

Bibliometric mapping of genotype × environment interaction in production animals

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ABSTRACT - The objective was to explore publications on the effects of genotype × environment interaction (GEI) in livestock farming. The dataset used for this analysis came from the Web of Science (WOS) database, and the search was carried out from the first article identified in the WOS database until the search date (August 17, 2023). A set of minimum parameters was defined, and then the data was processed using the VOSviewer® software. To generate visual representations in VOSviewer, fractional counting was used, in which the contribution of each article is divided proportionally based on the number of co-authors. Consequently, if an article has three authors, the weight of each author is calculated as 1/3. Brazil and the United States lead research on GEI, while India, China, and Uruguay are emerging countries on the subject. The most cited journals on GEI include the *Journal of Animal Science*, *Journal of Dairy Science*, *Animal*, *Livestock Science*, *Journal of Animal Breeding and Genetics*, and *Revista Brasileira de Zootecnia*. In Brazil, the research groups are at the forefront of publications related to GEI. Ongoing climate changes over the years have likely led to further investigations into this matter. In the Brazilian context, research groups from the São Paulo State University (UNESP), College of Agricultural and Veterinary Sciences - Jaboticabal, and the Faculty of Veterinary Medicine and Animal Science at the University of São Paulo (FZEA/USP, Campus Pirassununga) have played a prominent role in advancing this area of study. Furthermore, our bibliometric analysis revealed future trends in GEI publications, including an increasing integration of genomic information into research.

Keywords: beef cattle, climate challenges, cluster analysis, dairy cattle, timeline

1. Introduction

The majority of economically significant traits are under the influence of genetic and environmental factors, as well as the interaction between the two (Hay and Roberts, 2018). Genotype × environment interaction (GEI) constitutes a complex system that presents challenges for advancing genetics in livestock animals (Araújo et al., 2022). However, despite the potential influence of GEI on animal performance, most selection programs in Brazil do not incorporate this factor into their evaluations (de Paula Freitas et al., 2021). Neglecting GEI in selection makes it challenging to select animals that exhibit plasticity in the face of differing climatic challenges (Tiezzi et al., 2017).

Bibliometric analysis is a statistical methodology that permits the quantitative examination of studies within a specific domain (Chen et al., 2014). It enables the establishment of connections between research articles and topics (McManus et al., 2023a), provides information on the evolution and changes in a field of study (Yu et al., 2020), and aids in determining the origins of key concepts (Fellnhöfer, 2019). As such, this analysis facilitates the understanding of the diverse areas of research including GEI and the identification of the main research groups and publications within the field.

VOSviewer®, a tool for conducting bibliometric analysis, allows users to create and explore network-based maps. It facilitates the examination of co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation links (Westby, 2021).

In the literature, several studies have employed literature mapping to investigate the areas of animal genetic resources and their response to climate change (Vieira and McManus, 2023), as well as heat tolerance in production animals (McManus et al., 2023a). However, there is a noticeable gap in research addressing GEI in livestock animals.

Given the significance of accounting for GEI effect on animal performance and its impact on the proper selection of breeding stock, this study identified the principal countries and research groups focused on the subject. Additionally, it highlighted novel methodologies employed in GEI research. Therefore, the objectives were to unveil research trends through publications addressing GEI in production animals and to elucidate the strengths and weaknesses of research conducted in this area.

2. Material and Methods

In examining the global literature concerning GEI in production animals (cattle, sheep, goats, pigs, and poultry), we utilized the Web of Science database, renowned for its extensive publication coverage (Singh et al., 2020). The search on Web of Science incorporated criteria such as year of publication, language, journal, title, author, affiliation, keywords, document type, abstract, and citations. These data were exported in comma-separated values (CSV) format to Microsoft Excel, with information retrieval completed on August 17, 2023.

A set of minimum parameters was defined (Table 1). Following this, the data underwent processing via VOSviewer® software (version 1.6.15) (Van Eck and Waltman, 2020) to generate the figures and

Table 1- Bibliometric parameters for publications on genotype × environment interaction in farm animals

	Total	Minimum number of papers or citations	After minimum applied ¹	Linked ²	Number of clusters ³
Co-authors	1,326	2	283	136	7
Countries	50	3	28	83	6
Keywords	715	3	103	388	12
	715	5	52	201	6
Citation - documents	415	10	189	443	13
Sources	76	3	27	131	7
Authors	1,382	3	112	1,197	9
Countries	50	3	28	218	5
Bibliometric coupling	415	15	142	1,967	11
Sources	76	3	27	320	6
Authors	1,382	3	112	3,364	14
Countries	50	3	28	378	6
Co-citation - references	9,106	20	23	219	4
Sources	2,738	20	76	2,296	7
Authors	5,421	20	77	71	4

¹ Number of authors, countries, keywords etc, after applying for the minimum number from the previous column.

² Number of authors, countries, and keywords with linkages to others in the analysis.

³ Total number of clusters formed per the criteria defined in the analysis.

tables featured in this study. The choice of VOSviewer was justified by its user-friendly interface, high-quality graphics, and seamless integration with the Web of Science database (Westby, 2021). In generating the visual representations in VOSviewer, fractional counting was employed, wherein the contribution of each article is divided proportionally based on the number of co-authors (Martínez-López et al., 2020). Consequently, if an article has three authors, each author's weight is calculated as 1/3 (Perianes-Rodriguez et al., 2016). This methodology results in the creation of networks illustrating co-authorship, keyword co-occurrence, citation relationships, bibliographic coupling, and co-citation (Van Eck and Waltman, 2020).

Co-authorship analysis took into account the number of co-authors in articles found on Web of Science, their countries, affiliations, and the link between them (McManus et al., 2023b). This approach visualizes outcomes as a collaborative network image, highlighting the academic frequencies of authors and countries (Shah et al., 2020), with cluster size representing the relevance of the author of the article and its country of origin. Keyword co-occurrence analysis, as specified by the authors, is represented as nodes, and each instance of co-occurrence is depicted as a link (Radhakrishnan et al., 2017).

Citation analysis was conducted based on documents (articles), sources (journals), authorship, and the countries of origin of articles. This analysis discerns the link between variables, in which one entity cites the other (McManus et al., 2023b). A higher frequency of citation of information (documents, sources, authors, and countries of origin) signifies its greater importance for science (Small, 2003).

Bibliographic coupling identifies documents (articles), sources (journals), references, and countries addressing the subject matter, gauging the similarity between two documents based on the number of shared references or the extent to which two documents are interconnected via their bibliographies or reference lists (Maseda et al., 2022). Co-citation analysis, in turn, ascertains the extent to which two or more documents are frequently cited together in other scientific articles. This method allows for the identification of influential articles and researchers in a given research area (Mas-Tur et al., 2021).

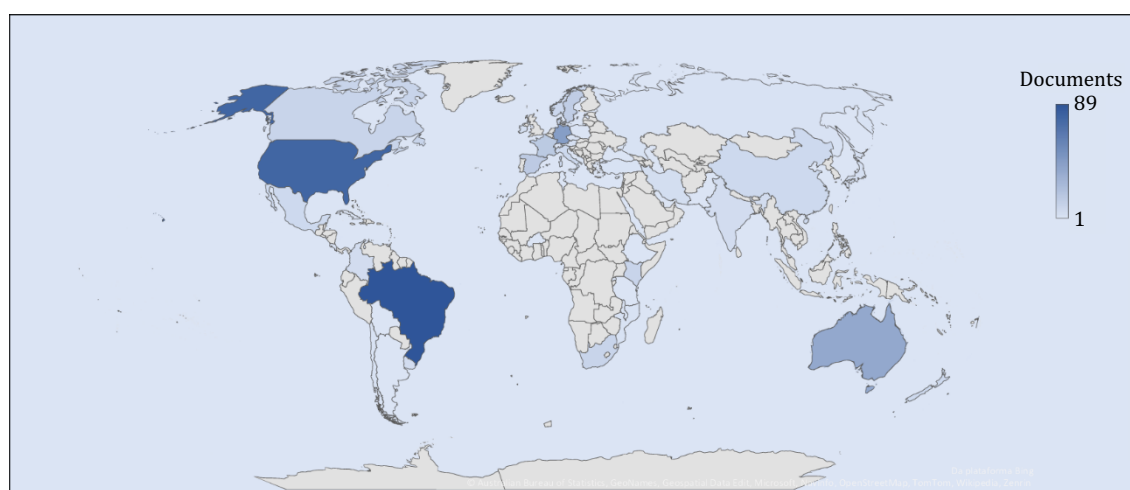
Larger clusters indicate a greater contribution of information (author, country of origin of the article, source [journal], keywords, document [article], and reference). Additionally, if the color of the connection between words is more vibrant, it means that the information appears more frequently in various documents. If the connection is small, the color will be less vibrant (Bilad, 2022). Furthermore, we can identify the evolution of information over the years and its future trends (Ding and Yang, 2022).

3. Results

The countries with over 20 documents were Brazil (89 articles), the United States (79 articles), Germany (45 articles), Australia (38 articles), The Netherlands (28 articles), and Scotland (23 articles) (Figure 1).

Most of the published documents on GEI demonstrate a concentration in the bovine species (Figure 2A). The earliest recorded published article in the database dates back to 1952 (Figure 2B). There was a significant increase in publications from 2000 to 2022. The year with the highest number of publications in the field was 2020, with 26 documents, followed by 2021 with 24 publications.

