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Article

Hen feeding and egg quality in alternative poultry farming systems: A bibliometric analysis

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Abstract:

This work aimed to analyze research published in scientific articles; using bibliometric techniques, a study on the type of food provided to hens and egg quality in alternative production systems was conducted. The most frequently evaluated breeds or lines of hens,

diet ingredients, and egg quality variables were identified. The keywords used for this search were “Organic egg production”, “Free range”, “Hen eggs”, “Backyard laying hens”, and “Backyard egg”. From 1976 to 2023, 197 scientific articles were identified; their publication frequency followed an exponential trend (R^2= 0.8137). Research on alternative systems appeared after 2012, and most of it was conducted in Europe. Eighty point seven (80.7) percent of the articles addressed topics associated with egg quality (23.86 %), production systems (21.32 %), food safety (16.24 %), animal welfare (10.15 %), and hen diet (9.14 %). The most studied hen genotypes were Hy-Line Brown, ISA Brown, and Lohmann Brown. Most diets included grasses among their ingredients, with corn standing out in the Americas, and wheat and sorghum standing out in Europe and Oceania. Regarding egg quality, the most commonly used indicators were volume, egg shape, shell thickness, yolk (pigmentation), and white (Haugh units). Finally, in the case of Mexico, little research was documented, which represents an area of opportunity to generate new knowledge on the use of local resources that provide protein and energy.

Keywords: Bibliometrics, Egg production systems, Animal welfare, Local resources.

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Introduction

The poultry industry is one of the most important sectors worldwide for the production of meat (104 million tonnes) and eggs (92 million tonnes)[(1)]. It has developed conventional intensive production methods that respond to specialized purposes and are increasingly productive[(1)]. These methods involve different technologies aimed at improving the productive performance of poultry, giving rise to advances in production through genetic improvement techniques, feeding, management, and health[(2)].

The shift towards alternative cage-free hen production systems has been significantly influenced by consumer demand and regulatory changes, particularly in the European Union, where traditional cages were banned in 2012; in addition, there is a global trend towards animal welfare and sustainable practices[(2)]. The alternative egg production method emphasizes a natural environment for laying hens, allowing them to adopt natural behaviors, such as foraging, dustbathing, and social interaction[(3)].

Among the alternative systems for egg production, the most common are free-range systems (where hens have access to outdoor areas to look for their food without any restrictions), cage-free systems (where hens are placed in aviaries with access to nests, feeders, and drinkers), and systems of rearing in pens or aviaries (where hens can move relatively freely, limited by pens or aviaries); these systems have been adopted mostly by countries in Europe, Asia, and the United States; in contrast, in countries such as Mexico and Latin America, backyard or pen systems tend to be more frequent[4,5].

The holistic approach to free-range egg production not only benefits hens and consumers but also plays a vital role in preserving the ecosystem, focused on minimizing the negative impact on the environment. Thus, it contributes to cleaner, more sustainable production, aligned with the growing demands of environmentally conscious and health-conscious consumers[5].

However, despite the environmental benefits of the free-range egg production system and its alignment with new market trends, which demand quality products produced under animal welfare standards, there is little research assessing its scope and relevance[5]. In this sense, bibliometric studies based on the analysis of scientific articles are usually a good tool for learning about the scientific information published on a topic and for detecting areas of opportunity for research[6].

The publication of a scientific work is the most effective way to transmit knowledge acquired through research, and, using bibliometrics, indicators can be generated to measure the results of scientific activity[7]. In this context, the objective of this work was to analyze, through bibliometric techniques, the information published in scientific articles on egg production in alternative systems to identify the most frequently used breeds or genetic lines of poultry, the most commonly used diet ingredients, and the most frequently evaluated egg quality variables.

Material and methods

Source of information and data preparation

This work considered scientific articles aimed at identifying the types of ingredients used in the diet of cage-free hens and the egg quality variables frequently evaluated in these production systems. These texts were collected in major publishers (Elsevier, Scopus, Frontiers, MDPI, Taylor & Francis, and Springer) and websites (Scielo, Redalyc, and Google Scholar). The keywords used for this search were “Organic egg production”, “Free range”, “Hen eggs”, “Backyard laying hens”, and “Backyard egg”. The papers were collected from May to September 2023, and texts published up to June 2023 were considered. The keywords

were used only in English because it is considered that texts in English are more likely to be cited, allowing us to capture most of the relevant publications[8].

The variables analyzed for each published text were the journal name, authors, title, abstract, keywords, and number of citations. For each paper, the first author's country of origin, the common name of the hen species evaluated, the ingredients of the diets, and the variables analyzed for egg quality were located through a content analysis.

