

BIBLIOMETRIC ANALYSIS ON FORAGE CACTUS PRODUCTION, MANAGEMENT AND USE IN ANIMAL NUTRITION: DEVELOPMENT, CURRENT STATUS AND FUTURE RESEARCH

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ABSTRACT

Forage cactus (FC) is a perennial crop primarily developed in semi-arid regions. In Brazil, it is one of the main feed sources for ruminants during the dry season. However, scientific research and publication on FC seem limited and recent. Bibliometric studies allow measuring publication patterns and understanding the evolution of scientific production. Thus, a bibliometric analysis was carried out to evaluate the scientific production on productive aspects, management, and use of FC in animal feed (1800-June 2022). The literature search was based on keywords, including "cactus, cacti, nopal, prickly pear, palma forrageira, cacto, *Nopalea*, *Opuntia*, forage, forragem, and forraje". Data were analyzed using the Bibliometrix tool based on the R language through the Biblioshiny interface. A total of 514 publications were identified, with a predominance of research articles (92.6%). Scientific production includes authors from 40 countries, highlighting Brazil (1094 authors). The main sources were: *Revista Brasileira de Zootecnia*, *Acta Horticulturae*, *Tropical Animal Health and Production*, *Revista Caatinga*, *Journal of the Professional Association for Cactus Development*, and *Revista Brasileira de Engenharia Agrícola e Ambiental*. The 10 most frequent words were: *Opuntia*, *Semiarid*, *Nopalea*, *Forage*, *Cactaceae*, *Opuntia ficus-indica*, *Cactus*, *Cactus pear*, *Intake*, and *Digestibility*. Scientific production on FC is led by researchers from Brazil, notably

from Northeastern Brazil. Publications on the economic evaluation, establishment and maintenance of promising species, soil conservation, micronutrient content and the use of FC as a supplementary source of water, are less frequent. These sub-areas suggest future lines of research that may be inter-institutional to increase collaboration networks between countries.

Keywords: bibliometrix, bibliometric studies, *Nopalea*, *Opuntia*, semi-arid.

INTRODUCTION

Forage cactus (*Opuntia* and *Nopalea*) is a perennial crop, significantly developed in semi-arid regions of the United States of America (USA), Mexico, South Africa, and Australia in the early 19th century, and introduced in Brazil in 1880 (Souza et al., 2018). It has been much explored for feeding ruminants, mainly in the semi-arid region of Brazil (Rocha Filho et al., 2021; Santos et al., 2013). In this region, the cactus is the primary source of food for ruminants (Dubeux Jr. et al., 2021; Felix et al., 2018). According to Santos et al. (2013), the advantage of these plants in semi-arid environments is their mechanism of carbon fixation, known as Crassulacean Acid Metabolism (CAM). The CAM is a modality of photosynthesis that allows the assimilation of atmospheric CO₂ in locations with low water availability in the soil. Unlike C₃ and C₄ plants, CAM plants partially or predominantly absorb CO₂ from the atmosphere at night, allowing high efficiency in the use of the available water (Silvera et al., 2010; Yamori et al., 2014). Its taxonomy is widely disseminated among vascular plants and is present in many succulent species that occupy semi-arid regions (Silvera et al., 2010).

However, some authors highlight the reduced number of studies with forage cactus addressing issues such as climate needs (Souza et al., 2018), productive and structural responses of genotypes (Rocha et al., 2017), as well as phytosanitary issues, such as major pests, diseases, and control methods (Pinheiro et al., 2020). According to Bravo-Vinaja and Mendez-Gallegos (2016), the research trends in the last 10 years, mainly in the genus *Opuntia*, evaluate the functional properties of these types of plants. However, analyses of scientific production are recommended to quantify current productions on specific topics and areas that lack information and require greater attention for scientific research.

Currently, quantitative studies, known as bibliometrics, are being carried out to measure publication patterns and understand the evolution and production of scientific knowledge (Kent Baker et al., 2020; Machado Junior et al., 2016; Pimenta et al., 2017). Through bibliometrics,

it is possible to identify common features between scientific publications, inform the development of journal collections, identify citation patterns, recognize authorship, and suggest potential areas of research in several areas of knowledge (Machado Junior et al., 2016; Mongeon and Paul-Hus, 2016; Pimenta et al., 2017).

Bibliometric analyses are mainly carried out based on different international databases (Costas, 2017; Mongeon and Paul-Hus, 2016). In these databases, the main document used to publish information are scientific and review articles, with the advantage that they index information on authors, countries, institutions, and bibliographic references (Costas, 2017; Mongeon and Paul-Hus, 2016; Urbizagastegui, 2016). Among the disadvantages, the use of these databases highlights the coverage that focuses mainly on journals in relation to other sources of publication; journals in languages other than English are underrepresented; and the unavailability of complete information about an article (Alryalat et al., 2019; Mongeon and Paul-Hus, 2016).