The majority of documents (Figure 3A) consists of scientific articles published in journals (88.94%), followed by review articles (4.94%), simple and expanded abstracts published in conference proceedings (3.29%), conference papers (2.35%), and books (0.47%). The three primary areas of knowledge (Figure 3B) that we identified are Agriculture (67.86%), Veterinary Science (13.57%), and Food Science and Technology (9.64%).



Color darkness for a country indicates progressively larger numbers of publications in Web of Science.

Figure 1 - Heat map by country of papers focusing upon genotype × environment interaction in farm animals.

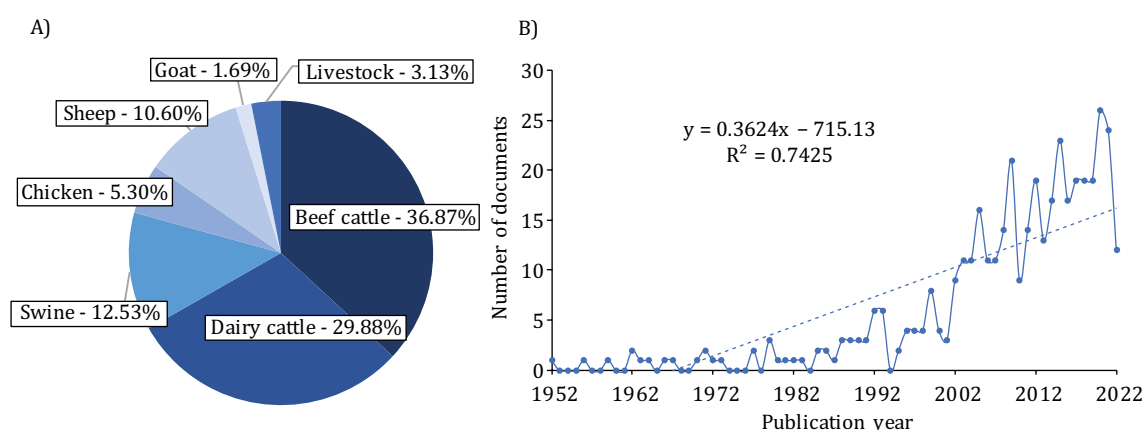


Figure 2 - Animal species used in genotype × environment interaction studies (A) and number of documents published per year from 1952 to 2022 (B).

The three most prominent institutions (Figure 3C) in this field are Brazilian, including the Brazilian Agricultural Research Corporation (EMBRAPA), Wageningen University Research, and São Paulo State University (UNESP). The leading Brazilian funding bodies (Figure 3D) include the National Council for Scientific and Technological Development (CNPq), linked to the Ministry of Science and Technology; the Coordination for the Improvement of Higher Education Personnel (CAPES), linked to the Ministry of Education; and the São Paulo Research Foundation (FAPESP).

According to the parameters we retrieved from the article in Web of Science (Table 1), 1,326 authors were identified. Of these, approximately 283 authors had at least two published documents in this area. Among the 50 countries with publications, only 28 had at least three publications. Of the 715 keywords, 103 were repeated at least three times, and 52 were repeated at least five times in publications. The most frequently used keywords include “genotype-environment interaction” (101 repetitions), “beef cattle” (47 repetitions), “dairy cattle” (47 repetitions), and “reaction norm model” or “reaction norms” (38 repetitions).

However, based on the timeline (Figure 4), as of 2020 (yellow cluster), words such as “environmental gradients”, “heat stress”, “thermoregulation”, “Genome-Wide Association Studies” (GWAS), and “SNP” (Single Nucleotide Polymorphism) gain increased prominence.

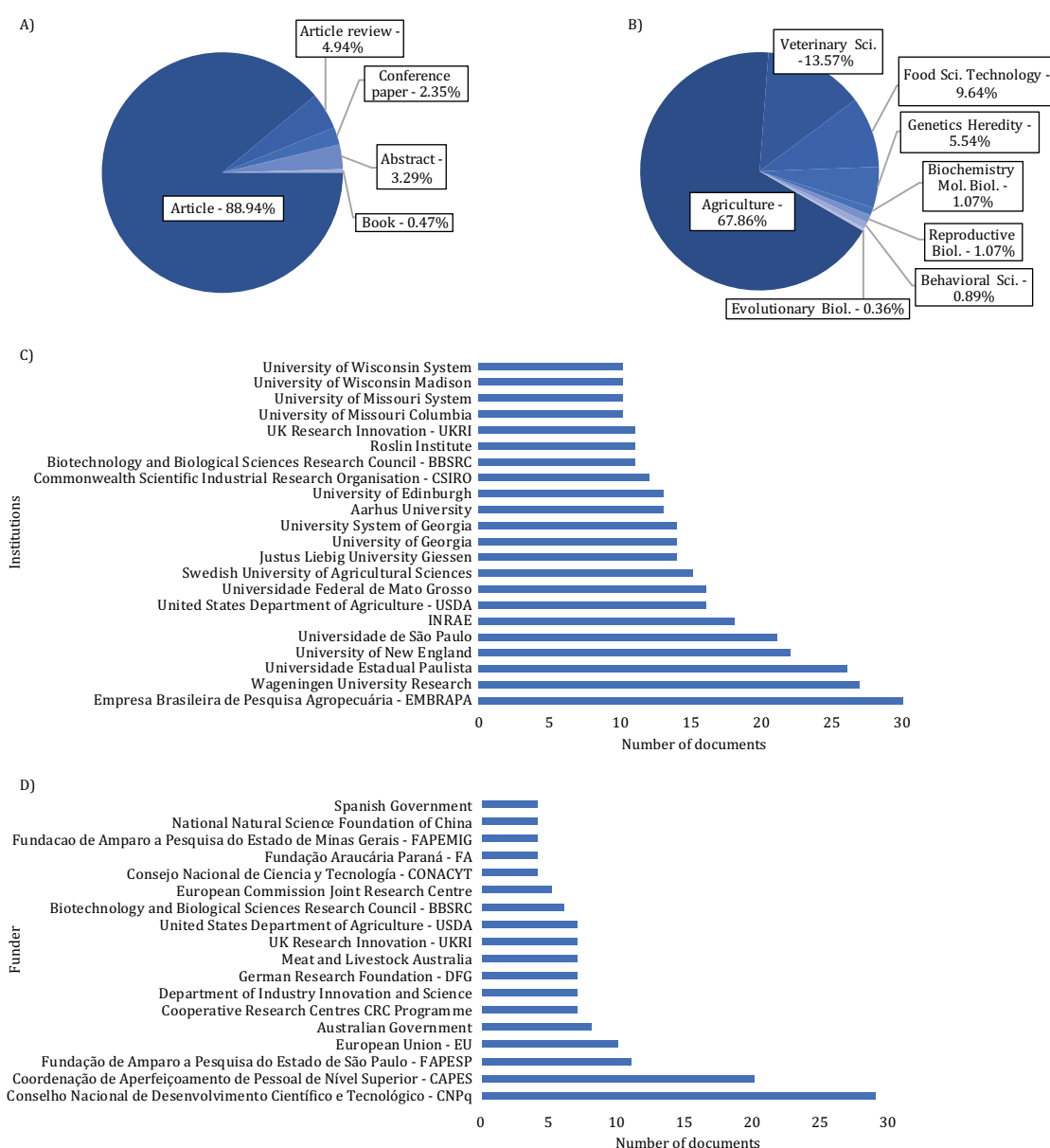


Figure 3 - Type of document (A), area of knowledge (B), top institutions (C), and financing agencies (D) in genotype × environment interaction in farm animals.

In co-authorship analysis (Figure 4), we identified the formation of clusters for authors (seven clusters), countries (six clusters), and keywords (12 clusters). Different cluster sizes correspond to the relevance of the information. Furthermore, the timeline provides information on the average year of publications, with darker colors indicating older publications and lighter colors representing more recent publications. In the list of the main authors and their countries of origin (Table 2 and Figure 4), we observed a predominance of authors from Brazil, the USA, and the Netherlands, with 12, five, and three authors, respectively.