Using a spreadsheet, all variables were recorded, preserving the original language of each text and standardizing only some records because the information available in the texts was sometimes incomplete or presented variations[9]. In addition, special characters, such as ñ (for n), accents, superscripts, subscripts, ®, and ©, among others, were removed or changed to facilitate the analysis.

Analysis of information

The methodology described by Santillán-Fernández *et al*(2021)[10] was followed, which consists of conducting a content analysis of publications to represent spatial and temporal aspects, author networks, and key concepts on the topics to be analyzed. The content analysis of each scientific paper enabled to discard studies that did not specify the ingredients used in cage-free hen diets or the egg quality variables frequently evaluated in these production systems.

In this way, a temporal chart of scientific production was built using the variables of year of publication and number of citations. For the variable of frequency of scientific articles per year, an ordinary least squares regression model was estimated to determine the trend in the frequency of publications[11]. The countries of origin of the first author were also mapped to determine where research on the diet of cage-free hens and its effect on egg quality has been conducted. For the spatial representation, the ARGIS®[12] geographic package was used.

Based on the analysis of the titles of the scientific articles, their abstracts, and keywords, the topic addressed by each of the texts was determined, grouping the information into six categories: 1) egg quality; 2) production system; 3) food safety; 4) animal welfare; 5) poultry diet; 6) others (animal behavior, hen genetics, environmental impact of the production system, egg authentication methods, niche markets, consumer perception-preference, food safety, backyard, and economic viability of production systems). Once the scientific articles were classified by the topic they addressed, a chart of the issues was generated according to the first author's country of origin.

Bibliometric indicators were also generated for the following: journals that published most frequently; main ingredients that make up the diets; breeds and lines of hens considered in the studies; and variables analyzed to determine egg quality. Using the Gephi software[13], co-authorship networks (to identify the leading researchers) and keywords (to know the most recurrent concepts in the analysis of ingredients in hen diets and their effect on the quality of the eggs produced under an alternative system) were generated.

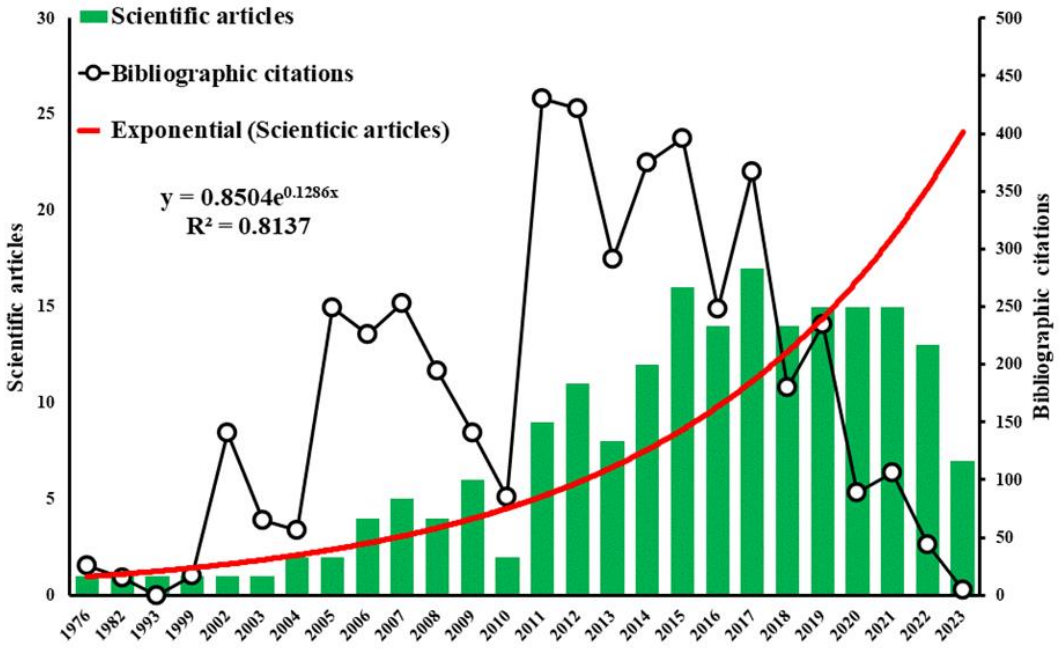
Finally, in the case of Mexico, bibliometric indicators were obtained for the institution of affiliation of the first author who developed the research, the breeds or genetic lines of hens evaluated, the diets supplied, the study areas, and the egg quality parameters analyzed. Likewise, a keyword network was generated to determine the concepts most used by researchers.

