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GLOBAL TRENDS FOR FODDER SORGHUM PRODUCTION UNDER SALINE SOILS FROM 2000 TO 2023: A BIBLIOMETRIC ANALYSIS

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SUMMARY

Livestock sector directly supports the livelihoods and food security of many people, globally. A 65% shortage in green fodder and a 25% deficit in dry fodder are predicted to exist by 2025. Sorghum being a hardy crop can be used for forage purpose. It can tolerate abiotic stress like soil salinity. To cope up this green and dry fodder deficit, sorghum production for forage purpose from saline soils is needed. Therefore, the bibliometric analysis evaluated the general state, research trends, updates and hotspots of fodder sorghum production under saline soils. Scopus database was used to select journal publications from 2000 to 2023 and the analysis was carried out using VOSviewer and Bibliometrix software. The results demonstrated that 569 documents (542 original research and 27 reviews) studied the fodder sorghum production from saline soils over the last 23 years. Increasing number of publications can be associated with the demand of fodder production from salty areas. Author's keywords analysis suggested that the studies focused on sorghum, salt stress, salt tolerance, physiological changes, gene expression regulation and plant proteins with aim to increase the sorghum production from saline soils. Asian countries (China and India) are more focused on the alternative for pasture lands. This in-depth analysis offers future prospects for using sorghum as a fodder crop grown in saline conditions for sustainable fodder management.

Key words: Fodder sorghum, salinity, salt stress, salt tolerance and bibliometric analysis

Climate change scenarios have resulted in decrease of fertile and arable lands. In addition to that world human population has also reached 8 billion (United Nations, 2022), which is projected to increase to 9.2 billion people by 2050, with developing nations seeing the majority of this rise (FAO, 2009). The ever-increasing human population resulted in increase of food consumption to production ratio thus, needs much more resources to avert hunger. Most people throughout the world use livestock and its products as their main source of food (Herrero *et al.*, 2009). Livestock helps to reduce poverty, provide food security and supply vital components to country economies all around the world. Owing to the ever-growing human population, the food and cash crops are the principal crops grown on arable land, there is limited likelihood of getting high harvests of fodder from these lands. The growing number of cattle, partially as a result of animal husbandry practices, without equivalent focus on boosting forage output, is projected to increase pressure on the global healthy lands which already have limited fodder supplies (Singh *et al.*, 2022). Due to use of high yielding varieties, chemical fertilizers and assured irrigation, healthy soils are at their maximum production which are being used for cereal crops production (Acevedo *et al.*, 2022). Due to this, there is an immense need to switch on degraded soils like saline soils for fodder crops production (Aziz *et al.*, 2022).

Under climate change scenarios, such as sea level rise and its effects on coastal regions, temperature rise and an increase in evaporation, improper management practices, growing population etc., cause cultivated land to become more or less dry land resulted in increase of salt affected areas (Soares *et al.*, 2021). Significant portions of land have become less or unproductive due to soil salinization alone making it a dynamic problem that is expected to get worse in future (Kumar and Sharma, 2020). Most current estimates, with an extent of 1,128 million ha, indicate a growing tendency in the world's salt-affected region with 6% of the global land surface (Mandal *et al.*, 2018). Excessive salinity affects 33% of irrigated agricultural fields and 20% of all farmed lands globally. In South

Asia, almost 52 million acres of lands are salinity affected (Mandal *et al.,* 2018) whereas in India alone it is 6.7 mha (Mukhopadhyay *et al.,* 2021). Salinity adversely affects plant growth development and yield by inducing water and ionic stress, causing cytotoxicity and hyperaccumulation of ions in the soils which then causes nutritional imbalance and ultimately result in the death of the plants (Yang *et al.,* 2020).

