The use of H-index to assess research priorities in poultry diseases

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ABSTRACT Identifying which diseases represent a priority is crucial to optimize resources for diagnostics, control, and prevention. Here, the impact of 111 poultry pathogens belonging to Viruses (n = 31), Bacteria (n = 33), and Other (n = 47) was assessed using the H-index. The overall mean H-indexes suggested that poultry Viruses have statistically greater impact than Bacteria, which in turn are statistically more relevant than Others. Among the 20 highest H-indexes, 45% were zoonotic, and almost a third was Office International des Epizooties-listed. Avian influenza virus (H-index 127), *Salmonella enteritidis* and *Salmonella typhimurium* (H-index 72), and *Eimeria spp* (H-index 70) ranked the highest in Virus, Bacteria, and Other, respectively. Pathogens that produce overt clinical diseases and economic damage, cause immunosuppression, and/or are zoonotic had the highest H-index scores. The evolution of citations of particular pathogens reflected severe poultry outbreaks and/or zoonotic outbreaks in relatively wide geographic areas. Also, the evolution of citations based on taxonomic groups mirrored major changes in poultry production practices and management throughout history. Thus, Others were the most cited pathogens until the 1970s and, following 3 decades of unpopularity because of widespread use of intensive production practices, regained importance in the 2000s thanks to welfare regulation changes. Citations for Bacteria increased especially from the 1990s onward, probably because of the ban of growth promoters in western countries and the need to find new control methods for bacterial and protozoal infections. In general, countries with the greatest poultry production and research budgets had higher research production, that is the United States of America (**USA**) and China. Interestingly, the United Kingdom was among the top research producers despite falling behind other countries in poultry production and research budget. Moreover, the USA exhibited the strongest poultry research production based on number and diversity of publications (Dcos-index). In conclusion, the H-index could be a valid, simple tool to prioritize funding or interest in poultry diseases, especially when used as a preliminary selection approach in combination with other metrics.

Key words: poultry, pathogen, H-index

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INTRODUCTION

Global production of poultry meat has increased rapidly over the past 50 yr and is currently the world's primary source of animal protein, with growing trends all over the world (Shahbandeh, 2018; FAO, 2019; Ritchie and Roser, 2019). Infectious diseases of poultry not only threaten the poultry industry worldwide but can also affect public health and wildlife conservation. As a result, diseases of poultry have consequences that go beyond losses on farms and include poultry trade prohibition, food insecurity in developing countries, and risk of fatal human infections.

The poultry industry worldwide is strikingly diverse and complex in the type of farms and the range of species bred. On the one hand, farms vary from large industrialized integrated production systems to small extensive, rural, family based systems supporting livelihoods and supplying local or niche markets (FAO, 2019). On the

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other hand, chickens, turkeys, ducks, and geese are the primary source of eggs, meat, and/or feathers, but other species such as guinea fowl, quail, pheasants, partridges, and ostriches also contribute, albeit in a smaller scale, to agricultural production and livelihoods in both developed and developing countries (Sims et al., 2016). To complicate things further, some species or even breeds are more abundant in certain continents, countries, or production systems (Sims et al., 2016; FAO, 2019). This intricate scenario hampers effective detection and control strategies designed to fight against infectious diseases.

The economic impact of diseases is difficult to assess, especially in a production system in which the economic return is based not only on flock productivity but also on product quality and viability (Collett, 2020). To effectively target and optimally use disease diagnostics, control, surveillance, and prevention efforts, as well as funding priorities, it is crucial to identify which diseases are a priority in poultry. The H-index was initially proposed as a measure of a researcher's scientific output based on counting the number of publications (N) by that researcher cited N or more times (Hirsch, 2005). This metrics shortly became relevant across most fields of science (Kustritz and Nault, 2019) and is nowadays displayed in the researcher profiles on citation databases such as Scopus, Web of Science (**WOS**), and Google Scholar. Regrettably, the H-index has also become a "magic tool" to summarize the science quality of a candidate's career in the hands of hiring committees and funding agencies (Kreiner, 2016). Despite its criticisms (Gasparyan et al., 2018; Conroy, 2020; Hirsch, 2020) and a growing number of alternative indexes attempting to overcome its limitations (Wildgaard et al., 2014), the H-index is still the most popular bibliometric index worldwide. Noteworthy, this metric seems to be a good quantitative indicator of disease impact both in humans (McIntyre et al., 2011; Cox et al., 2016; Sweileh, 2017) and in domestic animals (McIntyre et al., 2014; Diaz et al., 2016; Murray et al., 2016).

The main objective of the present work was to analyze the relevance and impact of avian pathogens in the major poultry production species using the H-index. The evolution and geographical distribution of the publications contained in the H-indexes cores (defined as the publications included in the H-index) were also examined and compared with the census of the poultry species and the research budgets per country.

MATERIALS AND METHODS

Selection of Pathogens

The study comprises known organisms (from now on, pathogens) that cause infection/infestation in the major poultry production species which are chickens, turkeys, ducks, and geese. The H-index was calculated for a total of 111 pathogens: Viruses (n = 31), Bacteria (n = 33), and Other (n = 47); in Other, helminths, protozoa, external parasites (classes Insecta and Arachnida), and fungi (plus mycotoxins) were included. The final database (Table 1) comprises the distribution of pathogens based on the aforementioned taxonomic division, their zoonotic potential, and whether they cause an Office International des Epizooties (OIE)-notifiable disease as of 2020 (OIE, 2020). The major internationally recognized reference book in poultry veterinary medicine "Diseases of poultry" (Swayne et al., 2020b) was the main source to construct the final database of pathogens. Other sources such as International Committee on Taxonomy of Viruses (https://talk.ictvonline.org/), The Poultry Site (https://thepoultrysite.com/publications/diseases-of-poultry), FAO (http://www.fao.org/home/en/), and NCBI Taxonomy (National Center for Biotechnology Information: Taxonomy browser, 2020) were also used to complete the list of pathogens.

Table 1. Distribution of pathogens of the major poultry production species used in the study.

	Total		Zoonotic potential		OIE-listed [2]	
Taxonomic group	Number	%	Number	%	Number	%
Virus	31	28	4	13	9	29
Bacteria	33	30	18	55	5	15
Other[1]	47	42	18	38	0	0
Total	111		40	36	14	13

[1]Other includes helminths, protozoa, external parasites, fungi, and mycotoxicosis.
[2]OIE list of 2020 (OIE, 2020).

Calculation of the H-index Scores and Comparison With Other Indexes

The bibliographic software package WOS (www.webofknowledge.com) was used to calculate H-index scores. Searches were undertaken during March and April 2020 and were restricted to publications in English between years 1900 and 2019, both inclusive. Similar to Díaz et al. (2016), multiple names, synonyms, and acronyms used over time for a given pathogen, and even the name of the lesions or the disease caused by a given pathogen, were used in the searches (Diaz et al., 2016). Terms as "poultry", "chicken", "hen", "rooster", "broiler", "fowl", "turkey", "duck", and "goose" were used to delimit the searches to avoid including studies in species other than the ones evaluated here. The Boolean options "AND" and "OR", and "NOT" for exclusion terms were used when necessary to link multiple search terms. When searching, several biases occurred (Diaz et al., 2016); consequently, publications in the automatically generated lists were curated one by one to ensure database accuracy. Publications related to poultry products or wild animals were not considered. The total number of citations for the publications included in the H-index cores were calculated over time from each taxonomic category as well as from the 20 highest H-index scores regardless of the taxonomy. In the latter, the percentage of yearly increase of citations from the first publication of the 20 highest H-index scores was also noted.

