmitted horizontally (laterally) by direct contact between infected and non-infected birds.

The most critical problems in turkeys are respiratory diseases, possibly caused by avian metapneumovirus and *Ornithobacterium rhinotracheale* and *E. coli*. Furthermore, enteric disorders caused by several viral agents such as coronavirus, astrovirus, rotavirus or due to parasitic infestation such as coccidia and histomonas are common problems. *Ornithobacterium rhinotracheale*, belonging to the family *Flavobacteriaceae*, is an emerging bacterial pathogen in turkeys and chickens, causing severe economic losses. The most common infection features with *Ornithobacterium rhinotracheale* are airsacculitis and pneumonia (van Empel and Hafez, 1999). The host range of infected or carrier birds of *Ornithobacterium rhinotracheale* in the respiratory tract has continuously increased (Thieme et al., 2016), highlighting the urgency for a better understanding of its genetic diversity, ecology and transmission cycles (Veiga et al., 2019; Nisar et al., 2020).

Turkey coronaviruses of the family *Coronaviridae* is one of the major causative agents of enteritis in turkeys and associated with severe economic losses, but it is not zoonotic. However, coronavirus disease 2019 (COVID-19) pandemic, caused by severe acute respiratory syndrome coronavirus type 2 (SARS-CoV-2) virus, belongs to the same family, is a zoonotic disease that poses severe hazards to humans (Gollakner and Capua, 2020). However, poultry is not susceptible to SARS-CoV-2 and unlikely to disseminate or serve as a reservoir for this virus (Schlottau et al., 2020). However, limited research has been performed on the SARS-CoV-2 virus in turkey. Additionally, the lockdown in several countries has accentuated the crippling poultry industry following the arrest of feed and healthcare essentials and the destruction of eggs, chicks, and birds (Kolluri et al., 2021). A lesson learned from this pandemic is that biosecurity, hygiene, and immunity are front lines of defense, as well as a demand for new regulations for animal health care, trade, and movements of domestic and wild animals to ensure a continuous supply of animal protein (Hafez and Attia, 2020).

The severity of clinical signs, duration of the disease and mortality are extremely variable and are influenced by the kind, virulence and pathogenicity of the infectious agent as well as by many environmental factors such as poor management, inadequate ventilation, high stocking density, poor litter conditions, poor hygiene, high ammonia level, concurrent diseases and the type of secondary infection.

Future expectations: disease diagnosis, treatment, and control

In the future, improvements in laboratory diagnosis, such as diagnostic microarray and other technologies, will allow faster, more sensitive and more accurate diagnosis of infectious diseases, and early interventions will become a reality. However, only a few authorized pharmaceutical veterinary products will be available to treat poultry as food-producing animals. Future scientific findings on the pathogenic mechanisms of bacteria will enhance the bacterial infection treatment protocols. Instead of non-specific antibiotic therapy, new drugs will target the signaling mechanisms that can disrupt bacterial pathogenic effects.

Vaccination is regarded as one of the most beneficial biopharmaceutical interventions due to its ability to induce protection against infectious diseases through targeted immune system activation. Many valuable new vaccine production technologies have been developed due to rapid progress in various areas. The use of future progressive vaccine production technologies, such as recombinant, subunit, reverse genetic and nucleic acid vaccines, can significantly reduce the cost of vaccines, ensure better efficacy, and allow easy and rapid intervention to face the steady mutation of the microorganisms. Furthermore, the development of efficient vaccines against bacterial infections will reduce antibiotic use and, subsequently, the development of resistant bacteria.

Genetic resistance and selective breeding to improve production traits and health are long-standing industry goals. The need to enhance breeding strategies through molecular techniques (genetic linkage maps) will lead to the characterization of genome structure and genes associated with production traits and disease susceptibility and resistance. This will allow selecting bird lines that are genetically resistant to several pathogens. Also, rearing technology, management, and nutrition will help maintain bird comfort.

Conclusions

In the future, global cooperation and trade will force the governments to harmonize the different existing legislation related to trade, animal disease control, animal nutrition, and the licensing of drugs and vaccines for veterinary use. Finally, the consumer expectations for poultry products' high standards will strongly influence the production methods. This means that farmers, veterinarians, stockholders, and all other partners involved in the production chain will have to share more responsibilities and intensify cooperation.

Article Information
Funding. This research received no funds.
Conflict of Interest.The authors declare no conflict of interest.

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