Around 7.5 million hectares of land used for cultivating sweet sorghum, India is the greatest producer of sorghum in the world, followed by Nigeria (7.6 million hectares) (Yang *et al.,* 2020). Sorghum (*Sorghum bicolor* (L.) Monech) is a nutraceutical crop for small and marginal farmers, extensively grown for fodder purpose drier parts of the world such as Asia, China, Nigeria, India and Africa. Sorghum is expected to become more critical under climate change paradigm due to its greater adaptability to high temperatures, drought and salinity that can even tolerate salinity up to 6-8 dS/m making it a valuable crop under such conditions (Punia *et al.,* 2021). Sweet sorghum has benefits over the original feed crops, including high levels of tolerance to heat and drought, large yields, a minimal need for soil fertility, and good digestibility and palatability (Chen *et al.,* 2018). Higher salinity in environment induces oxidative/ionic and water stress conditions in the plants which ultimately result in physiological drought conditions (Zhang *et al.,* 2012). It is consistent with the notion that, like any other abiotic stress, salinity stress also alters gene expression, which eventually has an impact on the expression of gene products, the proteins (Ngara *et al.,* 2012). Plant breeding initiatives have long sought to sustain crop yield in semiarid and saline regions by developing salt-tolerant cultivars.

In 1969, Pritchard established bibliometry as a technique for statistical and mathematical analysis (Pritchard, 1969). It is used to identify trends of secondary journal coverage, authorship, publications and citations. Bibliometric studies are frequently used to examine research trends. The literature on fodder sorghum production from saline soils is reviewed and summarized in this paper to give succinct insights for next strategic research development and identify gaps that need to be focused on which further may be helpful to increase crop production for human livelihood. We are looking for the answers to following questions:

(a) How has research on fodder sorghum production under saline soils changed during the period of 23 years, from 2000 to 2023?
(b) How are papers distributed among the various nations?
(c) Who are the most well-known scientists?
(d) Which journals and organizations publish the most often and have the most impact on related research?

MATERIALS AND METHODS

This bibliometric analysis used scientific publication data from the core collection of Scopus (Fig. 1). More than 22,000 titles and high-impact scientific research from international publishers are housed in Scopus, the biggest database of scientific peer-reviewed literature established by Elsevier BV Corporation, USA (Elsevier.Com). We needed to choose the right search phrases before we could query the database. So, we choose the intended terms. To collect potential articles, we searched a combination of words as TITLE-ABS- KEY(((“sorghum” OR “fodder sorghum” OR “forage sorghum” OR “sweet sorghum”) AND (salinity OR “salt stress” OR “salt tolerance”). Based on chosen terms found in the title, abstract, author’s keywords, and not in the keywords-plus of each paper on the issue, this search query was used to find accurate information. We got 777 periodicals. Then we proceeded with advanced search applying logic operations as type of documents: “articles” and “review”. In order to track the progress of the publication through time and the most popular study fields, this systematic search was done from 01-01- 2000 to 21-02-2023. We limited the number of articles published in English language in journals only. After applying all these filters, we got a total of 569 publications (542 articles and 27 review). Data from the acquired documents was exported and examined using bibliometric software. The top authors’ output across the timing diagram, thematic map, word cloud, world map and a three-field plot were obtained using the “Bibliometrix” programme (R software v4.2.0). The dataset was then examined using the VOSviewer software.

RESULTS AND DISCUSSION

The findings of the bibliometric study on fodder sorghum production from saline conditions are shown in the sections below, along with the most important research fields, keywords, affiliations, journals, authors and nations. Each component of the data was examined in order to highlight the hotspots,