Results

Spatial-temporal analysis

It was found 197 scientific articles that assessed the diet of hens or egg quality in cage-free production systems. These publications were extracted from 1976 to 2023, totaling 4,656 bibliographic citations (Figure 1). The period with the highest scientific production corresponded to the years from 2015 to 2022, with a total of 119 articles, representing 60.04 % of the total publications, and contributing to an exponential trend in the growth of publications (R^2= 0.8137). The most cited articles were those published in 2011, 2012, and 2015, which together totaled 1,248 citations, representing 26.08 % of the total. The growing trend in publications from 2012 onwards coincided with the prohibition of egg production in conventional cages in Europe[2,14].

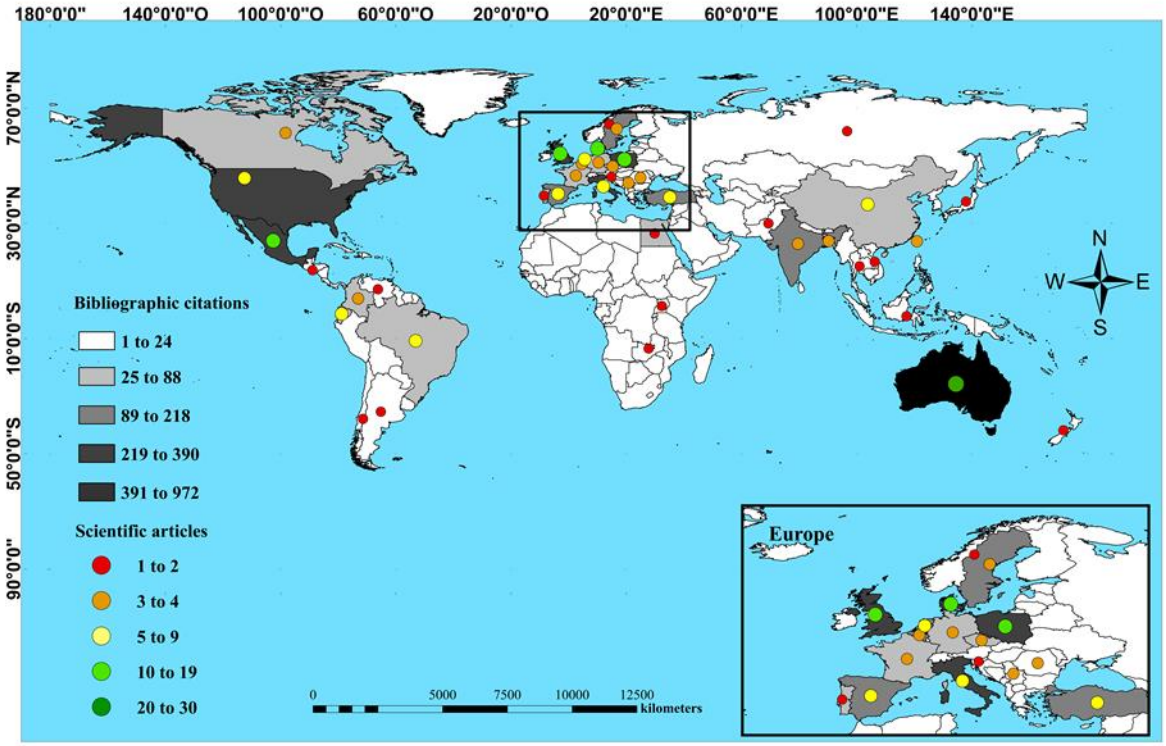
Figure 1: Temporal evolution of scientific production and bibliographic citations on topics related to the diet of hens and the quality of eggs produced under an alternative system, from 1976 to 2023



Alternative egg production systems contribute to Goal 2 of the United Nations: End Hunger, since they address food security from a multidimensional approach, prioritizing egg production in a more sustainable way[15]. The countries where the research reported in this study was conducted are signatories to the UN commitments; in the case of Australia, alternative systems are presented as options for the consumer to appreciate the production methods and revalue animal welfare and environmental sustainability[16].