Despite the prolific production of works in Brazil on this topic, the works of Brazilian researchers are not among the most cited (Figure 5). The paper with the highest number of citations is by Warner et al. (2010) from Australia (Figure 5 and Table 3), a review work in which the researcher gathered articles that analyzed and identified the effects of GEI on meat quality traits in beef cattle. The second most cited article is by Kolmodin et al. (2002) from Sweden, who evaluated the magnitude of GEI for milk protein

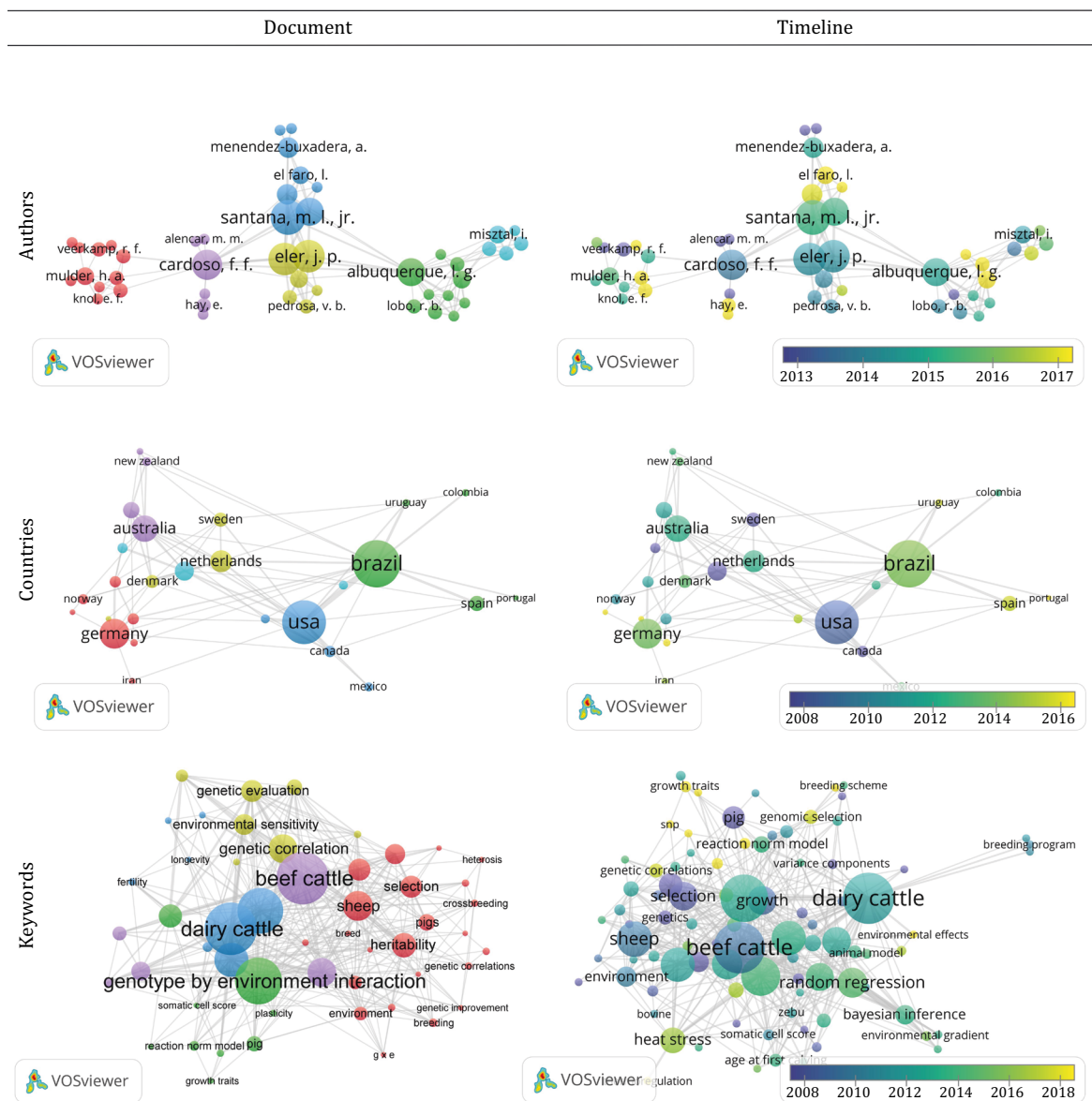


Figure 4- Publication parameters for co-authorship in publications on genotype $\times$ environment interaction in farm animals.

production traits and fertility traits (service period) in Nordic Red cattle using reaction norms. Several factors can influence the citation of an article, including its age (more than 20 years since first publication), the species studied (dairy cows), and, most importantly, the methodology used for the analyses.

The top six journals with the highest number of citations on the effects of GEI are: the Journal of Animal Science (81 documents with 1,190 citations), Journal of Dairy Science (50 documents with 1,814 citations), Animal (27 documents with 491 citations), Livestock Science (25 documents with 234 citations), Journal of Animal Breeding and Genetics (16 documents with 167 citations), and Revista Brasileira de Zootecnia (15 documents with 168 citations) (Figure 5).

In bibliographic coupling (Table 4 and Figure 6), the article with the highest total link strength is by Cardoso and Tempelman (2012), followed by Streit et al. (2012). In the article by Cardoso and Tempelman (2012) the authors evaluated alternative reaction norm models for the genetic evaluation of Angus cattle in Brazil. This article was published in the Journal of Animal Science, which has an impact factor of 3.338. The article by Streit et al. (2012), published in the Journal of Animal Breeding

Table 2 - Top 20 authors for publications on genotype × environment interaction in farm animals

Author	Country	Cluster	Links	Total link strength	Docs	Cites	Normalized citations	Publication year	Avg. citations	Avg. normalized citations
Cardoso, F. F.	Brazil (1)	4	14	8	9	194	11.63	2013	21.56	1.29
Albuquerque, L. G.	Brazil (02)	2	19	8	8	130	10.93	2014	16.25	1.37
Santana Jr, M. L.	Brazil (03)	6	10	11	11	139	10.13	2015	12.64	0.92
Misztal, I.	USA (01)	5	7	4	4	101	9.26	2014	25.25	2.32
Mulder, H. A.	The Netherlands (01)	1	7	4	4	68	8.16	2015	17.00	2.04
Lopes, P. S.	Brazil (04)	1	6	3	3	54	7.72	2017	18.00	2.58
Silva, F. F.	Brazil (05)	1	6	3	3	54	7.72	2017	18.00	2.58
KnoI, E. F.	The Netherlands 4(02)	1	4	2	2	54	7.33	2015	27.00	3.67
Mathur, P. K.	The Netherlands (03)	1	4	2	2	54	7.33	2015	27.00	3.67
Tsuruta, S.	USA (02)	5	7	3	3	78	7.26	2013	26.00	2.42
Bignardi, A. B.	Brazil (06)	6	9	8	8	102	7.19	2015	12.75	0.90
Lourenço, D. A. L.	USA (03)	5	7	3	3	59	6.72	2016	19.67	2.24
Baldi, F.	Brazil (07)	2	11	4	4	64	6.63	2017	16.00	1.66
Eler, J. P.	Brazil (08)	3	10	10	10	86	6.59	2014	8.60	0.66
Ferraz, J. B. S.	Brazil (09)	3	10	10	10	86	6.59	2014	8.60	0.66
Carvalho, R.	Brazil (10)	2	11	3	3	54	6.08	2017	18.00	2.03
Tempelman, R. J.	USA (04)	1	5	3	3	105	5.99	2015	35.00	2.00
Pereira, R. J.	Brazil (11)	6	10	5	5	66	4.70	2016	13.20	0.94
El Faro, L.	Brazil (12)	6	5	4	4	67	4.58	2017	16.75	1.15
De Los Campos, G.	USA (05)	1	2	1	2	60	4.47	2017	30.00	2.24