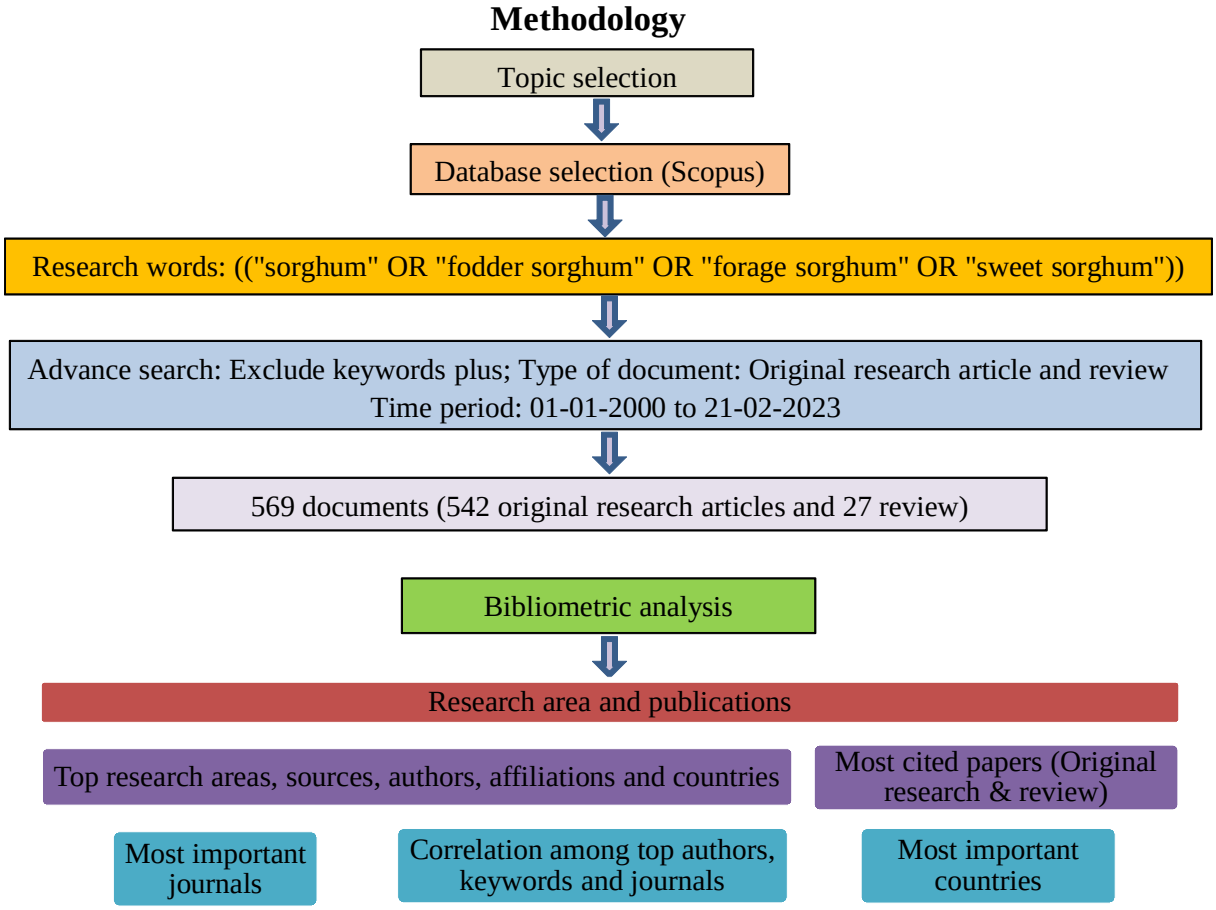

Fig. 1. Flowsheet of topic selection, literature search and bibliometric analysis.

trends and research advancements in salinity affected soil's ability to produce fodder sorghum.

Evolution of publication and research fields

The number of publications evolved 2000 to 2023 are represented in Fig. 2. In the last 23 years, the sorghum production for forage purpose under saline soils has been explored in 569 publications (542 articles and 27 reviews). It was observed that the lowest number of publications were in 2002. However, the highest number of publication were reported in 2022. The number of publications showed decrement in 2023 as we did the analysis on February 21, 2023. Publication evolution of fodder sorghum production under saline conditions from 2000 to 2023 (Fig. 2). After first decade, the number of publications escalated. The findings could indicate the growing interest in studies on fodder sorghum production from saline soils as a result of the rising need to reduce pressure on pasture lands, which is now a cutting-edge topic and required for an efficient livestock food management by pressing environmental issues. During earlier years research field were focused only on Agricultural, biological, veterinary science and biochemistry, genetics, molecular biology however, in recent years other fields like environment science, energy, earth, engineering, immunology, microbiology, multi disciplinary and social sciences are also focusing on fodder sorghum production from salinity affected soils.