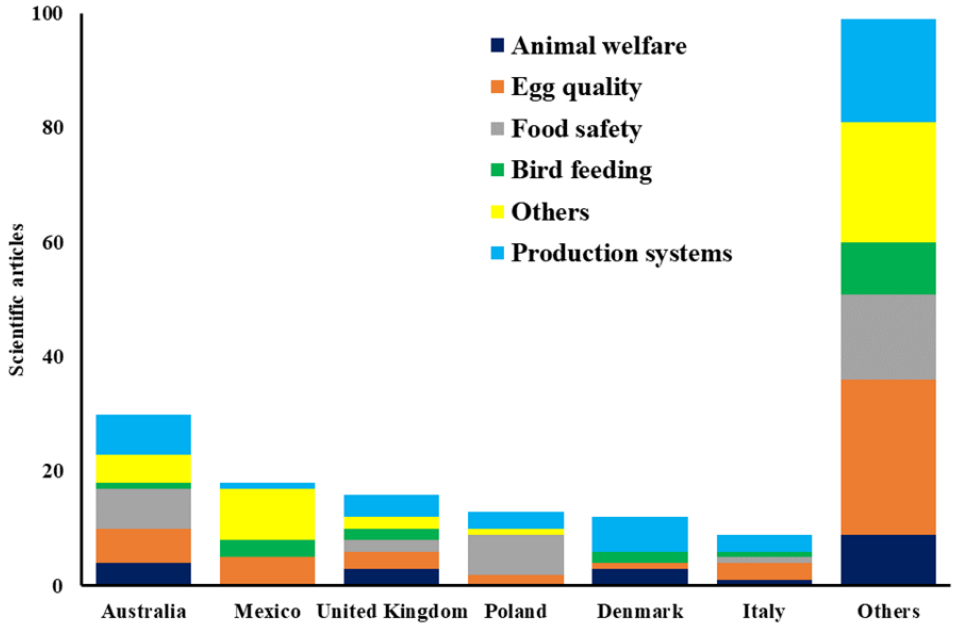
Regarding the country of origin of the first author of each scientific article, it was found that the 197 papers originated in 42 countries. Forty-five point eight (45.8) percent (89 texts) of the scientific production was concentrated in five countries: Australia (30 texts, 15.23 %), Mexico (18, 9.14 %), the United Kingdom (16, 8.12 %), Poland (13, 6.60 %), and Denmark (12, 6.09 %) (Figure 2).

Figure 2: Spatial relationship of scientific production and bibliographic citations on topics related to the diet of hens and the quality of eggs produced under an alternative system, from 1976 to 2023



In relation to the thematic areas, 47 scientific articles were counted in egg quality, which represented 23.86 % of the total, 42 works in production system (21.32 %), 32 in food safety (16.24 %), 20 in animal welfare (10.15 %), 18 in poultry feed (9.14 %), and 38 in others (19.29 %). Figure 3 shows that Australia, Mexico, and the United Kingdom have been the countries with the most research development. Nevertheless, unlike Mexico, Australia and the United Kingdom have considered issues associated with food safety and animal welfare in their research, whereas in developing economies, such as Mexico, the aim is to guarantee food security for their population[16].

Figure 3: Top nations, according to the first author's country of origin, and topics they address in scientific papers from 1976 to 2023 on alternative egg production systems



The 197 scientific articles analyzed were published in 128 scientific journals. Table 1 shows the leading journals that concentrate the largest number of scientific articles on hen diet and egg quality. These journals specialize in poultry science, veterinary science, and food science and technology, have impact factors greater than 2.0, and are indexed in the Journal Citation Reports[17]. They are published in English and in countries with a long tradition in poultry research, such as the United Kingdom and the United States. The impact factor plays a crucial role in deciding where to publish, as journals with a high impact factor increase the chances of reaching a wider audience[10].

Table 1: Bibliometric indicators of the leading journals that published scientific articles on the diet of hens and the quality of eggs produced in alternative systems, from 1976 to 2023

Journals					Articles		Citations	
Name	**Country**	**Publisher**	**Factor**	**Topics**	**No**	**%**	**No**	**%**
Poultry Science	USA	Elsevier	4.4	Poultry sciences	11	5.58	598	12.84
Animals	Switzer	MDPI	3.0	Veterinary sciences	8	4.06	138	2.96
Animal	UK	Elsevier	4.0	Animal biosciences	5	2.54	124	2.66
BP_Science	UK	T&F	2.0	Animal nutrition	5	2.54	219	4.70
Food Chemistry	UK	Elsevier	8.8	Food chemistry	5	2.54	243	5.22
AAJA_Science	R_Korea	AAAP	--	Animal biosciences	4	2.03	250	5.37
Chemosphere	N_Lands	Elsevier	8.8	Environmental chemistry	4	2.03	105	2.26
JAF_Chemis	USA	ACS	5.7	Food chemistry	4	2.03	105	2.26
JAP_Research	USA	Elsevier	1.9	Poultry sciences	4	2.03	118	2.53
JSF_Agricultur	UK	Wiley	3.3	Agricultural sciences	4	2.03	147	3.16
Others					143	72.59	2609	56.04