Bravo-Vinaja and Mendez-Gallegos (2016) performed a bibliometric study on cactus species of the genus *Opuntia*, identifying Web of Science categories with more than 50 records. Among them, the areas Plant Science, Agronomy, and Agriculture-Dairy-Animal Science represented 27, 5, and 4%, respectively, of the total documents found (1,472 documents). Nevertheless, Grünwaldt et al. (2015) concluded that there were few contributions regarding experiences with cactus (*Opuntia*) as part of the animal diet, with the main contribution being from countries such as Brazil, Ethiopia, Mexico, Tunisia, and the USA. However, there are few qualitative and quantitative bibliometric studies investigating the use of cacti in arid and semi-arid ecosystems. The hypothesis is that through a bibliometrics study, we can identify the main areas of research developed in the production, management, and use of forage cactus in animal production, allowing us to suggest directions for future research. Therefore, the objective was to analyze the bibliometric trajectory of studies on the production, management, and use of forage cactus in animal feed, according to the Scopus database.

METHODOLOGY

A bibliometric analysis was performed using the Scopus database (1800 – June 2022). The analysis included five steps: research design, compilation of bibliometric data, analysis, visualization, and interpretation, as described by Zupic and Čater (2015) and Donthu et al. (2021). For the research design, groups of words were carefully selected. Inclusive words (associated with forage cactus in the context of animal feeding) were: “cactus, cacti, nopal, prickly pear, palma forrageira, cacto, *Nopalea*, *Opuntia*, forage, forragem, forraje”. Some of the words that were excluded from the search results were: “biodiesel, biofuel, biofuels, biogas, biofertilizer, human, fruit, fructification, molecular marker, pectin, rabbit, fish, tragelaphus, cosmetic, cotton, oil, antioxidant, phenolic, markers and seed”.

Two groups of keywords or syntaxes were entered in the advanced search of the database. Each set of keywords included field labels and Booleans, selected to limit the search process (Table 1). The Booleans were OR, AND and NOT. Field labels were used to consider two types of searches: in the complete document and limited to the title, abstract and keywords of each document. For Scopus, the label “ALL” is used for the complete document, and has a unique label for the title, abstract and keywords, being “TITLE-ABS-KEY”.

Further, the search was guided based on the language and type of publication. There was no limitation for the language, while for the type of publication, only scientific research articles,

reviews and proceedings, open access or not, were selected. The documents obtained were reviewed, and those associated with the proposed topic were selected. The selection was performed for each combination of keywords and syntax (Table 1). The information was combined, avoiding duplicated documents and information related to authorship. Additionally, document title, year of publication, document type, citations, “doi” record, affiliation, original language, mailing address and abstract keywords were collected.

Statistical analysis

The data from 514 publications from the Scopus database were processed and analyzed using the Bibliometrix tool, based on the R language (Aria and Cuccurullo, 2017), through the Biblioshiny interface. Thus, a bibliometric map for the production, management, and use of forage cactus in animal feed was prepared, including annual scientific production, production by country, sources of publication, affiliations, Bradford’s law, Lotka’s law, most frequent keywords, a network of co-occurrence of keywords and the network of collaboration between countries.

RESULTS

Dynamics of scientific production

Based on the grouping, the predominance of research articles (92.6%) was observed considering the three types of documents selected in the search criteria, with only 68% of these publications being open access (Table 2).

Table 1. Syntaxes used in the bibliometric analysis on the production, management, and use of forage cactus in animal feed.

| Syntaxes | Scopus |
|----------|--|
| Group 1 | ALL ((cactus) OR (cacti) OR ("prickly pear") OR ("palma forrageira") OR (cacto) OR ("spineless cactus")) AND ((<i>Opuntia</i>) OR (<i>Nopalea</i>)) AND ((forragem) OR (forage) OR (forraje)) AND NOT TITLE-ABS KEY ((biodiesel) OR (biofuel) OR (biofuels) OR (biogas) OR (biofertilizer) OR (human) OR (fruit) OR (fructification) OR ("molecular marker") OR (pectin) OR (rabbit) OR (fish) OR (tragelaphus) OR (cosmetic) OR (cotton) OR (oil) OR (antioxidant) OR (phenolic) OR (markers) OR (seed)) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "cp")) |
| Group 2 | TITLE-ABS-KEY ((cactus) OR (nopal) OR (cacti) OR ("prickly pear") OR ("palma forrageira") OR (cacto) OR ("spineless cactus") OR (<i>Opuntia</i>) OR (<i>Nopalea</i>)) AND ((forragem) OR (forage) OR (forraje)) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "re")) |

Table 2. Documents selected from the Scopus database for the bibliometric analysis on the production, management, and use of forage cactus in animal feed.

| | Scopus |
|----------------------------|------------------|
| Number of documents | 514 |
| Period | 1984 – June 2022 |
| Document type | |
| Research article | 476 |
| Review article | 25 |
| Proceedings | 13 |
| Open access | 349 |
| Number of authors | 1,610 |

Additionally, there is a short period since the beginning of publications with the use of forage cactus, but with oscillations between 1984–2015. However, publications increased from 2016, comprising 56% of the recorded scientific production between 2016–2022 (Fig. 1).