The top 10 research areas, affiliations, nations, journals and authors for articles pertaining to fodder sorghum production under saline soils were classified in Table 1. The agricultural & biological (72.93%), biochemistry, genetics & molecular biology (36.91%) and environmental sciences (16.34%) were the

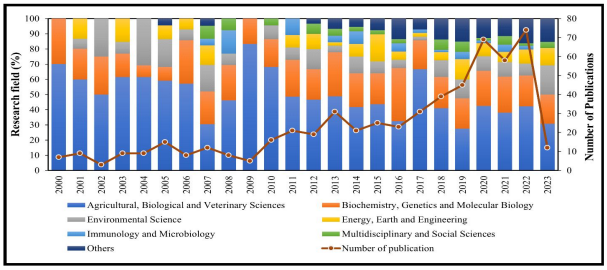

Fig. 2. Publication evolution of fodder sorghum production under saline conditions from 2000 to 2023.

dominant research areas. International Journal of Molecular Sciences was the most expressive journal in this field. Zhou G was the most productive authors with highest number of publications (17) during the 23 years' period. Yangzhou University (China) did the significant work to focus on the fodder sorghum production under saline soils. China and India with 53.08% and 37.08% contributed highest during the study period, respectively.

Most used author's keywords in research area

One of the most crucial components of a bibliometric study is the analysis of the key terms used in a particular field of study (da Rosa *et al.*, 2022). For determining advantages and possibilities for next study, keyword co-occurrence analysis might be helpful (Ampese *et al.*, 2022). The study of the top 50 keywords used by writers during the previous 23 years is shown in Fig. 3(a). Keywords having at least 5 occurrences were taken into consideration for this analysis. It can be noticed that "sorghum", "salinity" and "salt stress" were the most often used terms, with "sorghum" being the keyword that was most closely associated with the others. The map analysis of the most popular keywords revealed that this word exhibits terminology variants, being stated as "*Sorghum bicolor*" and "sweet sorghum," with significant weight. Moreover, the yellow color fig. 3(b) indicates that the gene expression regulation in fodder sorghum is recently developing topic. As a result, current research efforts have concentrated on streamlining the mechanism of sorghum to escape or tolerate salinity stress for its sustainable production. Initially, the phrases "salinity," "salt stress," "plant growth," and others were identified around the word "sorghum," which was the focal point of the green cluster. Salinity is the most associated word with sorghum in studies being the most important stress type in sorghum production. Increasing salinity levels reduced the germination and root length of sorghum (Ali *et al.*, 2020). The words "gene expression profiling" and "phylogeny" were grouped together in a blue cluster around the phrase "gene expression". Eventually, the phrase "genetics" appeared in red, surrounded by other words like "metabolism," "plant proteins," and "gene expression regulation." A thematic map of the author's keywords organized by relevance and level of growth is shown in Fig. 4. The four quadrants of this topic map are niche, motor, basic and emerging or declining. themes, developing or waning themes, and highly specialized or niche topics are the four categories. The terms "salinity," "sorghum," and "salt stress" were found in basic theme quadrant of the bibliometric analysis. This circle indicates that they are significant themes for the field of research but have not been sufficiently developed. They also have a low density, which suggests that these subjects require more thorough investigation. It was observed that keywords composed of abiotic stress, gene expression and soil salinity had high density in niche theme. Abiotic stress like soil salinity may hamper the production of sorghum (Mansour *et al.*, 2021). However, the gene expression of sorghum might be the best option to study for increasing its production (Xin *et al.*, 2021). These findings demonstrate the relevance of research in sorghum production under salt stress by studying the abiotic stress and gene expression for sustainable fodder sorghum production. Table 2. represents the list of keyword's clusters as per represented in Fig. 4.