BP_Science: British Poultry Science; AAJA_Science: Asian Australasian Journal of Animal Sciences; JAF_Chemis: Journal of Agricultural and Food Chemistry; JAP_Research: Journal of Applied Poultry Research; JSF_Agricultur: Journal of the Science of Food and Agriculture; T&F: Taylor & Francis; UK: United Kingdom; USA: United States of America; R_Korea: Republic of Korea (South Korea); AAAP: Asian-Australasian Association of Animal Production Societies; N_Lands: Netherlands (Holland); ACS: American Chemical Society.

Table 2 shows the most common variables to determine egg quality, diets, and breeds of hens used in the main countries that have developed research on cage-free production systems. To evaluate egg quality, there are various physical, chemical, and subjective methods that allow describing the internal and external characteristics of the egg; these methods usually resort to the analysis of variables such as egg shape index, shell thickness, albumen height, as well as the contents of water, total solids, and protein in the yolk and albumen[18,19].

Although egg quality is influenced by hen genetics, diet is a factor that directly affects this property[20,21]. In the present analysis, the genetic lines most frequently used in alternative production systems were Hy-Line Brown (Australia, Denmark, and Italy), ISA Brown (Australia and Denmark), and Lohmann Brown (Australia and Denmark). Regarding diets, most included grasses among their ingredients, with corn standing out in the Americas, and wheat and sorghum standing out in Europe and Oceania. According to Gutiérrez *et al*[22], in cage-free production, the use of local resources for feeding hens is essential, since on the one hand, they reduce production costs, and on the other hand, they are environmentally friendly, as they are produced in the same regions, reducing the import of other types of food.

Table 2: Egg quality indicators, breed or genetic lines, and diets used in cage-free egg production systems, according to scientific articles published on this topic, from 1976 to 2023

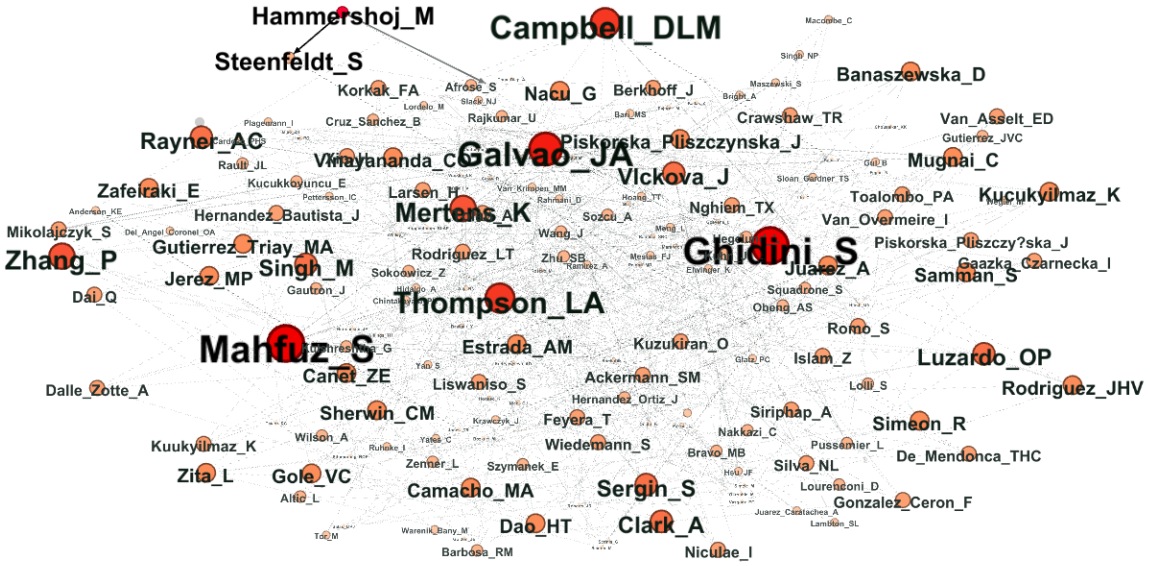
Quality parameters	Diet	Breed	Country	Reference
Egg weight, shell (weight, percentage, reflectivity, thickness, color, and strength), yolk (color and Haugh units), albumen height, and cuticle quantity.	Pea, wheat, and sorghum grasses, soybean meal, meat meal, and vegetable oil	Hy-Line Brown, ISA Brown, Bond Brown, Bond White, Bond Black, Lohmann Brown, Plymouth Rock, Australorp	Australia	(23) (24) (25) (26) (27) (28)
Egg (weight, longitudinal and transverse diameters), shell (weight, thickness, and index), yolk (pH, weight, diameter, height, and pigmentation), white (pH, weight, diameter, height, and Haugh units), and air cell height.	Based on corn, food scraps, dough, and commercial feed	Native INPEMA-Plymouth, Plymouth, Harco and Tetra sl, Rhode Island Red, Playmouth Rock Barrada	Mexico	(29) (30) (31)
Contents of moisture, nitrogen, amino acids, fats, fatty acids, and cholesterol, ash, sodium, potassium, calcium, and iron, thiamin, riboflavin, nicotinic acid, pantothenic acid, folic acid, vitamin B12, tocopherols, and retinol.	Typical food for organic laying hens and whole wheat	Bovans Brown, ISA Brown, Lohmann Brown, Novogen	United Kingdom	(32)
Egg (weight and shape index), shell (L*a*b* color, weight, thickness, density, and strength), yolk (pH, color, weight, percentage, Ca, Mg, and Zn contents, presence of flesh and blood stains, and tocopherol and carotenoid contents), white (Ca, Mg, and Zn contents, and Haugh units), albumen (percentage, height, and color).	Typical food for organic laying hens	Hy-Line Brown, native Greenleg Partridge hens, Araucana hens, Polish Greenleg Partridge, Yellowleg Partridge	Poland	(33) (34) (35) (36)
Weight, diameter, width, and shape index of the egg, physical traits of the shell, yolk, and albumen.	Whole wheat, forage crops (peas and oats), and quinoa.	ISA Brown, Isa Babcock, Hy-line Brown, Lohmann Brown, Hellevad White	Denmark	(37) (38)
Weight, diameter, width, and shape index of the egg,	Typical food for organic	Hy-Line Brown, Hy-Line White,	Italy	(39) (40)