The ranking generated by the H-index scores was compared with the prioritization of pathogens obtained using other indicators. Because there were noticeable differences among pathogens regarding year of the first description or year of the first publication included in the H-index core, the M-quotient (Hirsch, 2005) (i.e., H-index score divided by years from oldest publication included in the H-index core) was calculated. The A-index (Jin et al., 2007) (i.e., mean number of citations of publications that are included in the H-index core) was directly obtained from the WOS output.

Origin of the Research Productivity

The total number of citations, the mean citations per publication, and the country of origin of the publications were directly obtained from the WOS output. Three-letter country codes defined by the International Organization for Standardization (**ISO**-3166-1) (ISO: Online Browsing Platform, 2020) were used. To accurately assess the impact of each country's research, the **Dcos** (Deciphering Citations Organized by Subject)-index, consisting of 2 figures (i.e., number of publications that a certain individual, institute, or country holds within the set of publications included in the H-index core of a given area or subject, plus the number of different areas with publications in the H-index cores) was also calculated (Diaz et al., 2016). In addition, the total number of publications included in the H-index cores was summarized by continents. The 2018 census of chickens, turkeys, ducks, and geese per country was obtained from FAOSTAT (http://www.fao.org/faostat/). The most recent research and development (R&D) investment by country was obtained from UNESCO (https://en.unesco.org/), the World Bank (https://www.worldbank.org/), and EUROSTAT (https://ec.europa.eu/eurostat).

Statistical Analyses

Microsoft Excel Software 2016 was used to calculate descriptive statistics. Box-plot representations and inferential statistics were done using StatsDirect v3.2.8, including nonparametric tests to compare H-index means among taxonomic groups (Kruskal-Wallis test), zoonotic potential, or OIE-listed status (Mann-Whitney test). A P-value of <0.05 was considered to be significant.

RESULTS

H-Index Scores

H-index scores were significantly different among all 3 taxonomic groups (means ± SD): Viruses 39.0 ± 28.6 > Bacteria 23.9 ± 17.2 > Other 14.4 ± 14.2; ($P < 0.05$) (Figure 1). When pathogens were grouped by their zoonotic potential (zoonotic 25.5 ± 24.7; not zoonotic 23.0 ± 20.6) or by their OIE-listed status (OIE-listed 47.0 ± 31.4; not OIE-listed 20.6 ± 18.4), significant differences were not found. When such grouping was done within each taxonomic group, significant differences were observed for OIE-listed status in Bacteria (OIE-listed 35.6 ± 8.0 > not OIE-listed 21.8 ± 17.7) and for zoonotic potential in Other (zoonotic 17.9 ± 14.0 > not zoonotic 12.0 ± 14.0) ($P < 0.05$).

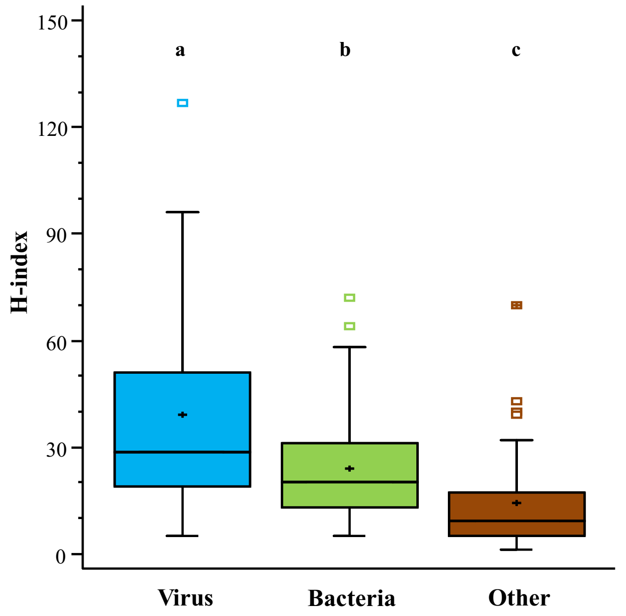

Figure 1. Box plot. Box plot of the H-index score quartiles for the major poultry production species according to taxonomic groups Virus, Bacteria, and Other for the 1900–2019 period. Other includes helminths, protozoa, external parasites, fungi, and mycotoxicosis. (+) Mean. Letters show significant differences a > b > c ($P < 0.05$).

The highest frequency of H-index scores was observed in the H-index interval 21–30 for Virus, in the interval 11–20 for Bacteria, and in scores <10 for Other (Figure 2). Of the 111 pathogens analyzed, almost 90% had an H-index <50; only 10 pathogens had an H-index >50 (6 from Virus, 3 from Bacteria, and 1 from Other) and just 2 pathogens, which belonged to Virus, had an H-index >90.

Among the 20 highest H-index scores, 11 pathogens were from Virus, 5 from Bacteria, and 4 from Other (Table 2). Within each taxonomy group, avian influenza virus (H-index 127), *Salmonella enteritidis* and *Salmonella typhimurium* (as etiological agents of salmonellosis) (H-index 72), and *Eimeria spp* (H-index 70) ranked the highest in Virus, Bacteria, and Other, respectively. Among the 20 highest H-index scores, 45% were zoonotic, 30% were OIE-listed, 10% were both zoonotic and OIE-listed, and 35% were in neither zoonotic nor OIE-listed (Table 2).

Comparison With Other Indexes

The H-index and A-index rankings were similar (Table 3), given that number of citations of the publications in the H-index core tended to yield higher H-index scores especially for the highest H-index scores (Table 2). In contrast, the H-index and M-quotient rankings

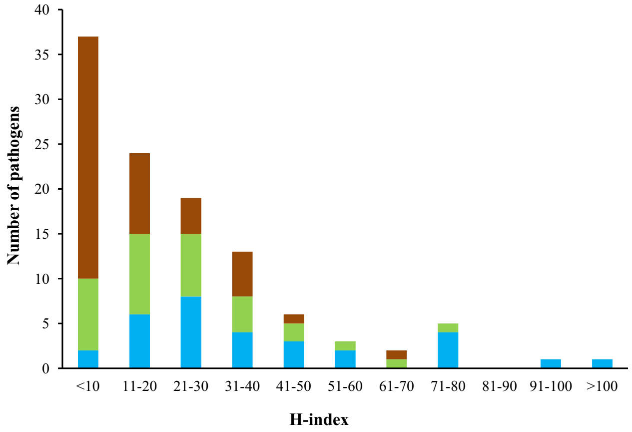

Figure 2. Frequency histogram. Frequency of the H-index scores according to taxonomic groups Virus (blue), Bacteria (green), and Other (brown). Other includes helminths, protozoa, external parasites, fungi, and mycotoxins.

differed substantially, especially for the top 10 pathogens, because years from oldest publication included in H-index cores varied greatly among pathogens (Table 3). A striking example of such disparity was *Eimeria spp* which, despite ranking eighth in H-index, is ranked 18th in M-quotient because it held the oldest publication (from 1929) in its H-index core. The opposite case was represented by avian influenza virus, which first publication in its H-index core was relatively recent (from 1983), yielding both the highest H-index and the highest M-quotient (Table 3).