The total scientific production derives from the participation of authors (n=1,610) from 40 countries, highlighting Brazil with 1094 registered authors. Countries such as Mexico (n=143), USA (n=55), Tunisia (44), India (n=37), and Argentina (n=22) have the highest number of authors after Brazil (Fig. 2).

Regarding publication sources, the 514 documents were published in 133 different journals. Considering Bradford's Law (Fig. 3), the journals that stood out in the publication on forage cactus were *Revista Brasileira de Zootecnia-Brazilian Journal of Animal Science* (Brazil), *Acta Horticulturae* (Belgium), *Tropical Animal Health and Production* (Netherlands), *Revista Caatinga* (Brazil), *Journal of the Professional Association for Cactus Development* (Mexico), and *Revista Brasileira de Engenharia Agrícola e Ambiental* (Brazil). These journals account for 35.4% (n=182) of intellectual property (Zone 1). Zone 2 is represented by 20 sources, comprising 32% of the documents (n=164), while Zone 3, not illustrated in Fig. 3, accounts for 32.6% of documents (n=168), distributed in 107 publication sources.

Regarding the institutions where the main authors are affiliated, 17 associated teaching and research institutions were identified in the evaluated period. The data presented (Fig. 4) consider a total of 688 mentions of institutions, of which the Universidade Federal Rural de Pernambuco has 32%. However, it is important to highlight that the total record of mentions of institutions (1,367) does not match the total number of authors (1,610), leaving a total of 243 authors without recorded affiliation.

The 41 main authors associated with these institutions have between 10 and 68 published documents each, 39 authors being from Brazil and the remaining two from Tunisia and Argentina. These authors represent 2.5% of the total number of authors and appeared in 22.2% of the analyzed documents (n=114), 39 of which are from Brazil and the remaining two from Tunisia and Argentina. Furthermore, it is important to highlight that, out of the 1,569 remaining authors, 415 registered between 2 and 9 documents (25.8%), totaling 40.5% of the analyzed documents (n=208). Thus, the remaining documents (n=192) correspond to publications whose authors presented a single published document (1,154 authors). This relationship between the proportion of authors in relation to the number of published documents is known as Lotka's Law (Fig. 5).

Keywords, keyword co-occurrence and collaboration networks

Regarding keywords, out of the 1,152 words associated with forage cactus, 40 are highlighted in Fig. 6, appearing with a frequency of 32% (n=743). Among the ten most frequent keywords (proportional to the size of the word illustrated in Fig. 6), the terms *Opuntia* (1996–2022), Semiarid (2001–2022) and *Nopalea* (2006–2022) were highlighted. Words such as Forage and Cactaceae had the lowest occurrence between 1996–2015, but with a notable increase in occurrence in the period 2016–2022. However, words such as *Opuntia ficus-indica*, Cactus, Cactus pear, Intake and Digestibility remained oscillating, mainly between 1996–2015 (Table 3).

Furthermore, the co-occurrence of the 40 most frequent keywords in the abstracts was verified, identifying four clusters from the words *Opuntia* (red), Semiarid (blue), *Opuntia ficus-indica* (green) and Intake (purple) (Fig. 7). The word size is proportional to its relevance in relation to the

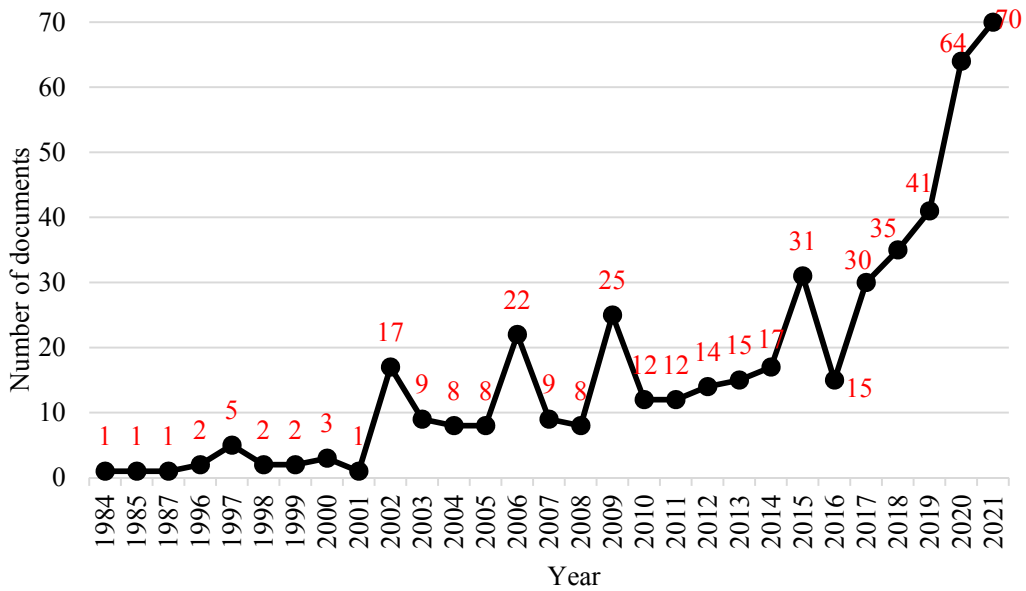


Fig 1. Annual scientific production (1984-2021) on the production, management, and use of forage cactus in animal feed, obtained from the Scopus database.