The bibliometric analysis produced 1604 author's keywords, out of which top 20 terms used in the field of sorghum production for fodder purpose from saline soils are listed in Table 3 based on number of occurances. Overall, sorghum (285 occurrences), salinity (195 occurrences), *Sorghum bicolor* (159

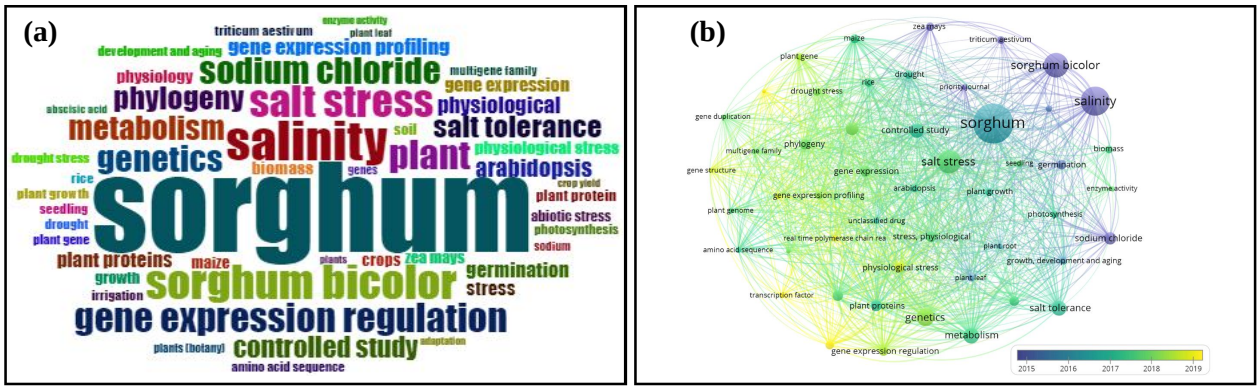

Fig. 3. Top 50 author's keywords clustering pertaining to the fodder sorghum production under salt stress. a) Word cloud b) Map based on term average year.

TABLE 1
Top ten research areas, journals, authors, affiliations and countries on the basis of number of publications related to sorghum production

Ranking	Research areas	Number	%*
1st	Agricultural and Biological Sciences	415	72.93
2nd	Biochemistry, Genetics and Molecular Biology	210	36.91
3rd	Environmental Science	93	16.34
4th	Medicine	29	5.10
5th	Immunology and Microbiology	28	4.92
6th	Chemical Engineering	27	4.75
7th	Chemistry	26	4.57
8th	Multidisciplinary	23	4.04
9th	Earth and Planetary Sciences	20	3.51
10th	Engineering	16	2.81
Ranking	**Sources**	**Number**	**%***
1st	International Journal of Molecular Sciences	14	2.46
2nd	Agricultural Water Management	11	1.93
3rd	Frontiers in Plant Science	11	1.93
4th	Planta	11	1.93
5th	Bmc Genomics	10	1.76
6th	Communications in Soil Science and Plant Analysis	10	1.76
7th	Journal of Plant Nutrition	10	1.76
8th	Plants	10	1.76
9th	Pakistan Journal of Botany	9	1.58
10th	Plos One	9	1.58
Ranking	**Authors**	**Number**	**%***
1st	Zhou G	17	2.99
2nd	Gomes-Filho E	15	2.64
3rd	Sui N	15	2.64
4th	Yang Z	12	2.11
5th	Nimir Nea	11	1.93
6th	Prisco Jt	11	1.93
7th	Wang B	10	1.76
8th	Wang X	10	1.76
9th	Zheng H	10	1.76
10th	Zhu G	10	1.76
Ranking	**Affiliations**	**Number**	**%***
1st	Yangzhou University (China)	23	4.04
2nd	Shandong Normal University (China)	22	3.87
3rd	Universidade Federal Do Ceará (Brazil)	20	3.51
4th	CCS Haryana Agricultural University (India)	18	3.16
5th	University of Khartoum (Sudan)	15	2.64
6th	Tottori University (Japan)	13	2.28
7th	Universidad De Sevilla (Spain)	12	2.11
8th	University of Agriculture (Pakistan)	12	2.11
9th	University of the Western Cape (South Africa)	12	2.11
10th	King Saud University (Saudi Arabia)	11	1.93
Ranking	**Countries**	**Number**	**%***
1st	China	302	53.08
2nd	India	211	37.08
3rd	Brazil	134	23.55
4th	Unites States of America	130	22.85
5th	Iran	83	14.59
6th	Pakistan	74	13.01
7th	Australia	62	10.90
8th	Egypt	59	10.37
9th	Sudan	39	6.85
10th	Japan	38	6.68