Evolution of Citations

The evolution of citations for the publications included in the top 20 H-index cores showed marked differences among pathogens (Figure 3). Overall, a clear increase in number of citations was observed for all pathogens from the 1980s onward, except for avian leukosis virus, which increase was evident since the 1960s. In some cases, a steady increase in number of citations was followed by an abrupt growth for a short period, such as avian influenza virus (2002–2009). For other pathogens, such as avian leukosis virus, infectious bursal disease virus, duck hepatitis B virus, or avian pneumovirus, a constant increase was observed over time, but maximum number of citations was reached several years ago, regardless of the year of the first publication. Regarding avian leukosis virus, although its H-index ranked second, the mean of percentage of yearly increase of citations from the first publication was one of the lowest (1.3%). In contrast, the highest means of percentage of yearly increase were seen for avian influenza virus (2.6%) and avian pneumovirus (2.4%).

Up until the 1970s, Others were the pathogens mostly cited in the H-index cores (Figure 4). In the subsequent 3 decades, citations for Viruses became predominant, whereas citations for Bacteria increased especially in the 1990s and 2000s. Interestingly, Others regained popularity during the 2000s. During the last decade (2010–2019), most citations belonged to Bacteria and Others (Figure 4).

Research Productivity by Countries and Continents

In most of the 20 highest H-indexes (15/20 pathogens), the United States of America (**USA**) was the first contributor of publications, in 1 case (avian leukosis virus) reaching a contribution of 84% (Table 2). In most of the pathogens in which USA was not the first contributor (4/5), this country held the second place. In general, only 3 countries accounted for ≥50% of the publications of a given H-index core, with the exception of avian adenovirus 1 (Table 2).

Europe had 40.7% of all publications (1,295 of 3,184 publications), followed by North America (35.1%), Asia (14.5%), Oceania (4.0%), Africa (3.6%), and South America (2.2%) (Figure 5). Contributions from each continent to a particular taxonomic group were overall similar to the global contribution for that continent, with some exceptions. Thus, compared with their global percentages, North America and Asia contributed greater to Virus (39 and 20.1% of all Virus publications, respectively), Europe and Oceania to Bacteria (44 and 7.9%, respectively), and Africa and South America to Other (9.7 and 5%, respectively) (Figure 5).

The USA, United Kingdom (UK, or GBR as per ISO code, as shown in tables), and China were the greatest contributing countries in total publications (Table 4). These countries also topped the ranking when taxonomic groups were analyzed separately, except for Bacteria, for which the third contributor was Australia, and Other, for which the third contributor was Denmark. The USA accounted for almost one-third of the total publications (32.5%), being the first contributor in all taxonomic groups. The second country with the highest contribution overall and in each taxonomy was the UK (11.4%). The third position was for China, which highest contribution was for Virus, well beyond Bacteria and Other. Interestingly, when countries beyond the 10 highest total contributors were ranked for a specific taxonomic group, new countries appeared in the top 10; Ireland ranked 10th for Virus, Belgium fifth for Bacteria, whereas Brazil, Sweden, Austria, and Tanzania ranked sixth, eighth, ninth, and 10th for Other, respectively (data not shown). In contrast, some countries from the global top 10 ranked lower in specific taxonomic groups; Denmark ranked 40th for Virus, the Netherlands ranked 11th for Bacteria, and China, Japan, and the Netherlands ranked 18th for Other (Table 4). Based on Dcos-index, the USA was not only the major contributor but also its research was evenly distributed among groups: 1,035 out of 3,184 total publications studying 91 out of 111 pathogens (Table 4). Similar results were obtained for this country when Dcos-index was calculated for each taxonomic group.

Regarding poultry census, China topped chicken, duck, and goose productions, whereas the USA was by

Table 2. Pathogens of the major poultry production species with the highest H-index scores.

Rank[1]	Pathogen	Group[2]	H-index	Zoonotic	OIE-listed[3]	Total[4]	Mean ± SD[4]	Countries[5]
1	Avian influenza virus	Virus	127	X	X	33,404	263.0 ± 293.1	USA (36%), CHN (15%), GBR (8%)
2	Avian leukosis virus	Virus	96			24,820	258.5 ± 228.1	USA (84%), CHE (5%), GBR (3%)
3	Avian paramyxovirus (Newcastle)	Virus	77	X	X	10,967	142.4 ± 82.7	USA (26%), GBR (16%), NLD (9%)
4	Infectious bursal disease virus	Virus	76		X	9,148	120.4 ± 48.0	USA (26%), DEU (17%), GBR (10%)
5	Infectious bronchitis virus	Virus	73		X	8,259	113.1 ± 45.6	GBR (42%), USA (22%), NLD (12%)
6	Duck hepatitis B virus	Virus	72			9,683	134.5 ± 75.3	USA (47%), DEU (17%), JPN (8%)
6	*S. enteritidis, S. typhimurium*[6]	Bacteria	72	X		7,869	109.3 ± 37.7	GBR (36%), USA (32%), BEL (7%)
8	*Eimeria* spp	Other	70			8,389	119.8 ± 58.7	USA (39%), GBR (17%), CAN (7%)
9	*Clostridium perfringens*	Bacteria	64	X		6,689	104.5 ± 50.0	CAN (26%), USA (21%), BEL (10%)
10	*Escherichia coli*	Bacteria	58	X		6,147	106.0 ± 65.9	USA (24%), CAN (21%), ESP (8%)
11	Chicken anemia virus	Virus	53			4,286	80.1 ± 38.2	JPN (24%), IRL (24%), NLD (16%)
12	Avian adenovirus 1	Virus	51			3,703	72.6 ± 30.7	USA (14%), DEU (12%), GBR (10%)
13	*Reticuloendotheliosis virus*	Virus	49			4,127	84.2 ± 43.5	USA (75%), JPN (4%)[7]
14	*Mycoplasma gallisepticum*	Bacteria	48		X	3,357	70.0 ± 24.7	USA (47%), AUS (15%), ISR (11%)
15	Avian reovirus	Virus	44			2,950	67.1 ± 23.6	USA (31%), ESP (22%), THA (13%)
16	*Aflatoxins*[8]	Other	43	X		3,448	80.2 ± 38.6	USA (52%), TUR (11%), ARG (9%)
17	*Pasteurella multocida*	Bacteria	42	X		2,861	68.1 ± 57.5	USA (44%), AUS (38%), CAN (5%)
18	Avian pneumovirus	Virus	41		X	2,757	67.2 ± 23.5	GBR (57%), USA (24%), FRA (9%)
19	*Fusarium* spp	Other	40	X		3,056	70.4 ± 65.8	USA (40%), AUT (14%), CAN (10%)
19	Ochratoxins[9]	Other	40	X		2,999	75.0 ± 34.8	USA (34%), IND (10%), DEU (6%)