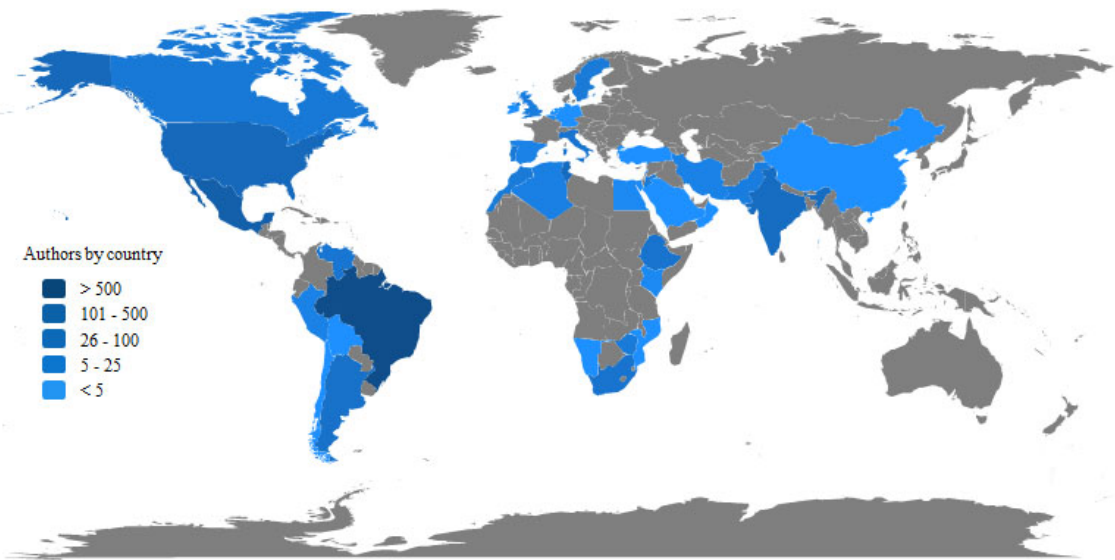


Fig. 2. Map of authors by country with scientific production (1984-2022) on the management and use of forage cactus in animal feed, obtained from the Scopus database.

words that head each cluster.

Thus, the dominant cluster was generated from the word *Opuntia*, but the highest number of associations were observed for the Semi-arid and *Opuntia ficus-indica* clusters. The terms *Nopalea*, Cactus, Irrigation, Intercropping and Biomass were linked to the word *Opuntia*; Forage, Cactaceae, *Nopalea cochenillifera*, Energy, Cladodes, Rumination, Cacti, *Opuntia ficus*

indica, *Opuntia stricta*, Livestock and Ruminant to the word Semi-arid; Cactus pear, Digestibility, Spineless cactus, Sheep, Chemical composition, Goats, Yield, Nutritive value, Fertilization, Growth and Performance to *Opuntia ficus-indica*. However, Intake was associated with Roughage, Milk yield, Forage cactus, Protein, Sustainability and Weight gain.

The collaboration network between countries

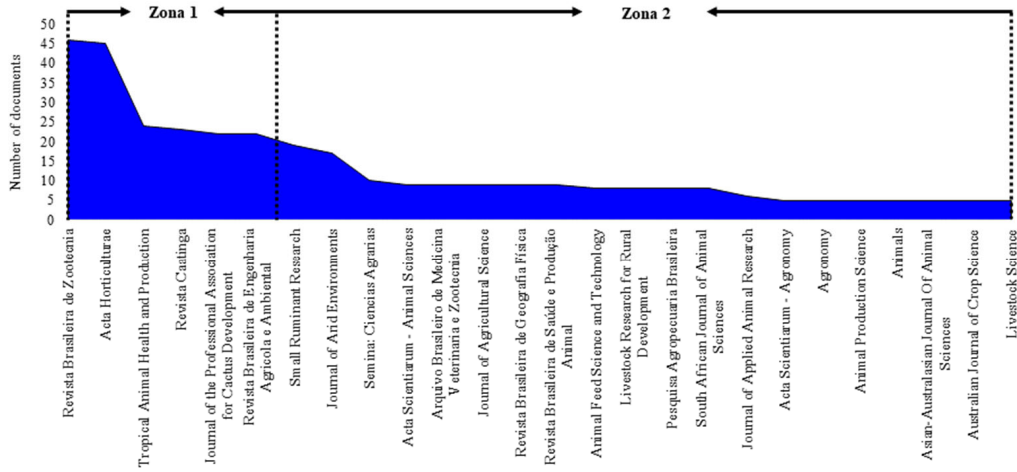


Fig. 3. Sources of greatest relevance and Bradford’s law scheme of scientific production (1984-2022) on the management and use of forage cactus in animal feed, obtained from the Scopus database.