Note: %* is the percentage of 569 documents. Search was conducted on 21st February, 2023.

occurrences), salt stress (146 occurrences), genetics (103 occurrences), metabolism (91) and salt tolerance (85) were the most often used terms in this research field. This finding raises the concern of soil salinity as a major stress for fodder sorghum production and suggests the breeding of sorghum for salt tolerance varieties (Amombo *et al.*, 2022). Moreover, analysing the most used terms reveals vital details about the research development and trends in this field. Most common author's keyword is sorghum and it is the hard crop (Teferra *et al.,* 2019) which tolerate abiotic stress to some extent. Coexisting keyword with sorghum is salinity which affecty sorghum production under saline conditions. Moreover the salt stress (146 occurances) can be mitigated by appropraite breeding (103 occurances) technique and salt tolerance (85 occurances) via understanding the plant proteins (59) and gene expression regulation (53 occurances) which ultimately will improve the plant growth (40 occurances) and biomass (39 occurances) under saline conditions.

The most significant and extensively researched issues in the field of study had to be checked using the indicator most cited articles in order to construct the visualization of forage sorghum production from saline soils correctly. To further comprehend this process and demonstrate its global relevance, the study of the most cited articles (original research and review) might be helpful.

Most cited experimental papers

Top ten most cited research articles on fodder sorghum production from saline lands are listed in Table 4. The original research paper publsihed by Netondo *et al.* (2004b) received highest citations (329). The research paper entitled "Sorghum and salinity: II. Gas exchange and chlorophyll fluorescens of sorghum under salt stress" evaluated the effect of different levels of soil salinity on physiological traits like chlorophyll a and b, net CO_2 assimilation, stomatal conductance, transpiration rate, photochemical quantum yield of PSII (Fv/Fm) and photochemical quenching coefficient of two sorghum varieties (Serena and seredo). The paper reveals that increasing salinity levels significantly reduced chlorophyll a and b, stomatal conductance, net CO_2 assimilation and transpiration rate in both two sorghum cultivars. Photochemical quenching coefficient and Fv/Fm decreased by 10 and 9%, respectively, for both varieties. Second most cited research article (301 citations) was published in "Environmental and Experimental Botany" journal in 2003 which focused on accumulation and distribution of solutes during leaf development in salt tolerant (CSF20) and salt sensitive (CSF18) fodder sorghum varieties. The results demonstrated that 100mM sodium chloride dominant salt stress enhanced leaf senescence, leaf injury and reduced leaf elongation. It also resulted in the buildup of toxic ions like Na^+ and Cl^-, organic solutes including proline, amino acids, carbohydrates and a decrease in the amount of K^+ in leaf blades. Compared to the tolerant genotype, all of these alterations were more obvious in the sensitive genotype.

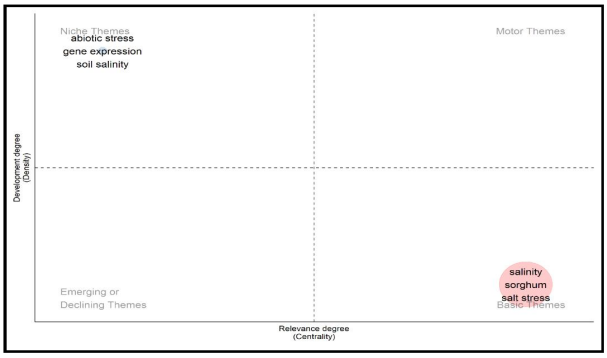

Fig. 4. Thematic map of most frequent author's keywords (50) in the field of sorghum.