physical traits of the shell, yolk, albumen, approximate composition, cholesterol content, and fatty acid profile of the edible portion.	laying hens, wheat and sorghum	Ermellinata di Rovigo, Robusta maculata Gallinas Ancona	(41)

Network of authors and keywords

In the 197 scientific articles, 175 first authors and 593 co-authors were found (Figure 4). The principal authors who developed research on topics related to the diet of hens and the quality of eggs produced under a cage-free system, from 1976 to 2023, were as follows: Campbell D.L.M (3 texts) from the University of New England in Australia, who worked on topics of production and quality of eggs from free-range hens and animal welfare; Hammershøj_M (3 texts) from the Aarhus University in Denmark, who worked on issues of production and quality of organic chicken eggs using forage material in the diet of poultry; Steenfeldt_S (3 texts) from the Aarhus University in Denmark, who worked on issues of the production and quality of eggs from free-range hens and animal welfare; Bestman_M (2 texts) from the Louis Bolkn Institute in the Netherlands, who worked on animal welfare issues, and Galvao_JA (2 texts) from the Federal University of Paraná in Brazil, who worked on egg quality and food safety.

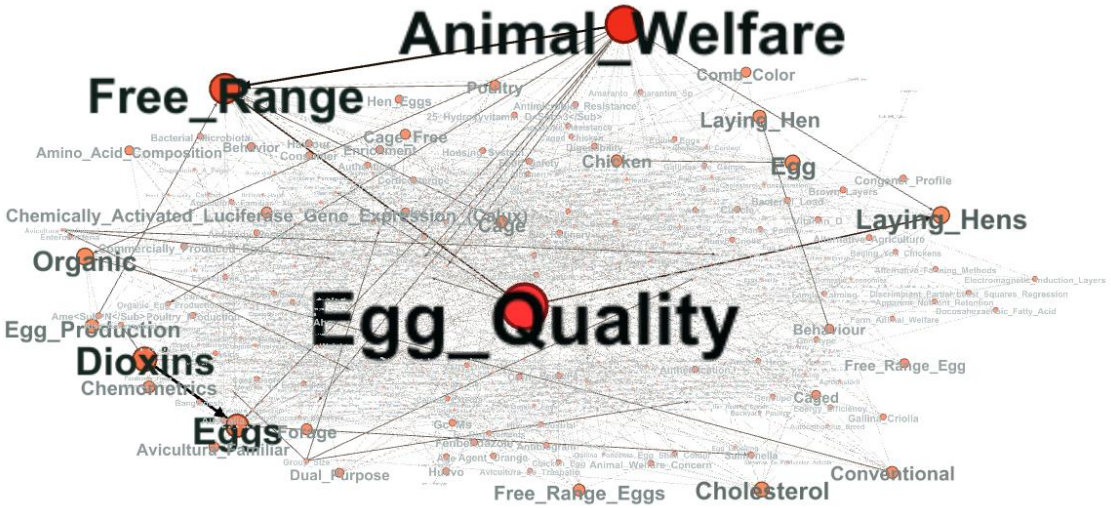
Figure 4: Worldwide network of authors and co-authors who have published papers on the diet of hens and the quality of eggs produced under cage-free systems, from 1976 to 2023. Node size corresponds to their productivity