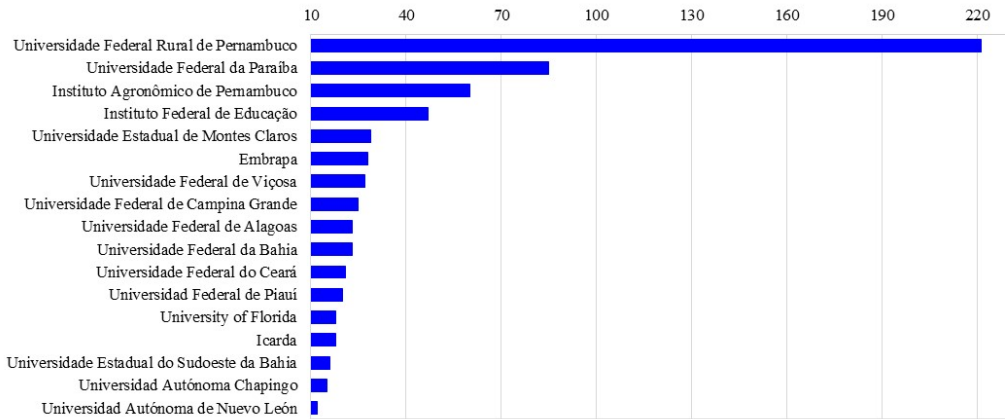


Fig. 4. Most relevant institutions in the global scientific production (1984-2022) on the management and use of forage cactus in animal feed, obtained from the Scopus database.

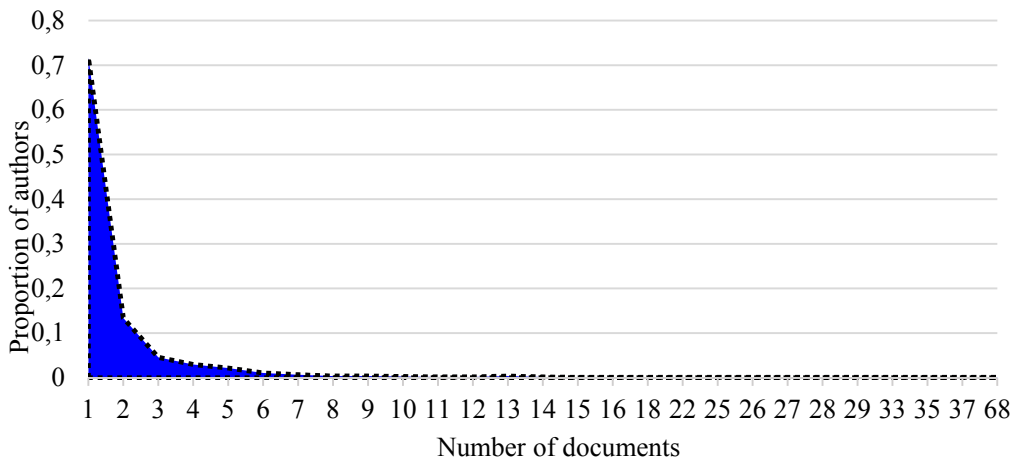


Fig. 5. Frequency distribution (Lotka’s Law) of scientific production (1984-2022) on the management and use of forage cactus in animal feed, obtained from the Scopus database.



Fig 6. Most frequent keywords in the abstracts of scientific articles (1984-2022) on the management and use of forage cactus in animal feed, obtained from the Scopus database.

Table 3. Growth dynamics on the use of the main keywords in the abstracts of scientific articles (1984-2022) on the management and use of forage cactus in animal feed, obtained from the Scopus database.

| Keywords | Period | | | | | Total |
|-----------------------------|-----------|-----------|-----------|-----------|-----------|-------|
| | 1996-2000 | 2001-2005 | 2006-2010 | 2011-2015 | 2016-2021 | |
| <i>Opuntia</i> | 2 | 3 | 13 | 23 | 52 | 93 |
| Semiarid | 0 | 3 | 9 | 22 | 45 | 79 |
| <i>Nopalea</i> | 0 | 0 | 3 | 8 | 29 | 40 |
| Forage | 2 | 3 | 6 | 9 | 18 | 38 |
| Cactaceae | 1 | 1 | 5 | 6 | 24 | 37 |
| <i>Opuntia ficus-indica</i> | 3 | 5 | 4 | 4 | 20 | 36 |
| Cactus | 3 | 1 | 5 | 9 | 12 | 30 |
| Cactus pear | 1 | 2 | 8 | 7 | 6 | 24 |
| Intake | 1 | 5 | 6 | 2 | 10 | 24 |
| Digestibility | 0 | 2 | 8 | 7 | 6 | 23 |

was generated considering the 19 countries of the total that presented scientific production around the research topic investigated. These countries correspond to those that have registered at least one association with another country. In this network, each color represents a cluster, and the country font size and the line connecting each country name are proportional to the collaboration with associated countries (Fig. 8). Thus, three clusters led by Brazil, Tunisia, and Morocco were identified. Brazil's main relations have been with the USA, Sweden, and Canada; Tunisia with Italy and Jordan; and Morocco with Belgium. The first two clusters (Brazil and

Tunisia) were not independent. The United States of America established a connection, specifically with India and Jordan.