TABLE 2
Clusters of top 50 main keywords

Cluster number	Number of items	Keywords
1	21	Abiotic stress, amino acid sequence, controlled study, drought, drought stress, gene duplication, gene expression, gene expression profiling, gene structure, maize, multigene family, phylogenetic tree, phylogeny, plant gene, plant genome, promoter region, real time polymerase chain reaction, rice, transcription factor, unclassified drug, upregulation
2	20	Biomass, enzyme activity, germination, "growth, development and aging", photosynthesis, physiology, plant growth, plant leaf, plant root, plants (botany), priority journal, salinity, salt stress, salt tolerance, seedling, sodium chloride, sorghum, Sorghum bicolor, Triticum aestivum, zea mays
3	9	Arabidopsis, gene expression regulation, plant, genetics, metabolism, physiological stress, plant proteins, stress

Sorghum bicolor's transcriptome response to dehydration, high Salinity and ABA was studied by Buchanan et al. (2005) which accounts for 233 citations (3rd most cited research paper). The results reported that more than 2200 genes were altered in response to high salinity levels in sorghum. These modulated sorghum genes had similarity with proteins involved in growth regulation, transport, metabolism, dehydration protection, ROS scavenging and plant defense.

Discussion: Insights on fodder sorghum production under salinity

Throughout the last 23 years, there has been a considerable increase in the output of sorghum related research. Most of the research output was focused on soil salinity, salt stress, agronomic themes such as crop yield, biotic and abiotic stress management and tolerance, and use attributes related to livestock nutrition. Nonetheless, the major topics that have sparked the most academic attention during the past few years are:

(a) Specifically, genome sequencing and tying the results to the development of sorghum's resistance to salinity stress
(b) Climatic resilient sorghum production
(c) Stress induced changes in sorghum physiology like ROS production
(d) Understanding mechanism of plant proteins and gene expression regulation for increasing sorghum biomass
(e) Breeding for salt tolerance in sorghum

Based on the rising importance of environmental effects like salinity and livestock food security, we predict that these study areas will gain in importance over couple of years. According to the retrieved articles, the dramatic increase in sorghum related research output over the last two decades reflects a rise in scientific interest in this crop for fodder purpose and supports increasing funding in fodder sorghum related research, particularly by governmental institutions. Despite the positive outlook for sorghum research spending, it has traditionally trailed behind those of other cereal grains, particularly maize (Pfeiffer *et al.*, 2019). In contrast to a 35% increase in maize output at that time, sorghum productivity barely changed. America and Asia had a fall of over 15% accounting for more than 50% of world output (FAOSTAT, 2020). It might be due to genetic advancements in maize, so it was well adopted in irrigated regions. As a result, sorghum has continued to be displaced in drought and salinity prone areas which has a detrimental influence on its output (Pfeiffer *et al.*, 2019). However, despite encouraging scientific

TABLE 3
List of top 20 keywords in the area of forage purpose sorghum production under saline conditions (ranking basis is occurances frequency)

Ranking	Keyword	Occurrences	Total link strength
1st	Sorghum	285	4753
2nd	Salinity	195	2253
3rd	Sorghum bicolor	159	1623
4th	Salt stress	146	2773
5th	Genetics	103	2639
6th	Metabolism	91	2223
7th	Salt tolerance	85	1458
8th	Abiotic stress	71	1689
9th	Sodium chloride	68	1249
10th	Gene expression	61	1518
11th	Plant proteins	59	1751
12th	Gene expression regulation	53	1619
13th	Physiological stress	51	1448
14th	Germination	51	792
15th	Physiology	50	1212
16th	Drought	43	1034
17th	Plant growth	40	1194
18th	Sweet sorghum	40	446
19th	Biomass	39	674
20th	Crops	39	530

TABLE 2
Bibliometric software based author's keyword cluster

Cluster	Main keyword	Number of items	Keywords on bibliometrix software
1	Salinity	10	Salinity, sorghum, salt stress, sorghum bicolor, sweet sorghum, salt tolerance, proline, germination, salinity stress, photosynthesis
2	Abiotic stress	10	Abiotic stress, gene expression, soil salinity, drought, rice, crop yields wheat maize, osmotic adjustment, biotic stress