[1]Rank according to the H-index.
[2]Other includes helminths, protozoa, external parasites, fungi, and mycotoxicosis.
[3]OIE list of 2020 (OIE, 2020).
[4]Total number of citations and mean number of citations ± SD of the publications included in the H-index core.
[5]Top 3 countries of origin of publications in the H-index core, and percentage of publications originating from the country. Three-letter country codes were used (International Organization for Standardization (ISO): Online Browsing Platform, 2020). GBR is used for the UK, United Kingdom of Great Britain and Northern Ireland (England, Scotland, Wales, and Northern Ireland).
[6]Salmonellosis caused only by *Salmonella enterica* serovar Enteritidis and *Salmonella enterica* serovar Typhimurium were grouped together as the etiological agents of salmonellosis and separated from other *Salmonella* species and subspecies causing pullorum disease or fowl typhoid.
[7]CZE, AUS, CAN, GBR, DEU, FRA, ISR, CHN, and CHE ranked third in contribution (2%).
[8]Aflatoxins produced by *Aspergillus flavus*, *Aspergillus parasiticus*, and *Penicillium puberulum*.
[9]Ochratoxins produced by *Penicillium viridicatum* and *Aspergillus ochraceus*.

far the highest turkey producer (Supplementary Material S1). These 2 countries also had the largest R&D budgets (Supplementary Material S2). In contrast to the H-index scores, a variety of countries followed in the ranking of top 10 poultry producers and R&D investment.

DISCUSSION

Since Hirsch proposed it in 2005 (Hirsch, 2005), the H-index has been both glorified and vilified (Gasparyan et al., 2018; Conroy, 2020; Hirsch, 2020). Nonetheless, the H-index has shown to be a valid alternative proxy for pathogen impact (McIntyre et al., 2011, 2014; Cox et al., 2016; Diaz et al., 2016; Murray et al., 2016; Sweileh, 2017). Furthermore, some limitations of the H-index occur to a lesser degree when applied to pathogens (reviewed by [Diaz et al., 2016]). In addition, measuring economic loss, prevalence, or mortality for pathogen risk prioritization appears highly time-consuming and not always comprehensive as opposed to measuring the H-index. Here, the impact of 111 pathogens of the major poultry species (chickens, turkeys, ducks, and geese) was assessed using the H-index.

Only pathogens that cause a significant impact (i.e., economic loss, prevalence, and/or mortality) in the poultry industry were considered. However, it is worth mentioning that some difficulties encountered during the searching process forced us to make certain decisions. Thus, pathogens used only in cell lines or vaccine development, such as certain adenoviruses, lymphoid leukosis virus, or avian paramyxovirus serotypes 2 to 13, were excluded. Similarly, food-borne pathogens generally considered commensals in birds, such as *Campylobacter jejuni* and *C. coli* (as opposed to spotty liver disease-causing *Campylobacter hepaticus*), were not considered. Likewise, antimicrobial-resistant bacteria studies were omitted. Besides, many pathogens have been renamed and taxonomically reclassified, hampering the distinction between renamed pathogens (e.g., *Riemerella anatipestifer*, previously *Pasteurella anatipestifer*, *Moraxella anatipestifer*, and *Pfeifferella anatipestifer*) and emerging ones (such as *Chlamydia gallinacea*). Searches were based on pathogens, not diseases; therefore, multipathogen syndromes, such as runting-stunting syndrome or poult enteritis mortality syndrome, both caused by a myriad of viruses, were not taken into account.

The overall mean H-index scores suggested that poultry Viruses have statistically greater impact than Bacteria, which in turn are statistically more relevant than Others. Similarly, Diaz et al. (2016) found in swine that both Bacteria and Viruses were statistically more important than Others (Diaz et al., 2016). Some well-known poultry viral diseases, such as avian influenza, Newcastle disease, or infectious bronchitis, cause economic damage by producing overt clinical diseases. However, many viruses reduce flock performance, and thus economic profits, without appearing as overt clinical diseases. Some of their outcomes include stunting,

Table 3. Comparison of the 20 highest H-index scores with other bibliometric indicators.

Pathogen	Group[1]	Year[2]	H-index (rank)	A-index[3] (rank)	M-quotient[4] (rank)
Avian influenza virus	Virus	1983	127 (1)	263.02 (1)	3.43 (1)
Avian leukosis virus	Virus	1941	96 (2)	258.54 (2)	1.22 (6)
Avian paramyxovirus (Newcastle)	Virus	1946	77 (3)	142.43 (3)	1.04 (9)
Infectious bursal disease virus	Virus	1964	76 (4)	120.37 (5)	1.36 (5)
Infectious bronchitis virus	Virus	1967	73 (5)	113.14 (7)	1.4 (4)
Duck hepatitis B virus	Virus	1970	72 (6)	134.49 (4)	1.44 (3)
S. enteritidis, S. typhimurium[5]	Bacteria	1975	72 (6)	109.29 (8)	1.60 (2)
Eimeria spp	Other	1929	70 (8)	119.84 (6)	0.77 (18)
Clostridium perfringens	Bacteria	1961	64 (9)	104.52 (10)	1.08 (8)
Escherichia coli	Bacteria	1956	58 (10)	105.98 (9)	0.9 (13)
Chicken anemia virus	Virus	1973	53 (11)	80.87 (12)	1.13 (7)
Avian adenovirus 1	Virus	1957	51 (12)	72.61 (16)	0.81 (16)
Reticuloendotheliosis virus	Virus	1966	49 (13)	84.22 (11)	0.91 (12)
Mycoplasma gallisepticum	Bacteria	1952	48 (14)	69.94 (17)	0.7 (20)
Avian reovirus	Virus	1972	44 (15)	67.05 (20)	0.92 (11)
Aflatoxins[6]	Other	1970	43 (16)	80.19 (13)	0.86 (14)
Pasteurella multocida	Bacteria	1962	42 (17)	68.12 (18)	0.72 (19)
Avian pneumovirus	Virus	1979	41 (18)	67.24 (19)	1.00 (10)
Fusarium spp	Other	1972	40 (19)	76.4 (14)	0.8 (17)
Ochratoxins[7]	Other	1973	40 (19)	74.98 (15)	0.85 (15)

[1]Other includes helminths, protozoa, external parasites, fungi, and mycotoxicosis.
[2]Year: year of the oldest publication included in H-index cores.
[3]A-index: mean number of citations of publications in the H-index core (Jin et al, 2007).
[4]M-quotient: H-index/years from oldest publication included in H-index core (Hirsch, 2005).
[5]Salmonellosis caused only by *Salmonella enterica* serovar Enteritidis and *Salmonella enterica* serovar Typhimurium were grouped together as the etiological agents of salmonellosis and separated from other *Salmonella* species and subspecies causing pullorum disease or fowl typhoid.
[6]Aflatoxins produced by *Aspergillus flavus*, *Aspergillus parasiticus*, and *Penicillium puberulum*.
[7]Ochratoxins produced by *Penicillium viridicatum* and *Aspergillus ochraceus*.

malabsorption, and immune suppression, the latter with insidious effects. In addition, owing to their frequent subclinical and multipathogen syndrome nature, the accurate diagnosis of viral infections can be complex, allowing these pathogens to easily spread and hindering their control. Moreover, efficacious vaccines are not available for all viruses, and their effectiveness is not immediate and easy to assess in the field. This is in contrast to Bacteria, which prevention and control using antimicrobials is relatively straightforward. Altogether, more resources have been devoted to viral diseases in poultry than to any other etiological agent.