This collaboration network can be associated with the amount of this scientific production, whether generated by a single country or by multiple countries of publication. This information is presented considering only the ten most outstanding countries in the number of publications (Fig. 9). Although Brazil stands out in terms of the number of publications and authors, the proportion of publications in association with other countries is low, especially compared to the USA, Argentina, Canada, Ethiopia, and Italy.

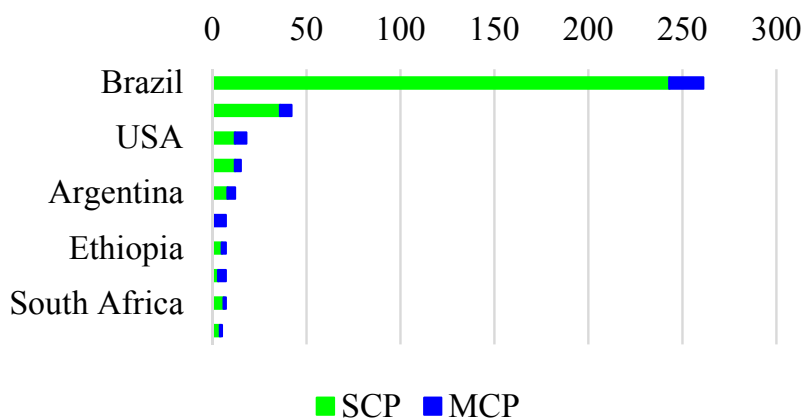


Fig. 9. Articles associated with the main authors of the most outstanding countries in the scientific production (1984-2022) on the management and use of forage cactus in animal feed, obtained from the Scopus database. SCP: Publications from a single country; MCP: Multiple countries of publication.

DISCUSSION

Scientific production dynamics

Forage cactus has been produced, used, and marketed in countries with areas characterized by droughts, irregular rainfall and poor soils exposed to erosion. These include Mexico, Brazil, Argentina, Italy, South Africa, USA, Morocco, Tunisia, Israel, North Africa, Spain, India, and Greece (Louhaichi et al., 2017; Singh, 2019). Among these countries, Brazil, Mexico, USA, Tunisia, India, and Argentina have the largest participation of authors in scientific production on forage cactus (Fig. 2). This production dates back a few years (38 years), being associated with the exploration and development of culture over time, especially when considering the semi-arid region of Brazil.

Brazil stands out in scientific production in relation to the production, management, and use of forage cactus in animal feed, being associated with historical events of drought in the Northeastern states. According to Lima and Gama (2001), the government began to encourage the planting of the spineless cactus after the 1932 drought. At that time, the plant was reported to be very acceptable to ruminants; however, it was poorly established. Subsequently, a prolonged drought was recorded in northeastern Brazil – between 1979-1983 (Singh, 2019). According to Marengo et al. (2016), it was the most costly drought of the 20th century, with government expenditures reaching an estimated US\$7.8 billion. Since then, numerous studies have focused on this forage, coinciding with the first bibliometric record. However, until now, a

significant amount of literature does not reach indexing services since it is not incorporated into bibliographic databases such as Scopus.

Another historic event in the Brazilian semiarid region was the 2012-2015 drought, with great economic losses due to the impacts of drought on the agricultural, livestock and industrial sectors (Marengo et al., 2016). From this event, the scientific production on forage cactus increased, and between 1984-2015, it remained oscillating (Fig. 1). Since then, Brazil has been presented as a leader in scientific research on this topic. This leadership is observed in the number of authors in the country (Fig. 1), with Brazil representing 50% of the main sources of publication (Fig. 3), and in the institutional affiliation of these authors (Fig. 4). According to Guerrero-Casado (2017), scientific production has increased significantly in the field of Agricultural Sciences in recent years, particularly in Latin America, with emphasis on Brazil, Argentina, and Mexico. The authors concluded that those countries with higher per capita income, greater investment in research and development and a greater number of researchers, are the ones that publish the most scientific articles in this area.