TABLE 4
Most cited research articles (10) in the field of fodder sorghum production under saline soils

Ranking	Title	Journal	Publication year	Total citations	TC per year	Reference
1.	Sorghum and Salinity: II. Gas Exchange and Chlorophyll Fluorescens of Sorghum under Salt Stress	Crop Science	2004	329	16.45	Netondo *et al.* (2004b)
2.	Solute accumulation and distribution during shoot and leaf development in two sorghum genotypes under salt stress	Environmental and Experimental Botany	2003	301	14.33	de Lacerda *et al.* (2003)
3.	*Sorghum bicolor*'s Transcriptome Response to Dehydration, High Salinity and ABA	Plant Molecular Biology	2005	233	12.26	Buchanan *et al.* (2005)
4.	Auxin-related gene families in abiotic stress response in *Sorghum bicolor*	Functional & Integrative Genomics	2010	207	14.79	Wang *et al.* (2010)
5.	Halotropism is a Response of Plant Roots to avoid a Saline Environment	Current Biology	2013	201	18.27	Galvan-Ampudia *et al.* (2013)
6.	Sorghum and Salinity I. Response of Growth, Water Relations, and Ion Accumulation to NaCl Salinity	Crop Science	2004	194	9.7	Netondo *et al.* (2004a)
7.	Drought and salinity stress alters ROS accumulation, water retention, and osmolyte content in sorghum plants	South African Journal of Botany	2017	181	25.86	Nxele *et al.* (2017)
8.	Proline over-accumulation alleviates salt stress and protects photosynthetic and antioxidant enzyme activities in transgenic sorghum [*Sorghum bicolor* (L.) Moench]	Plant Physiology and Biochemistry	2015	157	17.44	Reddy *et al.* (2015)
9.	The plant-growth-promoting bacterium *Klebsiella* sp. SBP-8 confers induced systemic tolerance in wheat (*Triticum aestivum*) under salt stress	Journal of Plant Physiology	2015	156	17.33	Singh *et al.* (2015)
10.	Enhanced root hydraulic conductance by aquaporin regulation accounts for silicon alleviated salt-induced osmotic stress in *Sorghum bicolor* (L.)	Environmental and Experimental Botany	2015	155	17.22	Liu *et al.* (2015)

developments that sorghum is more robust to climate change (Myers *et al.,* 2014), significant barriers still stand in the way of altering the fodder sorghum production, globally. It is admirable to see that there is ongoing study to increase the functioning of the sorghum protein to improve the crop's production for fodder purpose from saline areas (Teferra *et al.,* 2019). CRISPR gene manipulating techniques has the potential to impart salt tolerance and it can greatly increase the effectiveness of such initiatives (Parikh *et al.,* 2021; Pfeiffer *et al.,* 2019).

CONCLUSION

This study examined the fodder sorghum production under saline soils. A total of 569 publications (542 articles and 27 reviews) were recorded between 2000 and 2023. The bibliometric analysis revealed that salinity is a major abiotic stress diminishing fodder sorghum production from salt affected areas. Most used keywords were associated with the possibility of inducing salt tolerance via gene expression regulation for abiotic stress mitigation and increasing fodder sorghum biomass. The bibliometric analysis elucidated that fodder has to be encouraged in order to alleviate its scarcity and to decrease reliance on the forest, unsustainable grazing, and unorthodox feeds. The recovered literature was distinguished by its quick expansion, high number of citations, and participation of eminent journals. In this area of research, China and India participated actively as they have huge salinity affected areas. International scientific cooperation in the study area was very high which indicate the significance of the topic. To prevent food insecurity, particularly in those countries with limited resources, it is necessary to study new technology and possible methods to produce sorghum from saline lands. Use of novel molecular approaches-based technologies, such as CRISPR, can increase the salt resistance of fodder sorghum and provide more effective and desired end-use features.

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