In the keyword network, the most relevant concepts were animal welfare, egg quality, and free range. This explains why 60.41 % (119 texts) addressed topics related to organic egg

production and quality, comparisons of production systems, and animal welfare (Figure 5). The demand for eggs from cage-free hens is growing, primarily due to new consumption patterns that reward the most environmentally friendly modes of production and guarantee animal welfare[42].

Figure 5: Keyword network on topics related to the diet of hens and the quality of eggs produced under a cage-free system, from 1976 to 2023. Node size corresponds to their productivity



Analysis of alternative diets for feeding hens and the quality of eggs produced under an alternative system in Mexico

In the case of Mexico, was documented 18 scientific articles on topics related to the diet of hens and the quality of eggs produced under alternative systems. Table 3 shows the institutions with the most publications: Michoacana University of San Nicolás de Hidalgo (4 texts), where its researchers developed topics associated with egg quality, hen genetics, and backyard; Technological Institute of the Valley of Oaxaca (4 texts), where issues related to egg quality were worked on; and the Chapingo Autonomous University (3 texts), with topics on food security and economic viability of production systems.

The Rhode Island Red hen and its crosses were the most commonly used hen breeds in small-scale alternative egg production research. In developing countries, the vast majority of rural households own small flocks of poultry (mainly chickens) that are partially fed on kitchen waste, which often contribute significantly to poverty alleviation and improved household food security; hens usually have access to foraging where they consume grasses, purslane, and broadleaf plants[43].

The leading local resource that was used as a source of energy was corn. Nonetheless, several plants with considerable levels of protein were also used, such as alfalfa (*Medicago sativa*), white leadtree (*Leucaena leucocephala*), peanuts (*Arachis hypogaea*), beans (*Phaseolus vulgaris* L.), and amaranth (*Amaranthus* spp.). Some plants with antiparasitic properties have been included in the diet, such as epazote (*Dysphania ambrosioides*). Four studies were conducted in the southeast of Mexico, five in the center-west, and six in the center of the country, indicating more studies in the latter region of Mexico. The centralization of research in Mexico is a factor that limits technology transfer; however, it is also an area of opportunity for the development of research in the northern and southern regions of the country[10].

According to the Secretariat of Agriculture and Rural Development, Mexico is the largest egg-consuming country; to meet this national demand, more than 3 million tonnes are produced annually, which places Mexico as the fourth largest egg producer in the world; this production includes a large number of small-scale and medium-scale producers engaged in backyard poultry farming[44].

The development of traditional and alternative poultry farming is limited by many factors, with the hen's diet among the most important. Figure 6 shows a network of words of the most commonly used diet inputs in alternative poultry farming practiced in Mexico, where corn (7 texts) and wheat (5 texts) stand out as the primary inputs that are incorporated into the diet of poultry. This fact implies an area of opportunity to research the use of local resources that provide protein and energy.

Figure 6: Word network of ingredients used in the diet of hens under cage-free systems in Mexico, from 1976 to 2023. Node size corresponds to their frequency

Network built with the words in the original language of the publication.

Conclusions and implications

Global overview

A total of 197 scientific papers on the diet of hens and the quality of eggs produced under cage-free systems were published from 1976 to 2023. Between 2015 and 2022, 119 articles were published (60.04 % of the total), indicating a notable increase in scientific production. This growth was reflected in an exponential trend in the frequency of publications (R^2= 0.8137), coinciding with the ban on traditional cages in Europe. Six countries contributed 49.75 % of the global scientific production: Australia (30 papers, 15.23 %), Mexico (18, 9.14 %), the United Kingdom (16, 8.12 %), Poland (13, 6.60 %), Denmark (12, 6.09 %), and Italy (9, 4.57 %). The research was mainly concentrated in Europe and Australia, suggesting an opportunity to expand research in tropical countries.