Regarding publication sources, according to Bradford's Law, almost the same number of documents are concentrated in Zone 1 and 2, although with a contrasting number of sources (6 and 20, respectively). Of the sources registered in Zone 1, the Book Series Acta Horticulturae and the journal Tropical Animal Health and Production are the oldest, with Scopus records in 1976, 1988 and 1996-current for the former and, since 1969-current for the latter. However,

the Revista Brasileira de Engenharia Agrícola e Ambiental, Tropical Animal Health and Production, and Revista Caatinga are the journals with the best ranking according to the SCImago Journal Rank (SJR: 0.496, 0.450, and 0.385, respectively). This information partially coincides with the Journal Citation Report (JCR) of 2021, with the best ranking for Tropical Animal Health and Production, followed by the Journal of the Professional Association for Cactus Development, Revista Brasileira de Engenharia Agrícola e Ambiental, Revista Brasileira de Zootecnia, and Revista Caatinga (JCR: 1.893, 1.333, 1.220, 1.000, and 0.888, respectively).

It is important to highlight that choosing a high-impact journal to publish the results of research projects favors their visibility and, consequently, increases the probability that these products will be recognized and cited. The increase in the number of citations benefits both researchers and Higher Education Institutions in the positioning within the overall global university rankings and by disciplines. One of the most prestigious university rankings is the QS World University Ranking. By 2023, the assessment methodology used by QS will include the ability of institutions to diversify the geography of their international research network with other higher education institutions.

The Revista Brasileira de Ciências Agrárias of the Universidade Federal Rural de Pernambuco is a journal with few publications focusing on forage cactus. However, it is expected that this journal will soon become an essential source of knowledge about this research topic. Likewise, it will provide a new channel for authors to publish their findings, mainly for those from Northeastern Brazil – a pioneering region in research on forage cactus. In turn, it may provide an opportunity for the Revista Brasileira de Ciências Agrárias to be widely recognized and cited.

Considering the institutional affiliation of the main authors, a relatively uniform pattern was observed in the ten main registered institutions. All of them are public institutions, with nine of them being located in Brazilian semi-arid states. Of this group, six affiliations are in the Northeast Region and four in the Southeast Region. The Brazilian Agricultural Research Corporation (Embrapa) operates in different states of Brazil and is part of the ten highlighted institutions, but it is not possible to determine the region of operation because this information is not described in the affiliation, and thus it was not quantified in this group. At this point, it is necessary to highlight that some errors in the institutional affiliation information were observed in the Scopus database, which limited, at the beginning of the

analysis, a correct attribution of publications to the institutions. This type of error was previously documented by Donner et al. (2020), emphasizing the importance of the standardization of institutional affiliation provided by the authors. In other areas of expertise, Selivanova et al. (2019) found that 76% of institutions and 24% of authors of scientific publications have duplicate profiles on Scopus.

The main errors observed in the affiliations of scientific production on forage cactus were related to differences in the translation of the names of institutions, use of the full name of the institution plus its acronym, use of only the acronym, and use of the name of the institution plus the name of the campus. At Scopus, Affiliate Identifiers (AFIDs) assign each affiliation a unique number (Donner et al., 2020). Therefore, different styles for the same affiliation will generate different numbers of records. Manual correction of this information is an alternative but requires an investment of time proportional to the amount of data collected. Otherwise, potentially wrong conclusions and decisions could be reached (Schulz, 2016). Furthermore, due to a lack of knowledge of the correct affiliation, finding potential collaboration networks between institutions or countries can be limited.

Another indicator of bibliometric analysis is Lotka's Law. According to the description given by Thompson and Walker (2015), this law developed by Alfred Lotka estimates the number of authors who make "n" contributions through the expression $1/n^2$ and affirms that the proportion of authors with a single publication should be close to 60%. According to Lotka's Law, the bibliometric analysis on the production, management, and use of forage cactus in animal feed showed that 72% of registered authors have a single contribution. Thus, the scientific production of most researchers in this specific line is reduced to a single product. According to Solano and Orihuela (2010), the cost of scientific contribution could be very high for a country considering the time and resources invested in the training of the researcher and such a limited production. However, it is necessary to consider that the contribution of these authors could include products associated with other lines of research.

Keywords, keyword co-occurrence and collaboration networks

The occurrence of the main keywords in the analyzed data is related to the use of this family of plants in different regions of the world, classified as arid and semi-arid zones. The genus *Opuntia*, the most widely used word by authors (Fig. 6)

and with the highest frequency increase through the years (Table 3), is the best known among the 1600 species cataloged in the Cactaceae family (Nefzaoui et al., 2014). However, the most widely used species/cultivars, mainly in the Brazilian semi-arid region, are *Opuntia ficus-indica* 'Gigante', *O. ficus-indica* 'Redonda', Orelha de Elefante Mexicana (*O. stricta* Haw) and Miúda (*Nopalea cochenillifera* Salm Dyck) (Sá et al., 2018). According to Dubeux Jr. et al. (2021), the genera *Opuntia* and *Nopalea* have long been used by humans for food and forage, and this selection by humans could probably be the reason why species of these genera are more productive than other cactus species.