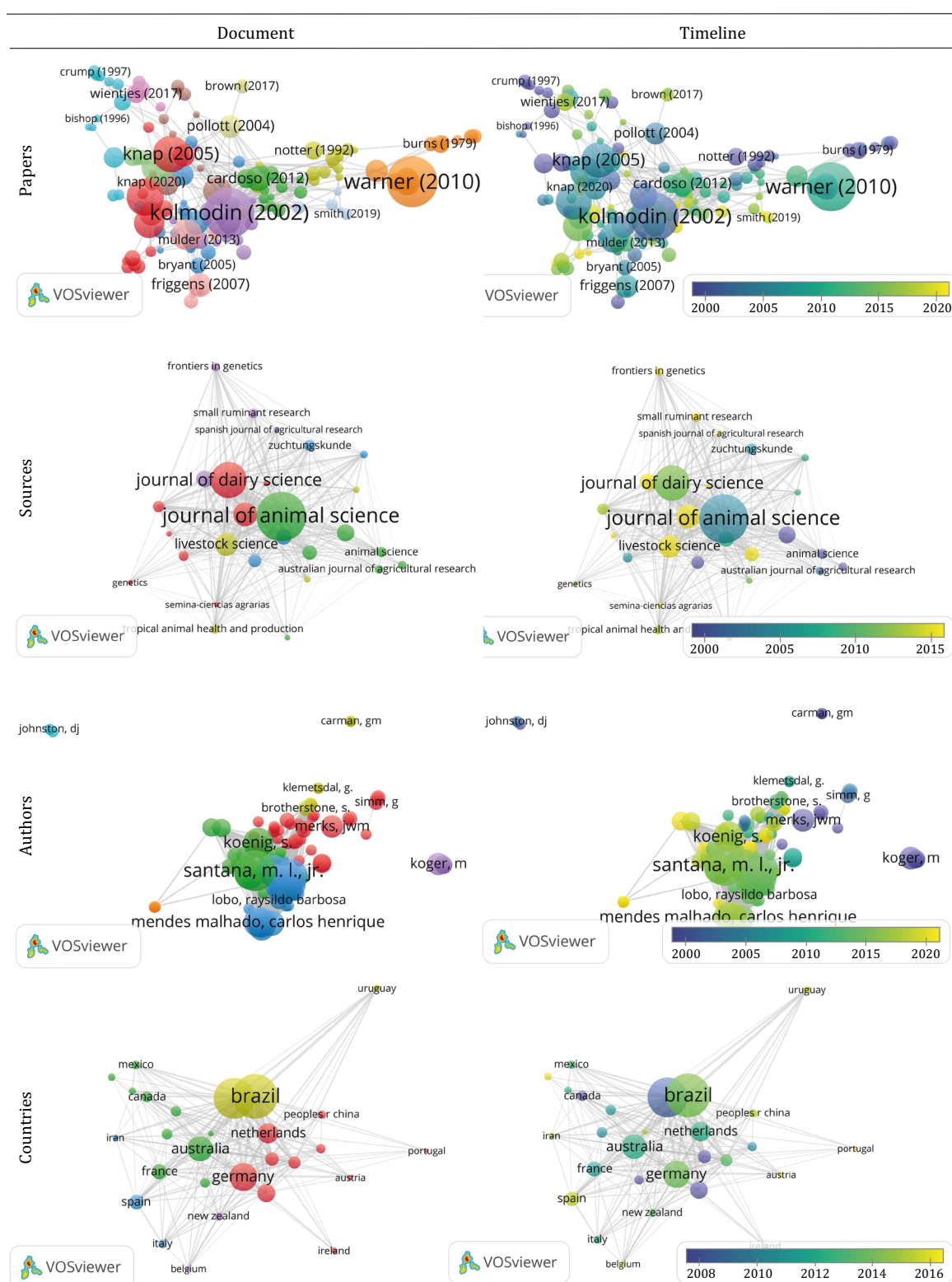


Figure 5 - Citation analysis for publications on genotype $\times$ environment interaction in farm animals.

and Genetics with an impact factor of 2.6, addressed random reaction norm regression models to identify the occurrence of GEI on productive traits (milk, protein, and fat production) and health traits (somatic cell score) in Holstein cattle in Germany. However, the Journal of Dairy Science was the most cited source in this area. The coupling of countries (Figure 5) is generally defined by the

Table 3 - Top cited papers of publications on genotype × environment interaction in farm animals

Reference	DOI	Cluster	Link	Citation	Normalized citation
Warner et al. (2010)	https://doi.org/10.1016/j.meatsci.2010.04.042	7	2	187	5.29
Kolmodin et al. (2002)	https://doi.org/10.1080/09064700252806380	5	37	184	3.81
Finocchiaro et al. (2005)	https://doi.org/10.3168/jds.s0022-0302(05)72860-5	1	3	117	3.14
Knap (2005)	https://doi.org/10.1071/ea05041	1	10	114	3.06
Mulder et al. (2006)	https://doi.org/10.3168/jds.s0022-0302(06)72242-1	11	16	94	1.45
Windig et al. (2006)	https://doi.org/10.3168/jds.s0022-0302(06)72245-7	10	12	89	1.37
Hammami et al. (2015)	https://doi.org/10.3168/jds.2014-9148	1	5	87	4.76
Calus et al. (2002)	https://doi.org/10.3168/jds.s0022-0302(02)74399-3	8	18	79	1.83
Cardoso and Tempelman (2012)	https://doi.org/10.2527/jas.2011-4333	2	31	66	2.88
Johnston et al. (2003)	https://doi.org/10.1071/ar02087	7	4	66	1.95

Table 4 - Top 10 papers in bibliographic coupling for publications on genotype × environment interaction in farm animals

Document	DOI	Cluster	Link	Total link strength	Citation	Normalized citation
Cardoso and Tempelman (2012)	https://doi.org/10.2527/jas.2011-4333	1	84	38	66	2.89
Streit et al. (2012)	https://doi.org/10.1111/j.1439-0388.2012.00999.x	1	62	38	15	1.13
Bryant et al. (2005)	https://doi.org/10.1016/j.agry.2004.09.004	1	49	33	34	0.91
Santana Jr et al. (2013)	https://doi.org/10.1017/s175173112001711	1	57	29	35	2.65
Carvalho et al. (2019)	https://doi.org/10.1186/s12711-019-0470-x	4	50	27	25	3.02
Mulder et al. (2006)	https://doi.org/10.3168/jds.s0022-0302(06)72242-1	2	57	26	94	2.74
Mattar et al. (2011)	https://doi.org/10.2527/jas.2010-3770	1	44	26	46	1.46
Mulder and Bijma (2006)	https://doi.org/10.3168/jds.s0022-0302(06)72241-x	2	45	26	30	0.46
Kolmodin et al. (2002)	https://doi.org/10.1080/09064700252806380	2	52	25	184	3.82
Tiezzi et al. (2017)	https://doi.org/10.3168/jds.2016-11543	4	61	25	37	2.76

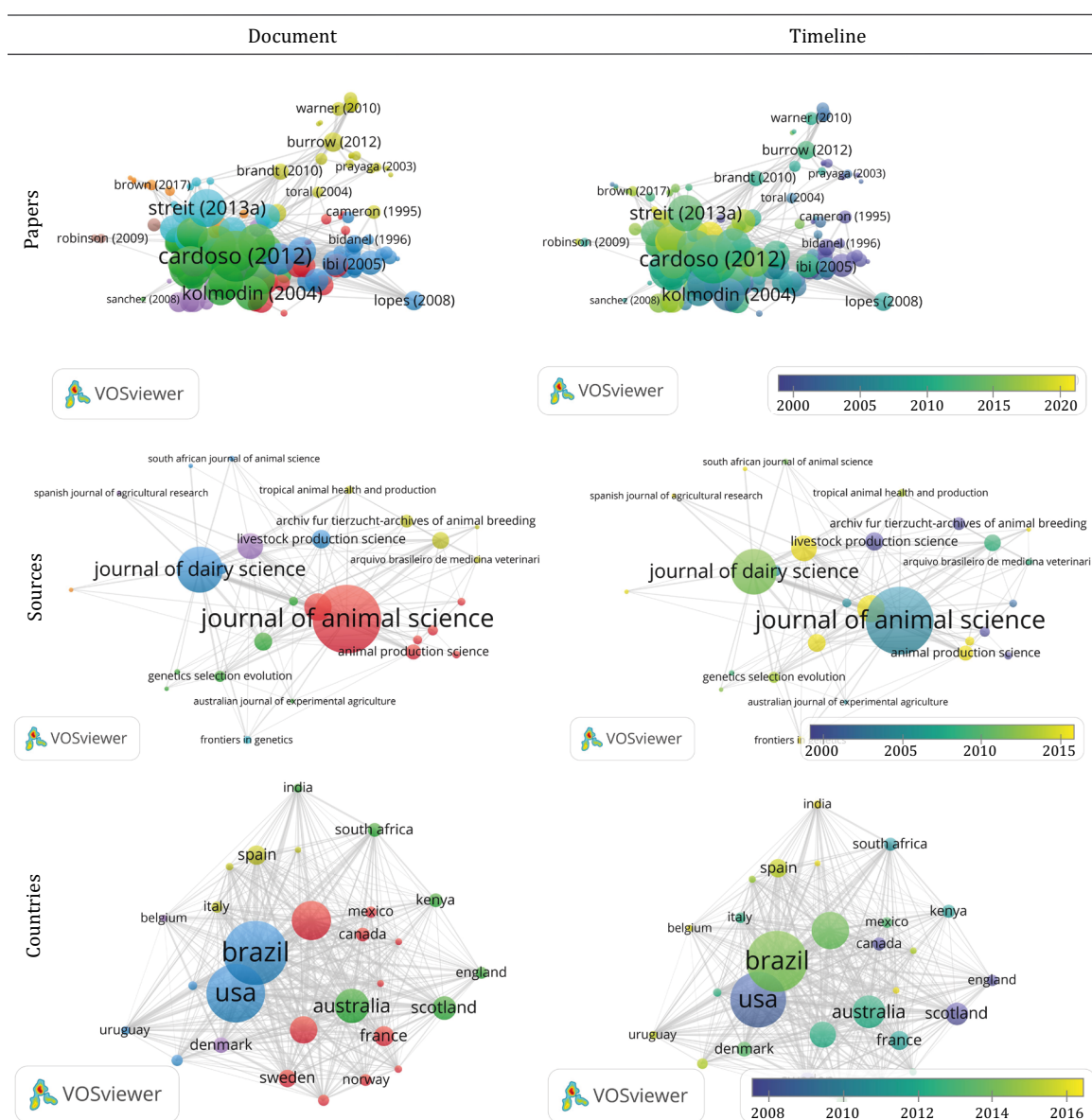


Figure 6 - Bibliographic coupling analysis for publications on genotype × environment interaction in farm animals.

researcher's country, with Brazil and the USA being the most prominent. Nevertheless, as indicated by the timeline, Uruguay, Portugal, China, Belgium, India, and Spain are becoming increasingly significant with recent publications in this field.

Among the 10 most cited references (Table 5), classified by the strength of the link based on the number of co-citations, the oldest is authored by Robertson (1959), and the most recent is by Cardoso and Tempelman (2012). The article by Robertson (1959) deals with the genetic correlation coefficient to determine the presence of GEI. Cardoso and Tempelman (2012), on the other hand, evaluated alternative reaction norm models to investigate GEI. The most cited source, forming the largest cluster, is from the Journal of Dairy Science, and the most prominent author is Falconer (Figure 7).