While a broader scientific interest would be expected from a zoonotic and/or OIE-listed pathogen, these categories did not necessarily increase the H-

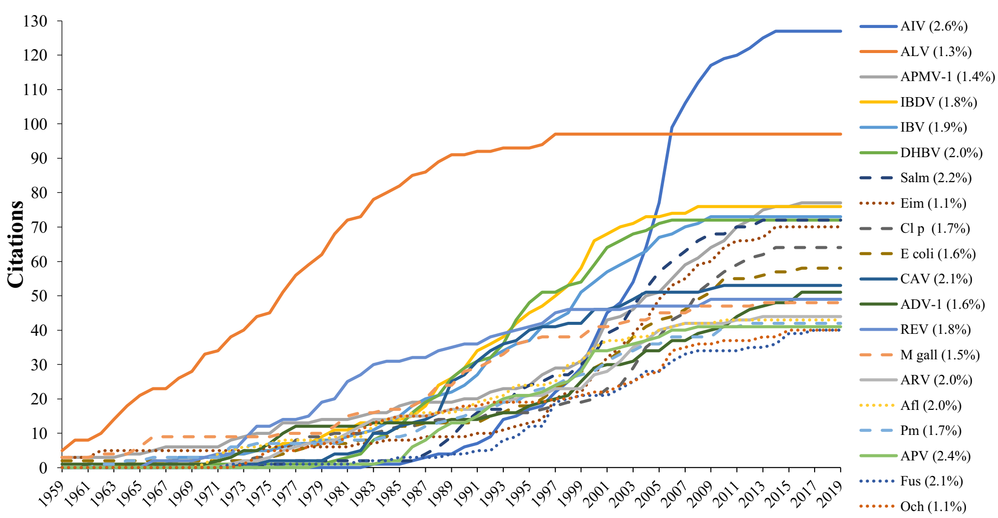

Figure 3. Evolution of citations for the publications included in the H-index cores. Evolution of citations (from 1959 to 2019) for the publications included in the H-index cores of the 20 highest H-index scores and percentage of yearly increase of citations from the first publication. Lines (Virus); Dashed lines (Bacteria); Dotted lines (Other). Abbreviations: AIV, avian influenza virus; ALV, avian leukosis virus; APMV-1, avian paramyxovirus (Newcastle); IBDV, infectious bursal disease virus; IBV, infectious bronchitis virus; DHBV, duck hepatitis B virus; Salm, *Salmonella enteritidis* and *S. typhimurium*; Eim, *Eimeria spp*; Cl p, *Clostridium perfringens*; E coli, *Escherichia coli*; CAV, chicken anemia virus; ADV-1, avian adenovirus 1; REV, reticuloendotheliosis virus; M gall, *Mycoplasma gallisepticum*; ARV, avian reovirus; Afl, aflatoxins; Pm, *Pasteurella multocida*; APV, avian pneumovirus; Fus, *Fusarium* spp; Och, ochratoxins.

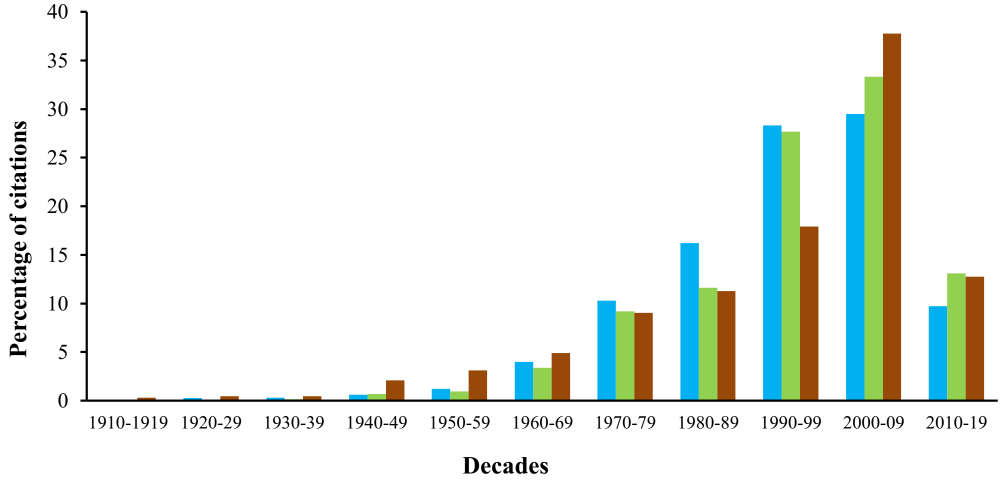

Figure 4. Citations (in percentages) per decade of the publications included in the H-index cores based on taxonomic groups. Virus (blue), Bacteria (green), and Other (brown).

index scores in our study—significantly higher H-indexes were only observed for OIE-listed Bacteria and zoonotic Others. Nevertheless, among the 20 highest H-index scores, 45% were zoonotic and almost a third was OIE listed. Interestingly, Diaz et al. (2016) observed that H-indexes of nonzoonotic swine pathogens were significantly higher than those of zoonotic ones (Diaz et al., 2016), whereas others found no differences in the H-indexes of OIE-listed vs. not OIE-listed animal pathogens (McIntyre et al., 2014; Murray et al., 2016). Previously, significant differences between H-indexes for human-only, zoonotic, and animal-only pathogens in Europe (ranked in this order) indicated that this single measure could be a One Health metric accounting for such factors (McIntyre et al., 2014). However, McIntyre et al. (2014) purposely included human and animal studies in searches for zoonoses, overestimating the animal contribution to their impact (McIntyre et al., 2014). Instead, our searches were carefully undertaken to only include studies with poultry species, thus ruling out any unwanted contribution from human studies.