Opuntia ficus-indica was the most named species in the keywords of *Opuntia* genus. According to Kiesling (2013), this species is the result of several thousand years of selection, being currently characterized by its large edible fruits and the absence of spine. It is cultivated in more than 20 countries, with approximately a planted area of 900,000 ha in North Africa, including 600,000 ha in Tunisia (Nefzaoui et al., 2014), being the species with the greatest research interest. In Brazil, the cultivated area is about 600,000 ha, with species such as Gigante, Redonda, and Miúda (the last being of the genus *Nopalea*). According to Dubeux Jr. et al. (2021), other cactus species used in ruminant feeding, but with less presence in scientific production, are *O. lindheimeri* Engelm, *O. ellisiana* Griffiths, *O. engelmannii* Salm Dyck, *O. chrysacantha* Berg, *O. amyclae*, *O. rastrera* Weber, and *O. stricta* Haw. Of these species, only *O. stricta* Haw appears in the bibliometric analysis with a low frequency of occurrence. Nevertheless, this species started to be cultivated in the last ten years, highlighting its low demand in soil fertility, drought tolerance, high productivity, and, above all, its resistance to carmine mealybug (*Dactylopius opuntiae* Cockerell) (Lopes et al., 2010; Silva and Sampaio, 2015).

Regarding keywords, it is important to highlight the need to standardize terminologies between research groups, as non-uniformity can limit the actual frequency of occurrence of certain words. For instance, genera such as *Opuntia* or *Nopalea* were observed in Scopus data in three formats, "*Opuntia*", "*Opuntia* sp." and "*Opuntia* spp.". Semi-arid word (in English) with two formats, "Semi-arid" and "Semi-arid", while the species *Opuntia ficus-indica* appear as "*Opuntia ficus-indica*", "*Opuntia ficus indica*", and "*Opuntia ficus-indica* Mill". This information was manually corrected to prevent generating false expectations about the main trends in research and underestimating the real occurrence of some words.

Furthermore, the observed co-occurrence of keywords could be associated with the lines of research developed. In general, the clusters associated with the words Semi-arid, *Opuntia ficus-indica* and Intake described topics with the objective of evaluating the use of forage cactus in ruminant feeding. In this line of scientific research, in addition to the use of large and small ruminants, the use of forage cactus cultivars Miúda, Gigante or Redonda, and Orelha de Elefante Mexicana stood out. According to Sá et al. (2018), the use of these species, specifically in Brazil, is determined by the climate and soil conditions of the planting sites. Only for the cluster from *Opuntia ficus-indica*, topics related to plant evaluation were observed. However, the cluster associated with the word *Opuntia* is considered the evaluation of crop production, mainly under irrigation conditions.

This analysis shows some unexplored areas. For the species of frequent use, yields below their productive potential due to a lack of crop care, such as weeding and fertilization, have been reported (Galvão Júnior et al., 2014). This fact leads to the need to explore and disseminate the results of experiences in using strategies to improve the productive indices and nutritional value of the culture beyond the use of irrigation, which was one of the management technologies with greater mention. Associated with the plant as forage and its use in animal production, some points with low frequency or absent among the keywords were identified. Among these, the economic evaluation of the establishment and maintenance of already used and promising species; soil conservation from the establishment and use of forage cactus; the micronutrient content in cladodes and their effect on animal production (Dubeux Júnior et al., 2010); the use of forage cactus as a supplementary source of water (Ferreira et al., 2021); and the production and management of species such as *Opuntia lindheimeri* Engelm, *O. ellisiana* Griffiths, *O. engelmannii* Salm Dyck, *O. chrysacantha* Berg, *O. amyclae*, and *O. rastrera* Weber, which are recognized for their potential to be used in ruminant feeding (Dubeux Jr. et al., 2021). Likewise, this information could be complemented by evaluating the environmental services promoted by the implantation of forage cactus, considering its use in erosion control, combating desertification, and supplying energy, among other support, provision, or regulation services. These topics could represent future research trends, contributing to the increase in the cultivated area of forage cactus with productive indices following its potential and use for each environment.

This co-occurrence observed between the

keywords could be associated with the identified collaboration networks (Fig. 8), which would probably point to areas of specialization or interdisciplinary networks of researchers from different countries. These networks could be influenced by economic and academic relations (Armenta-Medina et al., 2020) or closer cultural and idiomatic relations.

CONCLUSIONS

According to Scopus database, the dynamics of research on the production, management, and use of forage cactus in animal feed shows a growing trend from 2016 to now. This upward trend in publications is particularly marked in Brazil, driven by the demand from the livestock sector since forage cactus is one of the alternatives to mitigate the impacts arising from feed shortages in semi-arid regions. Scientific production on forage cactus is led by researchers mainly from the Northeastern states of Brazil.

In recent years, the use of forage cactus in animal feed has been widely studied, which can be demonstrated by the number of registered publications and co-occurrence between words. However, publications on the economic evaluation, establishment and maintenance of already used and promising species, soil conservation and use of forage cactus; micronutrient content and its effect on animal production, and the use of forage cactus as a supplementary source of water, are less frequent. These sub-areas suggest future lines of research that may be inter-institutional, aiming to increase collaboration networks between countries, considering current and potential relationships.

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