4. Discussion

Brazil showed most studies on GEI (Figure 1). This is likely due to the country's diverse biomes, climates, and production systems (Mota et al., 2020). Moreover, Brazil is a significant importer

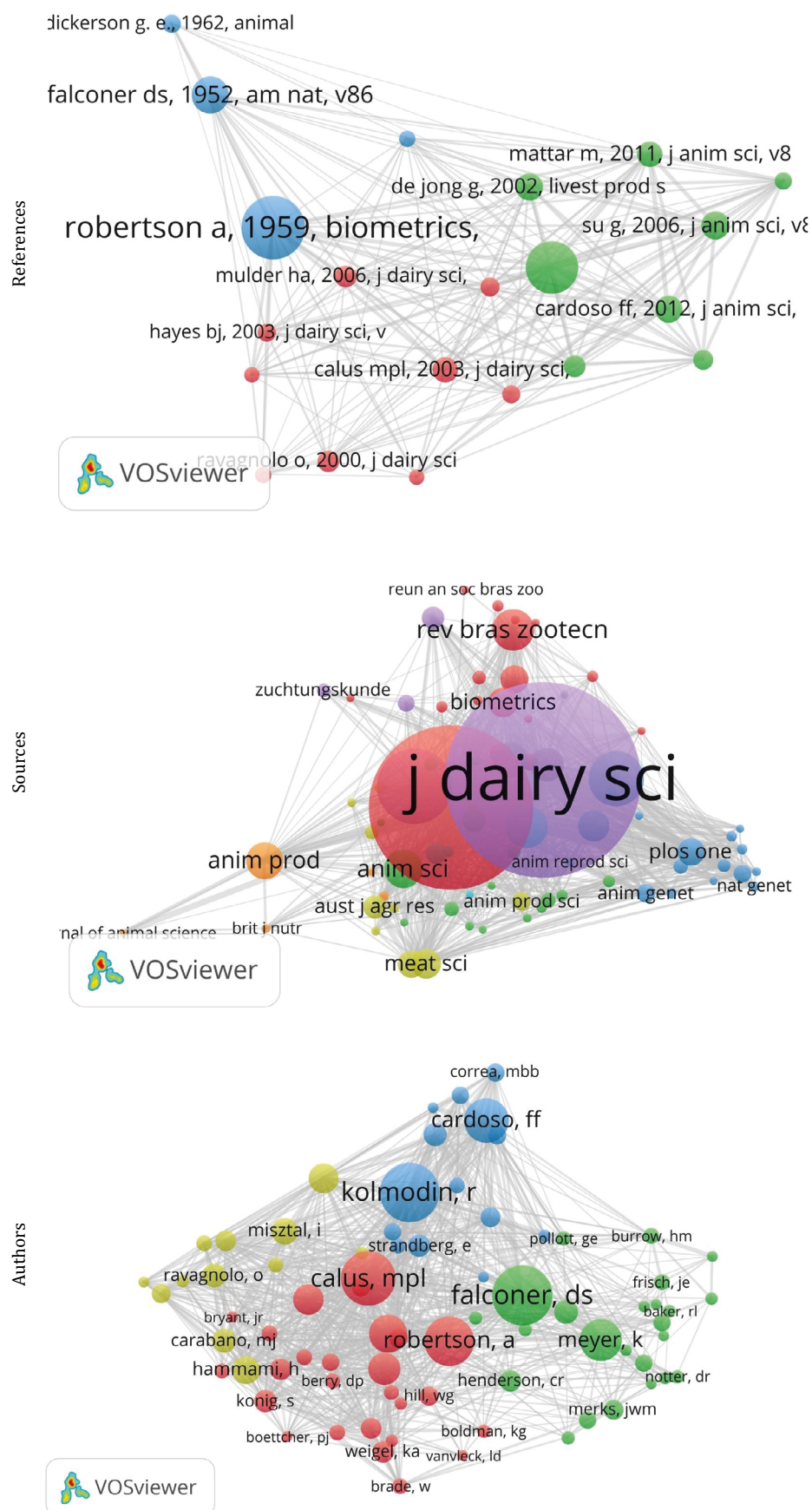


Figure 7 - Co-citation analysis for publications on genotype × environment interaction in farm animals.

Table 5 - Top co-cited documents for publications on genotype × environment interaction in farm animals

Label	DOI	Cluster	Links	Total link strength	Citations
Robertson (1959)	https://doi.org/10.2307/2527750	3	22	70	90
Kolmodin et al. (2002)	https://doi.org/10.1080/09064700252806380	1	21	69	73
Falconer and Mackay (1996)		3	21	44	51
Falconer (1952)	https://doi.org/10.1086/281736	3	21	42	50
Su et al. (2006)	https://doi.org/10.2527/jas.2005-517	1	19	37	38
De Jong and Bijma (2002)	https://doi.org/10.1016/S0301-6226(02)00096-9	1	21	34	36
Cardoso and Tempelman (2012)	https://doi.org/10.2527/jas.2011-4333	1	22	35	36
Mattar et al. (2011)	https://doi.org/10.2527/jas.2010-3770	1	21	33	34
Calus and Veerkamp (2003)	https://doi.org/10.3168/jds.S0022-0302(03)73982-4	1	20	34	34
Calus et al. (2002)	https://doi.org/10.3168/jds.S0022-0302(02)74399-3	1	20	27	29

of genetic material for production animals (Santos et al., 2020), emphasizing the importance of evaluating the performance of these selected genotypes in contrasting environments compared with those found in the country.

Additionally, among the 20 main authors engaged in GEI studies, 12 are of Brazilian origin (Table 2), underscoring the significance of the topic for the country. Moreover, most of the clusters formed (Figure 4) consist of Brazilian authors, including Albuquerque, L. G., Santana Jr, M. L., Cardoso, F. F. and Eler, J. P., who are prominent researchers in the field of animal genetic improvement. Their primary focus is on working with beef cattle, mainly Angus and Nellore breeds, widely used throughout the country, both as purebreds and crossbreds.

Institutions in Brazil are the leaders in the number of documents on this subject (Figure 3C), and the primary funding sources are organizations that promote research in the country (Figure 3D). These findings reaffirm the importance of GEI studies in Brazil, with Brazilian researchers actively contributing to the publication of documents/articles on the subject.

Most of these documents are published as scientific articles (over 88%) (Figure 3A), serving as the primary means for disseminating knowledge, ensuring accessibility to researchers globally (Canessa and Zennaro, 2008). However, various factors, such as limited access and high publication fees, especially in high-impact journals, can hinder publication or access behind paywalls. For instance, the publication fee for the Journal of Animal Science (JAS) averages US\$340 per page, that is, a 10-page article would cost a total of US\$3,400. Given the scarcity of resources for research and article publication in developing countries like Brazil, where the exchange rate is around five Brazilian Reals per US dollar, publishing in high-impact journals becomes a costly endeavor, leading many researchers to opt for local journals. Consequently, the dissemination of their content through citations is limited (McManus et al., 2020).

As regards the most repeated keywords (Figure 4), “genotype-environment interaction” takes the lead, followed by “beef cattle”, “dairy cattle”, and “reaction norm models”. In the case of cattle, concerns about the effects of GEI are more pronounced in animals raised in uncontrolled environments (Phocas et al., 2016), as controlled environments exhibit less pronounced GEI effects. Reaction norm models describe the trajectory of animal performance along environmental gradients (Falconer and Mackay, 1996), and although this knowledge is well known, the need for increased computational power to carry out these analyses limited its use until more recently.

Recent publications indicate a shift in keyword usage (Figure 4 – timeline), with increased emphasis on terms like “thermal stress”, “thermoregulation”, “environmental gradients”, and “genomics-related methodologies”. In reaction norm models, the environment is modeled as a continuous variable scale, often incorporating factors such as the temperature-humidity index and disease occurrence (Hayes et al., 2016). Novel approaches to describe the environmental gradient have emerged, including the use of previously estimated solutions from contemporary groups (Carvalho Filho et al., 2022; Nascimento et al., 2022).

Furthermore, there has been a noticeable increase in publications utilizing reaction norm models to assess GEI over the years. This applies to studies involving beef cattle (Bignardi et al., 2015; Fonseca et al., 2015; Ambrosini et al., 2016; Fennewald et al., 2017; MacNeil et al., 2017; Nascimento et al., 2022), dairy cattle (Bohlouli and Alijani, 2012; Montaldo et al., 2017; Zhang et al., 2019; Cheruiyot et al., 2020; Mulim et al., 2020, 2021; Santos et al., 2020), pigs (Camerlink et al., 2015; Hong et al., 2021), poultry (Santos et al., 2008; Felipe et al., 2012), and sheep (Wilkes et al., 2012; Hopkins and Mortimer, 2014). Notably, some more recent studies are already incorporating genomic information into reaction norm models to identify GEI (Tiezzi et al., 2017; Mota et al., 2020; Chen et al., 2021; Nascimento et al., 2022; Toro-Ospina et al., 2023).

The heterogeneity of Brazilian production systems, coupled with climate diversity and varied nutritional practices across farms, and even discrepancies between states, significantly affect the productive and reproductive performance of animals (Santos et al., 2020). Another noteworthy aspect

is the widespread utilization of genetic material from US companies, breeders' associations, and breeding programs by Brazilian breeders. Consequently, there is a pressing need to comprehend the arrangement of genotypes challenged by diverse environmental conditions to attain more efficient genetic advancement, thereby optimizing investments. Although the United States and Brazil lead in citations (Figure 5), Uruguay, Portugal, China, Belgium, India, and Spain have recently emerged with increased contributions in published papers on the topic. This underscores the growing concern about genotype behavior in the face of recurrent global climate changes, which can be attributed to the effects of global warming (Sammad et al., 2020).