Roughly half of the 20 highest H-indexes were Viruses, and the other half were Bacteria and Other. Distinct reasons for the highest ranked pathogens in each category could be made. First, avian influenza virus (H-index 127) is an economically devastating disease that affects poultry worldwide, with its highly pathogenic (**HP**) form being able to cause 100% mortality rates (Spickler et al., 2008; Pantin-Jackwood and Swayne, 2009; Swayne et al., 2020a,b). Additionally, goose/Guangdong-lineage H5N1 and Anhui-lineage H7N9 of avian influenza viruses are among the most high-profile zoonotic diseases (Collett, 2020). Second, *S. enteritidis* and *S. typhimurium* (as etiological agents of salmonellosis) (H-index 72) are 2 of the most common

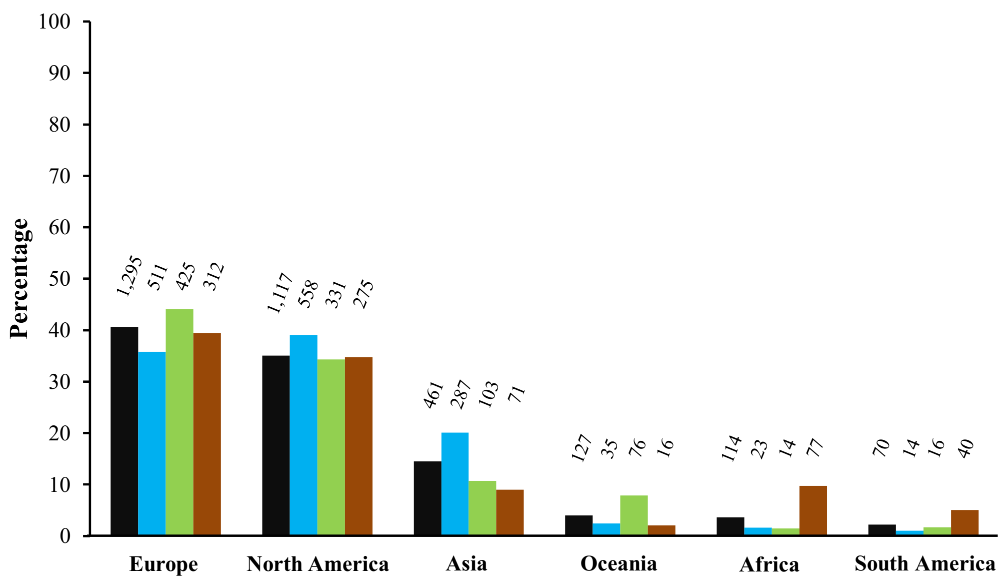

Figure 5. Distribution by continents of publications included in the H-index cores. Percentage of publications originating from the continent; total publications (n = 3,184) (black), Virus publications (n = 1,428) (blue), Bacteria publications (n = 965) (green), and Other publications (n = 791) (brown). Values above bars are absolute number of publications.

Table 4. Top 10 countries and continents of origin of all publications included in this study.

Country[3]	Continent[4]	Total publications[1]			Publications in Virus			Publications in Bacteria			Publications in Other			Dcos-index[2]			
		TNP	%	Rank	TNP	%	Rank	TNP	%	Rank	TNP	%	Rank	Total (n = 111)	Virus (n = 31)	Bacteria (n = 33)	Other (n = 47)
USA	NA	1,035	32.5	1st	524	36.7	1st	268	27.8	1st	243	30.7	1st	1,035 (91)	524 (30)	268 (31)	243 (30)
GBR	EU	363	11.4	2nd	172	12.0	2nd	130	13.5	2nd	61	7.7	2nd	363 (74)	172 (24)	130 (25)	61 (25)
CHN	ASIA	173	5.4	3rd	136	9.5	3rd	28	2.9	10th	9	1.1	18th	173 (39)	136 (20)	28 (13)	9 (6)
DEU	EU	172	5.4	4th	83	5.8	4th	49	5.1	6th	40	5.1	4th	172 (59)	83 (18)	49 (21)	40 (20)
AUS	OCE	118	3.7	5th	33	2.3	8th	70	7.2	3rd	15	1.9	11th	118 (41)	33 (15)	70 (16)	15 (10)
CAN	NA	116	3.6	6th	29	2.0	9th	61	6.3	4th	26	3.3	5th	116 (36)	29 (9)	61 (17)	26 (10)
DNK	EU	104	3.3	7th	3	0.2	40th	40	4.1	7th	61	7.7	3rd	104 (39)	3 (3)	40 (16)	61 (22)
JPN	ASIA	103	3.23	8th	62	4.3	5th	32	3.3	8th	9	1.1	18th	103 (38)	62 (15)	32 (15)	9 (8)
FRA	EU	88	2.8	9th	35	2.4	7th	30	3.1	9th	23	2.9	7th	88 (38)	35 (15)	30 (13)	23 (10)
NLD	EU	83	2.6	10th	47	3.3	6th	27	2.8	11th	9	1.1	18th	83 (29)	47 (12)	27 (13)	9 (4)

[1]Total number of publications (TNP), percentages (%), and ranking for total publications. Of the 3,184 total publications included in the H-indexes searched for 111 pathogens, 1,428 publications belonged to Virus (31 pathogens), 965 publications to Bacteria (33 pathogens), and 791 to Other (47 pathogens).
[2]Dcos-index: number of publications that a country holds within the set of publications included in the H-index core of a given subject (Diaz et al, 2016). For example, the USA holds 524 publications in the field of Viruses, which include 30 of the 31 virus pathogens analyzed.
[3]Three-letter country codes were used (International Organization for Standardization [ISO]: Online Browsing Platform, 2020). GBR is used for the UK, United Kingdom of Great Britain, and Northern Ireland (England, Scotland, Wales, and Northern Ireland).
[4]EU, Europe; NA, North America; OCE, Oceania.

nontyphoidal serovars isolated from humans (Gast and Porter, 2020). Although they only cause clinical disease in highly susceptible young birds exposed to stressful conditions (Gast and Porter, 2020), numerous studies in birds are probably aimed at understanding potential routes of transmission to humans and ultimately prevent zoonoses. Finally, *Eimeria spp* (H-index 70) is responsible for coccidiosis in poultry, one of the most common and economically important diseases of chickens worldwide (Cervantes et al., 2020). Anticoccidial drugs and vaccination are required for its control and, in recent years, consumer demand has fueled the development of alternatives to ionophores, a class of antibiotics for coccidiosis prevention (Cervantes et al., 2020). Interestingly, 6 of the 15 highest H-indexes belonged to pathogens causing immunosuppression: avian leukosis virus, infectious bursal disease virus, *Eimeria spp*, chicken anemia virus, reticuloendotheliosis virus, and avian reovirus. This is especially relevant because immunosuppression not only predisposes birds to infection by other agents but also can hamper optimal response to vaccination against any pathogen (Schat and Skinner, 2014). We note that some economically important diseases of poultry had a relatively lower H-index than expected, such as the herpesvirus-induced Marek's disease (H-index 33), mostly because of the exclusion of publications not strictly involving poultry species.

The evolution of citations reflected severe poultry outbreaks and/or zoonotic outbreaks in relatively wide geographic areas, as previously observed for swine (Diaz et al., 2016). The most striking example was the abrupt increase of avian influenza virus citations between 2002 and 2009, as a result of the emergence of goose/Guangdong-lineage H5 HP avian influenza virus in China in 1996 that subsequently spread to 4 continents, representing a major HP avian influenza panzootic (Sims and Brown, 2016). The polar opposite was avian leukosis virus, which citations stalled in 1997. Avian leukosis virus is the most common leukosis sarcoma group of retroviruses associated with neoplastic diseases in poultry (Nair et al., 2020). They were the first neoplastic diseases in any species to be shown, more than 100 yr ago, to be viral-transmissible and have consequently been studied extensively by biomedical scientists as models for the role of viruses in cancer (Payne and Nair, 2012). In the 1920s, they also became the major cause of mortality and economic loss to the developed poultry industry and were thus studied by agricultural scientists searching for control methods (Payne and Nair, 2012). The decrease in research production since the turn of the century could be related to the fact that meat-type broiler breeders and broilers have been generally free of avian leukosis virus for the last decades in western countries thanks to rigorous, well-tested eradication programs. Even if the disease remains and has spread to layer flocks in other countries, notably China (Payne and Nair, 2012), the impact of more recent publications on avian leukosis virus is not sufficient as to be included in its H-index core. We note that, since time is needed to accumulate citations and increase the H-index, more recently emerged pathogens are in a disadvantageous situation. Such is the case of *Gallibacterium anatis*, duck egg drop syndrome virus, *Helicobacter pullorum*, *Salmonella arizonae*, *C. hepaticus*, and *C. gallinacea*, all of them with H-indexes below 23 (data not shown).