Eighty point seven one percent (159) of the articles analyzed addressed issues associated with egg quality (23.86 %, 47 texts), production systems (21.32 %, 42), food safety (16.24 %, 32), animal welfare (10.15 %, 20), and hen diets (9.14 %, 18). The most studied hen genotypes were Hy-Line Brown (Australia, Denmark, and Italy), ISA Brown (Australia and Denmark), and Lohmann Brown (Australia and Denmark). Regarding the quality indicators, the most analyzed variables were egg (weight and longitudinal and transverse diameters), shell (weight, thickness, and index), yolk (pH, weight, diameter, height, and pigmentation), and white (pH, weight, diameter, height, and Haugh units). Most diets included grasses among their ingredients, with corn standing out in the Americas, and wheat and sorghum standing out in Europe and Oceania.

Therefore, this research can help to expand the state of the art of a topic with recent commercial value, such as the diet of hens and the quality of eggs produced under cage-free systems, which also represents an area of opportunity for the development of new research aimed at the genetic improvement of hens and the relationship of egg quality in the food sovereignty of developing countries. Nevertheless, the theoretical nature of the findings must be considered, so it is suggested that subsequent studies focus on the practical application of the scientific findings in food sovereignty and the sustainability of alternative systems.

Outlook in Mexico

Eighteen scientific articles on the subject were published in Mexico. The most studied types of hens were Rhode Island Red and its crosses, fed with combinations of grasses, broadleaf plants, kitchen waste, and commercial feed, with corn and wheat as the primary source of energy, suggesting opportunities to investigate the use of local resources that provide protein

and energy, especially in the north and south of the country, since the research that has been carried out was concentrated in regions of central Mexico.

Acknowledgements and conflict of interest

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Table 3: List of institutions in Mexico that published scientific articles related to the topics of breeds or genetic lines, diets, and quality indicators of eggs produced under cage-free systems, from 1973 to 2023

Institution	Articles	Breed/genetic line	Topic	Diet	Parameters*	Region	Ref.
UMSNH	4	NS	Backyard	NS	Egg, shell, white, and yolk	Michoacán	(29)
		NS	Genetics	NS	NS	Michoacán	(45)
		NS	Backyard	NS	NS	Michoacán	(46)
		NS	Quality	NS	Egg, shell, white, and yolk	Michoacán	(47)
UADY	1	NS	Backyard	NS	NS	Yucatán	(48)
UNAM	2	Rhode Island Red, Playmouth Rock Barrada	Backyard	Corn	NS	Puebla	(31)
		Leghorn	Quality	NS	Shell and white	State of México	(49)
UACh	3	NS	FS	NS	NS	Guerrero	(50)
		NS	EV	NS	NS	State of México	(43)
		Rhode Island Red Barred Plymouth Rock	Nutrition	Corn, beans, white leadtree, and peanuts	Egg	State of México	(51)
ITVO	4	NS	Consumer	NS	NS	Puebla	(42)
		INPEMA-Plymouth, Plymouth, Harco, and Tetra sl	Quality	Forage	shell, yolk, and white	Oaxaca	(30)
		NS	Nutrition	Corn	NS	Oaxaca	(22)
		Rhode Island Red Native hen cross	Quality	Corn, alfalfa, and purslane	NS	Oaxaca	(52)
COLPOS	2	Rhode Island-Araucana	Production	Weeds, grasses, and	NS	Veracruz	(53)

				broadleaf plants			
		NS	Backyard	NS	NS	Campeche	(54)
UMAR	1	NS	Nutrition	Amaranth, epazote, white leadtree, and purslane	NS	Oaxaca	(55)
UPFIM	1	Tufted Creole Hens, Marans Hens	Quality	Commercial feed	Egg	Hidalgo	(56)

UMSNH= Michoacana University of San Nicolás de Hidalgo; ITVO= Technological Institute of the Valley of Oaxaca; COLPOS= College of Postgraduates; UNAM= National Autonomous University of Mexico; UACh= Chapingo Autonomous University; UADY= Autonomous University of Yucatan; UMAR= University of the Sea; UPFIM= Francisco I. Madero Polytechnic University; NS= Not specified; FS= Food security; EV= Economic viability.

* Egg (weight and longitudinal and transverse diameters), shell (weight, thickness, and index), yolk (pH, weight, diameter, height, and pigmentation), and white (pH, weight, diameter, height, and Haugh units).