The journals receiving the highest number of citations (Figure 5) in the context of GEI studies are the Journal of Animal Science and Journal of Dairy Science. Most research published in these journals is centered on studies involving cattle as the biological model, highlighting the significance of the topic for this species and its publication focus on these journals. Notably, recent citations have increasingly favored the journal Livestock Science, which has an impact factor of 1.8 and offers hybrid-access publication, making it an attractive choice for countries with limited research resources (McManus et al., 2020).

Analyzing the bibliographic coupling of countries (Figure 6), Brazil and the United States take the lead, likely owing to their vast geographical expanse and the climatic diversity they present (Beck et al., 2018). This reinforces the importance of GEI studies given the divergent environmental conditions and production systems these countries exhibit. However, in recent years, the United States has decreased its publications on the subject, while other countries, such as Germany, Spain, China, Portugal, and India, have entered this arena. Despite their smaller territorial extent, these countries still exhibit climatic diversity according to the Köppen classification (Beck et al., 2018) and are undergoing the effects of climate change. Furthermore, these countries mainly rely on genetic materials produced in the USA and Canada for dairy cattle production. In terms of bibliographic coupling, the Journal of Animal Science stands out as the most relevant journal (Figure 6) due to its long-standing adoption within the academic community and its current impact factor of 3.3.

Among the co-cited articles, high-impact journals such as Biometrics, Animal Science, Journal of Dairy Science, Journal of Animal Science, and Livestock Production Science stand out (Table 5 and Figure 7). Furthermore, the most frequently co-cited authors are Falconer and Mackay (1996) and Robertson (1959) (Table 5 and Figure 7), both affiliated with the Edinburgh quantitative genetics group (Hill and Mackay, 2004). These authors are frequently cited together in publications related to GEI. Falconer, in his two publications [Falconer and Mackay, 1996 (book) and Falconer, 1952 (article)], proposed an approach to identifying GEI by assessing the performance of a sire's daughters under different environments, effectively treating it as if they were distinct traits. This methodology allows the investigation of behavior fluctuations under changing environmental conditions. Robertson (1959) suggested that genetic correlations exceeding 0.80 indicate similarity in genotype behavior under different environments, signifying the absence of GEI. Conversely, if the genetic correlation between the performances of offspring from the same breeder, when exposed to different environments, falls below 0.80, it indicates the presence of GEI.

Lastly, it is important to acknowledge certain limitations of bibliometric mapping. Publication bias may emerge due to the reliance on published articles, potentially excluding unpublished or non-indexed studies and thus affecting the representativeness of the results (McManus et al., 2023a). Subjectivity in the study selection process, even with well-defined criteria, can introduce bias into the review. Additionally, relying on specific databases or limited sources may result in gaps in the coverage of relevant studies, as well as differences in the availability of articles in various languages.

5. Conclusions

Brazil and the United States are at the forefront of research on genotype $\times$ environment interaction. However, more recently, India, China, Uruguay, Portugal, and other nations have made scientific contributions to this topic. The ongoing climate changes over the years have likely driven new

investigations into this subject. In the Brazilian context, research groups at São Paulo State University (UNESP), School of Agricultural and Veterinary Sciences - Jaboticabal, and the Faculty of Veterinary Medicine and Animal Science of the University of São Paulo (FZEA/USP, Pirassununga Campus) have played prominent roles in advancing this area of study. Moreover, our bibliometric analysis has revealed forthcoming trends in genotype × environment interaction publications, including a growing integration of genomic information into research endeavors.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: Martins, R.; Padilha, D. A. O.; McManus, C. and Dias, L. T. **Data curation:** Martins, R. and McManus, C. **Formal analysis:** Martins, R. and Padilha, D. A. O. **Investigation:** Martins, R. and Padilha, D. A. O. **Methodology:** Martins, R.; Padilha, D. A. O.; McManus, C. and Dias, L. T. **Resources:** Martins, R.; Padilha, D. A. O.; Padilha, S. F.; Pedro, A. E. and McManus, C. **Supervision:** McManus, C.; Albuquerque, L. G.; Teixeira, R. A. and Dias, L. T. **Visualization:** McManus, C. **Writing – original draft:** Martins, R.; Padilha, D. A. O.; Padilha, S. F. and Pedro, A. E. **Writing – review & editing:** McManus, C.; Albuquerque, L. G.; Teixeira, R. A. and Dias, L. T.

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References

- Ambrosini, D. P.; Malhado, C. H. M.; Martins Filho, R.; Cardoso, F. F. and Carneiro, P. L. S. 2016. Genotype × environment interactions in reproductive traits of Nellore cattle in northeastern Brazil. *Tropical Animal Health and Production* 48:1401-1407. <https://doi.org/10.1007/s11250-016-1105-7>
- Araújo, T. L. A. C.; Feijó, G. L. D.; Neves, A. P.; Nogueira, E.; Oliveira, L. O. F.; Gomes, M. N. B.; Egito, A. A.; Ferraz, A. L. J.; Menezes, G. R. O.; Latta, K. I.; Ferreira, J. R.; Vieira, D. G.; Pereira, E. S. and Gomes, R. C. 2022. Effect of genetic merit for backfat thickness and paternal breed on performance, carcass traits, and gene expression in subcutaneous adipose tissue of feedlot-finished steers. *Livestock Science* 263:104998. <https://doi.org/10.1016/j.livsci.2022.104998>
- Beck, H. E.; Zimmermann, N. E.; McVicar, T. R.; Vergopolan, N.; Berg, A. and Wood, E. F. 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Scientific Data* 5:180214. <https://doi.org/10.1038/sdata.2018.214>
- Bignardi, A. B.; El Faro, L.; Pereira, R. J.; Ayres, D. R.; Machado, P. F.; Albuquerque, L. G. and Santana Jr., M. L. 2015. Reaction norm model to describe environmental sensitivity across first lactation in dairy cattle under tropical conditions. *Tropical Animal Health and Production* 47:1405-1410. <https://doi.org/10.1007/s11250-015-0878-4>
- Bilal, M. R. 2022. Bibliometric analysis for understanding the correlation between chemistry and special needs education using VOSviewer indexed by Google. *ASEAN Journal of Community and Special Needs Education* 1:61-68.
- Bohlouli, M. and Alijani, S. 2012. Genotype by environment interaction for milk production traits in Iranian Holstein dairy cattle using random regression model. *Livestock Research for Rural Development* 24(7).
- Bryant, J.; López-Villalobos, N.; Holmes, C. and Pryce, J. 2005. Simulation modelling of dairy cattle performance based on knowledge of genotype, environment and genotype by environment interactions: current status. *Agricultural Systems* 86:121-143. <https://doi.org/10.1016/j.agsy.2004.09.004>
- Calus, M. P. L.; Groen, A. F. and de Jong, G. 2002. Genotype x environment interaction for protein yield in Dutch dairy cattle as quantified by different models. *Journal of Dairy Science* 85:3115-3123. [https://doi.org/10.3168/jds.S0022-0302\(02\)74399-3](https://doi.org/10.3168/jds.S0022-0302(02)74399-3)
- Calus, M. P. L. and Veerkamp, R. F. 2003. Estimation of environmental sensitivity of genetic merit for milk production traits using a random regression model. *Journal of Dairy Science* 86:3756-3764. [https://doi.org/10.3168/jds.S0022-0302\(03\)73982-4](https://doi.org/10.3168/jds.S0022-0302(03)73982-4)