The evolution of citations based on taxonomic groups mirrors major changes in poultry production practices and management throughout history. On the one hand, Others were the most cited pathogens in the H-index cores until the 1970s and, following 3 decades of unpopularity, regained importance in the 2000s. Since the widespread use of modern production practices, and especially modern caging, in the 1970s, internal and external parasite exposure in intensively reared flocks had significantly reduced and only been maintained in backyard flocks (Murillo and Mullens, 2016; Hinkle and Corrigan, 2020). Reversion to husbandry practices that restore environmental conditions conducive to parasites, as has been demonstrated in European practices since 2000, has allowed a resurgence of poultry pests that had not been seem as problematic in commercial production for over 50 yr, such as the poultry red mite (Hinkle and Corrigan, 2020). As welfare regulations become ever more stringent in the years to come, Others are expected to maintain and even increase in relevance. On the other hand, citations for Bacteria increased especially in the 1990s and surpassed Viruses from the 2000s to date. EU-wide limitations on antimicrobial use began in 1997 with the ban of the growth promotion use of avoparcin, and by 2006, the remaining growth promoters were removed (U.S. Government Accountability Office, 2011; Maron et al., 2013). A similar prohibition in the USA followed a decade later, when the FDA banned growth-promoting and other nontherapeutic uses of antibiotics in 2017 (U.S. Food and Drug Administration, 2020). As a consequence of these regulatory changes, western and other countries have faced increasing challenges in the control of bacterial and protozoal infections, and more research has been devoted to nonantibiotic medications and preventive measures, such as changes in management and diet, use of chemically synthesized coccidiostats, and probiotics (Collett, 2020). Collectively, both welfare and medication regulations seem to be shifting control priorities toward diseases previously recognized as unimportant but that are now re-emerging as significant concerns (Collett, 2020).

The socioeconomic framework can influence the research contribution of a particular country or continent. China and the USA not only topped poultry productions but also had the largest R&D budgets, with figures around \$5.10 x 10^{11}. Japan, Germany, France, and the UK ranked among the highest 10 R&D budgets and also made the list of top countries of origin of publications for many pathogens. The USA exhibited, by far, the strongest poultry research production not only in number of publications but also in the diversity of pathogens studied, according to Dcos-index. Interestingly, the UK followed the USA in Dcos-index, despite falling behind other countries in poultry production and R&D budget.

The H-indexes are a delayed reflection of changes in regulations, as aforementioned, and in investment priorities over the past decades. One of the limitations of this study is that, because the most recently available R&D budgets were analyzed, their effect will only be seen in the years to come and do not necessarily explain the evolution of H-indexes and citations of the past decades. We speculate that China will soon surpass USA and other countries in number of publications and will be included among the top countries of origin of publications in the H-index core of the highest H-indexed pathogens (as of now, China is only shortlisted as second contributor for avian influenza virus). Also, we recognize that knowing the percentage of R&D dedicated to poultry or animal health would allow for more accurate conclusions.

Because the EU block has produced antibiotic-free poultry for longer than other continents, research on Bacteria control has been a greater priority than in other regions. Similarly, most African and South American countries with a great proportion of backyard holdings and farms with low biosecurity standards consequently exhibit high incidence of parasites (some of them geographically restricted) and contributed disproportionately to H-indexes of Other (Diaz et al., 2016). Pathogens that affect chickens ranked the highest in H-indexes, irrespective of whether they also affect turkeys, ducks, and/or geese, whereas diseases that present host restriction to species other than chickens had an insignificant relevance (data not shown). This can be because of the great importance of chickens in poultry—thanks to their high feed-meat conversion ratio and egg production, broilers and layers are the birds mainly produced by modern integrated poultry facilities to meet growing global demand for animal-source foods.

In conclusion, the H-index could be a valid tool to prioritize funding or interest in poultry diseases, and the evolution of the H-index of a particular pathogen may be used to identify major poultry outbreaks or zoonotic events. However, because of its intrinsic limitations, the H-index should be used as a preliminary selection approach in combination with other metrics, such as severity of disease, economic impact, trade bans, food insecurity, and zoonotic potential.

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SUPPLEMENTARY DATA

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REFERENCES

Cervantes, H. M., L. R. McDougald, and M. C. Jenkins. 2020. Protozoal infections. Coccidiosis. Pages 1193–1216 in Diseases of Poultry. D. E. Swayne, M. Boulianne, C. M. Logue, L. R. McDougald, V. Nair, D. L. Suarez, S. de Wit, T. Grimes, D. Johnson, M. Kromm, T. Y. Prajitno, I. Rubinoff, and G. Zavala, eds. 14th ed. Wiley-Blackwell, Hoboken, NJ.

Collett, S. R. 2020. Principles of disease prevention, diagnosis, and control. Introduction. Pages 3–4 in Diseases of Poultry. D. E. Swayne, M. Boulianne, C. M. Logue, L. R. McDougald, V. Nair, D. L. Suarez, S. de Wit, T. Grimes, D. Johnson, M. Kromm, T. Y. Prajitno, I. Rubinoff, and G. Zavala, eds. 14th ed. Wiley-Blackwell, Hoboken, NJ, Hoboken, NJ.

Conroy, G. 2020. What's wrong with the H-index, according to its inventor. Nature Index. Accessed Aug. 2020. https://www.natureindex.com/news-blog/whats-wrong-with-the-h-index-according-to-its-inventor.

Cox, R., K. M. McIntyre, J. Sanchez, C. Setzkorn, M. Baylis, and C. W. Revie. 2016. Comparison of the h-index scores among pathogens Identified as emerging Hazards in North America. Transbound Emerg. Dis. 63:79–91.

Diaz, I., M. Cortey, A. Olvera, and J. Segales. 2016. Use of H-index and other bibliometric indicators to evaluate research productivity outcome on swine diseases. PLoS One 11:e0149690.

FAO. 2019. Gateway to Poultry Production and Products. Accessed Aug. 2020. http://www.fao.org/poultry-production-products/production/en/.

Gasparyan, A. Y., M. Yessirkepov, A. Duisenova, V. I. Trukhachev, E. I. Kostyukova, and G. D. Kitas. 2018. Researcher and author impact metrics: variety, value, and Context. J. Korean Med. Sci. 33:e139.