- Camerlink, I.; Ursinus, W. W.; Bijma, P.; Kemp, B. and Bolhuis, J. E. 2015. Indirect genetic effects for growth rate in domestic pigs alter aggressive and manipulative biting behaviour. *Behavior Genetics* 45:117-126. <https://doi.org/10.1007/s10519-014-9671-9>.
- Canessa, E. and Zennaro, M. 2008. Science dissemination using Open Access. A compendium of selected literature on Open Access. ICTP - The Abdus Salam International Centre for Theoretical Physics.
- Cardoso, F. F. and Tempelman, R. J. 2012. Linear reaction norm models for genetic merit prediction of Angus cattle under genotype by environment interaction. *Journal of Animal Science* 90:2130-2141. <https://doi.org/10.2527/jas.2011-4333>
- Carvalho, R.; Costilla, R.; Neves, H. H. R.; Albuquerque, L. G.; Moore, S. and Hayes, B. J. 2019. Unraveling genetic sensitivity of beef cattle to environmental variation under tropical conditions. *Genetics Selection Evolution* 51:29. <https://doi.org/10.1186/s12711-019-0470-x>
- Carvalho Filho, I.; Silva, D. A.; Teixeira, C. S.; Silva, T. L.; Mota, L. F. M.; Albuquerque, L. G. and Carvalho, R. 2022. Heteroscedastic reaction norm models improve the assessment of genotype by environment interaction for growth, reproductive, and visual score traits in Nellore cattle. *Animals* 12:2613. <https://doi.org/10.3390/ani12192613>
- Chen, C.; Dubin, R. and Kim, M. C. 2014. Emerging trends and new developments in regenerative medicine: A scientometric update (2000-2014). *Expert Opinion on Biological Therapy* 14:1295-1317. <https://doi.org/10.1517/14712598.2014.920813>
- Chen, S. Y.; Freitas, P. H. F.; Oliveira, H. R.; Lázaro, S. F.; Huang, Y. J.; Howard, J. T.; Gu, Y.; Schinckel, A. P. and Brito, L. F. 2021. Genotype-by-environment interactions for reproduction, body composition, and growth traits in maternal-line pigs based on single-step genomic reaction norms. *Genetics Selection Evolution* 53:51. <https://doi.org/10.1186/s12711-021-00645-y>
- Cheruiyot, E. K.; Nguyen, T. T. T.; Haile-Mariam, M.; Cocks, B. G.; Abdelsayed, M. and Pryce, J. E. 2020. Genotype-by-environment (temperature-humidity) interaction of milk production traits in Australian Holstein cattle. *Journal of Dairy Science* 103:2460-2476. <https://doi.org/10.3168/jds.2019-17609>
- De Jong, G. and Bijma, P. 2002. Selection and phenotypic plasticity in evolutionary biology and animal breeding. *Livestock Production Science* 78:195-214. [https://doi.org/10.1016/S0301-6226\(02\)00096-9](https://doi.org/10.1016/S0301-6226(02)00096-9)
- de Paula Freitas, A.; Santana Júnior, M. L.; Schenkel, F. S.; Mercadante, M. E. Z.; Cyrillo, J. N. S. G. and Paz, C. C. P. 2021. Different selection practices affect the environmental sensitivity of beef cattle. *PLoS ONE* 16:e0248186. <https://doi.org/10.1371/journal.pone.0248186>
- Ding, X. and Yang, Z. 2022. Knowledge mapping of platform research: A visual analysis using VOSviewer and CiteSpace. *Electronic Commerce Research* 22:787-809. <https://doi.org/10.1007/s10660-020-09410-7>
- Falconer, D. S. 1952. The problem of environment and selection. *The American Naturalist* 86:293-298. <https://doi.org/10.1086/281736>
- Falconer, D. S. and Mackay, T. F. C. 1996. Introduction to quantitative genetics. 4th ed. Addison Wesley Longman, Harlow.
- Felipe, V. P. S.; Silva, M. A.; Wenceslau, R. R.; Valente, B. D.; Santos, G. G.; Freitas, L. S.; Corrêa, G. S. S. and Corrêa, A. B. 2012. Utilização de modelos de norma de reação com variância residual heterogênea para estudo de valores genéticos de peso de codornas de corte em função de níveis de proteína bruta na dieta. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia* 64:991-1000. <https://doi.org/10.1590/S0102-09352012000400028>
- Fellnhöfer, K. 2019. Toward a taxonomy of entrepreneurship education research literature: A bibliometric mapping and visualization. *Educational Research Review* 27:28-55. <https://doi.org/10.1016/j.edurev.2018.10.002>
- Fennewald, D. J.; Weaber, R. L. and Lamberson, W. R. 2017. Genotype by environment interactions for growth in Red Angus. *Journal of Animal Science* 95:538-544. <https://doi.org/10.2527/jas.2016.0846>
- Finocchiaro, R.; van Kaam, J. B. C. H. M.; Portolano, B. and Misztal, I. 2005. Effect of heat stress on production of Mediterranean dairy sheep. *Journal of Dairy Science* 88:1855-1864. [https://doi.org/10.3168/jds.S0022-0302\(05\)72860-5](https://doi.org/10.3168/jds.S0022-0302(05)72860-5)
- Fonseca, W. J. L.; Fonseca, W. L.; Luz, C. S. M.; Sousa, G. G. T.; Oliveira, M. R. A.; Sousa, K. J. V.; Costa, M. B. G.; Oliveira, A. M. and de Sousa Júnior, S. C. 2015. Interaction of genotype-environment Nellore cattle using models of reaction norms. *Journal of Animal Behaviour and Biometeorology* 3:86-91.
- Hammami, H.; Vandenplas, J.; Vanrobays, M. L.; Rekik, B.; Bastin, C. and Gengler, N. 2015. Genetic analysis of heat stress effects on yield traits, udder health, and fatty acids of Walloon Holstein cows. *Journal of Dairy Science* 98:4956-4968. <https://doi.org/10.3168/jds.2014-9148>
- Hay, E. H. and Roberts, A. 2018. Genotype $\times$ prenatal and post-weaning nutritional environment interaction in a composite beef cattle breed using reaction norms and a multi-trait model. *Journal of Animal Science* 96:444-453. <https://doi.org/10.1093/jas/skx057>
- Hayes, B. J.; Daetwyler, H. D. and Goddard, M. E. 2016. Models for genome $\times$ environment interaction: Examples in livestock. *Crop Science* 56:2251-2259. <https://doi.org/10.2135/cropsci2015.07.0451>

- Hill, W. G. and Mackay, T. F. C. 2004. D. S. Falconer and introduction to quantitative genetics. *Genetics* 167:1529-1536.
- Hong, J. K.; Cho, K. H.; Kim, Y. S.; Chung, H. J.; Baek, S. Y.; Cho, E. S. and Sa, S. J. 2021. Genetic relationship between purebred and synthetic pigs for growth performance using single step method. *Animal Bioscience* 34:967-974.
- Hopkins, D. L. and Mortimer, S. I. 2014. Effect of genotype, gender and age on sheep meat quality and a case study illustrating integration of knowledge. *Meat Science* 98:544-555. <https://doi.org/10.1016/j.meatsci.2014.05.012>
- Johnston, D. J.; Reverter, A.; Ferguson, D. M.; Thompson, J. M. and Burrow, H. M. 2003. Genetic and phenotypic characterisation of animal, carcass, and meat quality traits from temperate and tropically adapted beef breeds. 3. Meat quality traits. *Australian Journal of Agricultural Research* 54:135-147. <https://doi.org/10.1071/ar02087>
- Knap, P. W. 2005. Breeding robust pigs. *Australian Journal of Experimental Agriculture* 45:763-773. <https://doi.org/10.1071/EA05041>
- Kolmodin, R.; Strandberg, E.; Madsen, P.; Jensen, J. and Jorjani, H. 2002. Genotype by environment interaction in Nordic dairy cattle studied using reaction norms. *Acta Agriculturae Scandinavica, Section A — Animal Science* 52:11-24. <https://doi.org/10.1080/09064700252806380>
- MacNeil, M. D.; Cardoso, F. F. and Hay, E. 2017. Genotype by environment interaction effects in genetic evaluation of preweaning gain for Line 1 Hereford cattle from Miles City, Montana. *Journal of Animal Science* 95:3833-3838.
- Martínez-López, F. J.; Merigó, J. M.; Gázquez-Abad, J. C. and Ruiz-Real, J. L. 2020. Industrial marketing management: Bibliometric overview since its foundation. *Industrial Marketing Management* 84:19-38. <https://doi.org/10.1016/j.indmarman.2019.07.014>
- Mas-Tur, A.; Roig-Tierno, N.; Sarin, S.; Haon, C.; Sego, T.; Belkhouja, M.; Porter, A. and Merigó, J. M. 2021. Co-citation, bibliographic coupling and leading authors, institutions and countries in the 50 years of Technological Forecasting and Social Change. *Technological Forecasting and Social Change* 165:120487. <https://doi.org/10.1016/j.techfore.2020.120487>
- Maseda, A.; Iturralde, T.; Cooper, S. and Aparicio, G. 2022. Mapping women's involvement in family firms: A review based on bibliographic coupling analysis. *International Journal of Management Reviews* 24:279-305. <https://doi.org/10.1111/ijmr.12278>
- Mattar, M.; Silva, L. O. C.; Alencar, M. M. and Cardoso, F. F. 2011. Genotype × environment interaction for long-yearling weight in Canchim cattle quantified by reaction norm analysis. *Journal of Animal Science* 89:2349-2355. <https://doi.org/10.2527/jas.2010-3770>
- McManus, C.; Pimentel, F.; Pimentel, D.; Sejian, V. and Blackburn, H. 2023a. Bibliographic mapping of heat tolerance in farm animals. *Livestock Science* 269:105163. <https://doi.org/10.1016/j.livsci.2023.105163>
- McManus, C.; Pimentel, F.; de Almeida, A. M. and Pimentel, D. 2023b. Tropical Animal Health and Production: A 55-year bibliographic analysis setting the course for a globalized international reference journal. *Tropical Animal Health and Production* 55:160. <https://doi.org/10.1007/s11250-023-03577-5>
- McManus, C. M.; Neves, A. A. B. and Maranhão, A. Q. 2020. Brazilian publication profiles: Where and how Brazilian authors publish. *Anais da Academia Brasileira de Ciências* 92:e20200328. <https://doi.org/10.1590/0001-3765202020200328>
- Montaldo, H. H.; Pelcastre-Cruz, A.; Castillo-Juárez, H.; Ruiz-López, F. J. and Miglior, F. 2017. Genotype × environment interaction for fertility and milk yield traits in Canadian, Mexican and US Holstein cattle. *Spanish Journal of Agricultural Research* 15:e0402. <https://doi.org/10.5424/sjar/2017152-10317>
- Mota, L. F. M.; Fernandes Jr, G. A.; Herrera, A. C.; Scalez, D. C. B.; Espigolan, R.; Magalhães, A. F. B.; Carvalheiro, R.; Baldi, F. and Albuquerque, L. G. 2020. Genomic reaction norm models exploiting genotype × environment interaction on sexual precocity indicator traits in Nellore cattle. *Animal Genetics* 51:210-223. <https://doi.org/10.1111/age.12902>
- Mulder, H. A. and Bijma, P. 2006. Benefits of cooperation between breeding programs in the presence of genotype by environment interaction. *Journal of Dairy Science* 89:1727-1739. [https://doi.org/10.3168/jds.S0022-0302\(06\)72241-X](https://doi.org/10.3168/jds.S0022-0302(06)72241-X)
- Mulder, H. A.; Veerkamp, R. F.; Ducro, B. J.; van Arendonk, J. A. M. and Bijma, P. 2006. Optimization of dairy cattle breeding programs for different environments with genotype by environment interaction. *Journal of Dairy Science* 89:1740-1752. [https://doi.org/10.3168/jds.S0022-0302\(06\)72242-1](https://doi.org/10.3168/jds.S0022-0302(06)72242-1)
- Mulim, H. A.; Carneiro, P. L. S.; Malhado, C. H. M.; Pinto, L. F. B.; Mourão, G. B.; Valloto, A. A. and Pedrosa, V. B. 2021. Genotype by environment interaction for fat and protein yields via reaction norms in Holstein cattle of southern Brazil. *Journal of Dairy Research* 88:16-22. <https://doi.org/10.1017/S0022029921000029>
- Mulim, H. A.; Pinto, L. F. B.; Zampar, A.; Mourão, G. B.; Valloto, A. A. and Pedrosa, V. B. 2020. Assessment of genotype by environment interaction via reaction norms for milk yield in Holstein cattle of southern Brazil. *Annals of Animal Science* 20:1101-1112. <https://doi.org/10.2478/aoas-2020-0032>
- Nascimento, B. M.; Carvalheiro, R.; Teixeira, R. A.; Dias, L. T. and Fortes, M. R. S. 2022. Weak genotype x environment interaction suggests that measuring scrotal circumference at 12 and 18 mo of age is helpful to select precocious Brahman cattle. *Journal of Animal Science* 100:1-13. <https://doi.org/10.1093/jas/skac236>
- Perianes-Rodriguez, A.; Waltman, L. and van Eck, N. J. 2016. Constructing bibliometric networks: A comparison between full and fractional counting. *Journal of Informetrics* 10:1178-1195. <https://doi.org/10.1016/j.joi.2016.10.006>

- Phocas, F.; Belloc, C.; Bidanel, J.; Delaby, L.; Dourmad, J. Y.; Dumont, B.; Ezanno, P.; Fortun-Lamothe, L.; Foucras, G.; Frappat, B.; González-García, E.; Hazard, D.; Larzul, C.; Lubac, S.; Mignon-Grasteau, S.; Moreno, C. R.; Tixier-Boichard, M. and Brochard, M. 2016. Review: Towards the agroecological management of ruminants, pigs and poultry through the development of sustainable breeding programmes: I-selection goals and criteria. *Animal* 10:1749-1759. <https://doi.org/10.1017/S1751731116000926>
- Radhakrishnan, S.; Erbis, S.; Isaacs J. A. and Kamarthi, S. 2017. Novel keyword co-occurrence network-based methods to foster systematic reviews of scientific literature. *PLoS ONE* 12:e0172778. <https://doi.org/10.1371/journal.pone.0172778>
- Robertson, A. 1959. The sampling variance of the genetic correlation coefficient. *Biometrics* 15:469-485. <https://doi.org/10.2307/2527750>
- Sammad, A.; Umer, S.; Shi, R.; Zhu, H.; Zhao, X. and Wang, Y. 2020. Dairy cow reproduction under the influence of heat stress. *Journal of Animal Physiology and Animal Nutrition* 104:978-986. <https://doi.org/10.1111/JPN.13257>
- Santana Jr, M. L.; Eler, J. P.; Cardoso, F. F.; Albuquerque, L. G. and Ferraz, J. B. S. 2013. Phenotypic plasticity of composite beef cattle performance using reaction norms model with unknown covariate. *Animal* 7:202-210. <https://doi.org/10.1017/S1751731112001711>
- Santos, G. G.; Corrêa, G. S. S.; Valente, B. D.; Silva, M. A.; Corrêa, A. B.; Felipe, V. P. S. and Wenceslau, R. R. 2008. Sensibilidade de valores genéticos de codornas de corte em crescimento às modificações de níveis de proteína das dietas. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia* 60:1188-1196. <https://doi.org/10.1590/S0102-09352008000500022>
- Santos, J. C.; Malhado, C. H. M.; Carneiro, P. L. S.; de Rezende, M. P. G. and Cobuci, J. A. 2020. Genotype-environment interaction for age at first calving in Holstein cows in Brazil. *Veterinary and Animal Science* 9:100098. <https://doi.org/10.1016/j.vas.2020.100098>
- Shah, S. H. H.; Lei, S.; Ali, M.; Doronin, D. and Hussain, S. T. 2020. Prosumption: bibliometric analysis using HistCite and VOSviewer. *Kybernetes* 49:1020-1045. <https://doi.org/10.1108/K-12-2018-0696>
- Singh, S.; Dhir, S.; Das, V. M. and Sharma, A. 2020. Bibliometric overview of the Technological Forecasting and Social Change journal: Analysis from 1970 to 2018. *Technological Forecasting and Social Change* 154:119963. <https://doi.org/10.1016/j.techfore.2020.119963>
- Small, H. 2003. Paradigms, citations, and maps of science: A personal history. *Journal of the American Society for Information Science and Technology* 54:394-399. <https://doi.org/10.1002/asi.10225>
- Streit, M.; Reinhardt, F.; Thaller, G. and Bennewitz, J. 2012. Reaction norms and genotype-by-environment interaction in the German Holstein dairy cattle. *Journal of Animal Breeding and Genetics* 129:380-389. <https://doi.org/10.1111/j.1439-0388.2012.00999.x>
- Su, G.; Madsen, P.; Lund, M. S.; Sorensen, D.; Korsgaard, I. R. and Jensen, J. 2006. Bayesian analysis of the linear reaction norm model with unknown covariates. *Journal of Animal Science* 84:1651-1657. <https://doi.org/10.2527/jas.2005-517>
- Tiezzi, F.; de los Campos, G.; Parker Gaddis, K. L. and Maltecca, C. 2017. Genotype by environment (climate) interaction improves genomic prediction for production traits in US Holstein cattle. *Journal of Dairy Science* 100:2042-2056. <https://doi.org/10.3168/jds.2016-11543>
- Toro-Ospina, A. M.; Faria, R. A.; Dominguez-Castaño, P.; Santana, M. L.; Gonzalez, L. G.; Espasandin, A. C. and Silva, J. A. II. V. 2023. Genotype-environment interaction for milk production of Gyr cattle in Brazil and Colombia. *Genes and Genomics* 45:135-143. <https://doi.org/10.1007/s13258-022-01273-6>
- Van Eck, N. J. and Waltman, L. 2020. Manual for VOSviewer version 1.6.15. Centre for Science and Technology Studies (CWTS) of Leiden University, Leiden.
- Vieira, R. A. and McManus, C. 2023. Bibliographic mapping of animal genetic resources and climate change in farm animals. *Tropical Animal Health and Production* 55:259. <https://doi.org/10.1007/s11250-023-03671-8>
- Warner, R. D.; Greenwood, P. L.; Pethick, D. W. and Ferguson, D. M. 2010. Genetic and environmental effects on meat quality. *Meat Science* 86:171-183. <https://doi.org/10.1016/j.meatsci.2010.04.042>
- Westby, C. 2021. Resource Review. *Word of Mouth* 32:10-12. <https://doi.org/10.1177/10483950211008345b>
- Wilkes, M. J.; Hynd, P. I. and Pitchford, W. S. 2012. Damara sheep have higher digestible energy intake than Merino sheep when fed low-quality or high-quality feed. *Animal Production Science* 52:30-34. <https://doi.org/10.1071/AN11033>
- Windig, J. J.; Calus, M. P. L.; Beerda, B. and Veerkamp, R. F. 2006. Genetic correlations between milk production and health and fertility depending on herd environment. *Journal of Dairy Science* 89:1765-1775. [https://doi.org/10.3168/JDS.S0022-0302\(06\)72245-7](https://doi.org/10.3168/JDS.S0022-0302(06)72245-7)
- Yu, Y.; Li, Y.; Zhang, Z.; Gu, Z.; Zhong, H.; Zha, Q.; Yang, L.; Zhu, C. and Chen, E. 2020. A bibliometric analysis using VOSviewer of publications on COVID-19. *Annals of Translational Medicine* 8:816. <https://doi.org/10.21037/atm-20-4235>
- Zhang, Z.; Kargo, M.; Liu, A.; Thomasen, J. R.; Pan, Y. and Su, G. 2019. Genotype-by-environment interaction of fertility traits in Danish Holstein cattle using a single-step genomic reaction norm model. *Heredity* 123:202-214. <https://doi.org/10.1038/s41437-019-0192-4>