Gast, R. K., and R. E. J. Porter. 2020. *Salmonella* infections. Pages 719–753 in Diseases of Poultry. D. E. Swayne, M. Boulianne, C. M. Logue, L. R. McDougald, V. Nair, D. L. Suarez, S. de Wit, T. Grimes, D. Johnson, M. Kromm, T. Y. Prajitno, I. Rubinoff, and G. Zavala, eds. 14th ed. Wiley-Blackwell, Hoboken, NJ.

Hinkle, N. C., and R. M. Corrigan. 2020. External parasites and poultry pests. Pages 1135–1156 in Diseases of Poultry. D. E. Swayne, M. Boulianne, C. M. Logue, L. R. McDougald, V. Nair, D. L. Suarez, S. de Wit, T. Grimes, D. Johnson, M. Kromm, T. Y. Prajitno, I. Rubinoff, and G. Zavala, eds. 14th ed. Wiley-Blackwell, Hoboken, NJ.

Hirsch, J. E. 2005. An index to quantify an individual's scientific research output. Proc. Natl. Acad. Sci. U. S. A. 102:16569–16572.

Hirsch, J. E. 2020. Superconductivity, what the H? The Emperor has No Clothes. Phys. Soc. 49:4–9.

International Organization for Standardization (ISO). Online browsing Platform. 2020. Country codes. Accessed Aug. 2020. https://www.iso.org/obp/ui/#search.

Jin, B. H., L. M. Liang, R. Rousseau, and L. Egghe. 2007. The R- and AR-indices: Complementing the h-index. Chin. Sci. Bull. 52:855–863.

Kreiner, G. 2016. The Slavery of the h-index-Measuring the Unmeasurable. Front. Hum. Neurosci. 10:556.

Kustritz, M. V. R., and A. J. Nault. 2019. Measuring productivity and impact of veterinary Education-related research at the Institutional and individual Levels using the H-index. J. Vet. Med. Educ. e0618072r1.

Maron, D. F., T. J. Smith, and K. E. Nachman. 2013. Restrictions on antimicrobial use in food animal production: an international regulatory and economic survey. Glob. Health 9:48.

McIntyre, K. M., C. Setzkorn, P. J. Hepworth, S. Morand, A. P. Morse, and M. Baylis. 2014. A quantitative prioritisation of human and domestic animal pathogens in Europe. PLoS One 9:e103529.

McIntyre, K. M., I. Hawkes, A. Waret-Szkuta, S. Morand, and M. Baylis. 2011. The H-index as a quantitative indicator of the relative impact of human diseases. PLoS One 6:e19558.

Murillo, A. C., and B. A. Mullens. 2016. Diversity and prevalence of Ectoparasites on backyard chicken flocks in California. J. Med. Entomol. 53:707–711.

Murray, A. G., M. Wardeh, and K. M. McIntyre. 2016. Using the H-index to assess disease priorities for salmon aquaculture. Prev. Vet. Med. 126:199–207.

Nair, V., I. Gimeno, J. Dunn, G. Zavala, S. M. Williams, R. L. Reece, and S. Hafner. 2020. Neoplastic diseases. Pages 548–715 in Diseases of Poultry. D. E. Swayne, M. Boulianne, C. M. Logue, L. R. McDougald, V. Nair, D. L. Suarez, S. de Wit, T. Grimes, D. Johnson, M. Kromm, T. Y. Prajitno, I. Rubinoff, and G. Zavala, eds. 14th ed. Wiley-Blackwell, Hoboken, NJ.

National Center for Biotecnology Information. 2020. Taxonomy Browser. Accessed Aug. 2020. https://www.ncbi.nlm.nih.gov/Taxonomy/taxonomyhome.html/.

OIE. 2020. OIE-listed Diseases, Infections and Infestations in Force in 2020. Accessed Aug. 2020. https://www.oie.int/animal-health-in-the-world/oie-listed-diseases-2020/.

Pantin-Jackwood, M. J., and D. E. Swayne. 2009. Pathogenesis and pathobiology of avian influenza virus infection in birds. Rev. Sci. Tech. Off Int. Epiz 28:113–136.

Payne, L. N., and V. Nair. 2012. The long view: 40 years of avian leukosis research. Avian Pathol. 41:11–19.

Ritchie, H., and M. Roser. 2019. Meat and Dairy Production. Our World in Data. Accessed Aug. 2020. https://ourworldindata.org/meat-production.

Schat, K. A., and M. A. Skinner. 2014. Avian immunosuppressive diseases and immunoevasion. Pages 275–298 in Avian Immunology. K. A. Schat, B. Kaspers, and P. Kaiser, eds. 2nd ed. Academic Press, San Diego, CA.

Shahbandeh, M. 2018. Meat Consumption Worldwide from 2010 to 2021, by Meat Type (In Million Tons). Statista. Accessed Aug. 2020. https://www.statista.com/statistics/274522/global-per-capita-consumption-of-meat/#statisticContainer/.

Sims, L. D., and I. H. Brown. 2016. Multi-continental panzootic of H5 highly pathogenic avian influenza (1996–2015). Pages 202–247 in Animal Influenza. D. E. Swayne, ed. 2nd ed. Wiley-Blackwell, Hoboken, NJ.

Sims, L. D., J. Weaver, and D. E. Swayne. 2016. Epidemiology of avian influenza in agricultural and other man-made systems. Pages 302–336 in Animal Influenza. D. E. Swayne, ed. Wiley-Blackwell, Hoboken, NJ.

Spickler, A. R., D. W. Trampel, and J. A. Roth. 2008. The onset of virus shedding and clinical signs in chickens infected with high-pathogenicity and low-pathogenicity avian influenza viruses. Avian Pathol. 37:555–577.

Swayne, D. E., M. Boulianne, C. M. Logue, L. R. McDougald, V. Nair, D. L. Suarez, S. de Wit, T. Grimes, D. Johnson, M. Kromm, T. Y. Prajitno, I. Rubinoff, and G. Zavala. 2020a. Diseases of Poultry. 14th ed. Wiley-Blackwell, Hoboken, NJ.

Swayne, D. E., D. L. Suarez, and L. D. Sims. 2020b. Influenza. Pages 210–256 in Diseases of Poultry. D. E. Swayne, M. Boulianne, C. M. Logue, L. R. McDougald, V. Nair, D. L. Suarez, S. de Wit, T. Grimes, D. Johnson, M. Kromm, T. Y. Prajitno, I. Rubinoff, and G. Zavala, eds. 14th ed. Wiley-Blackwell, Hoboken, NJ.

Sweileh, W. M. 2017. Global research trends of World Health Organization's top eight emerging pathogens. Globalization and Health 13:9.

U.S. Food and Drug Administration. 2020. Timeline of FDA Action on Antimicrobial Resistance. Accessed Aug. 2020. https://www.fda.gov/animal-veterinary/antimicrobial-resistance/timeline-fda-action-antimicrobial-resistance.

U.S. Government Accountability Office. 2011. Antibiotic Resistance: Agencies Have Made Little Progress Addressing Antibiotic Use in Animals. Accessed Aug. 2020. https://www.gao.gov/assets/330/323090.pdf.

Wildgaard, L., J. W. Schneider, and B. Larsen. 2014. A review of the characteristics of 108 author-level bibliometric indicators. Scientometrics 101:125–158.