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Africa's natural fibres used in polymer composites: A systematic review

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Abstract

Environmental concerns and the depletion of petroleum resources have spurred research into natural fibres as sustainable alternatives to synthetic fibres as the reinforcement phase in polymer composites. Given that the local availability of materials is a crucial component in the sustainability framework, there is a need to map out the fibres used to develop natural fibre composites across geographical regions to optimize local resource utilization. Through a systematic review of publications sourced from Scopus and Web of Science databases, this study examines the contributions made by Africa to develop green polymer composites. The bibliometric data from both databases were systematically merged, and bibliometric analysis was carried out to identify trends and relevant relationships and provide a more general insight into Africa's progress in the natural fibre polymer composite field. A meta-analysis was then conducted to identify the natural fibres exclusively sourced from Africa that have been used to develop polymer composites. The study also discussed natural fibre classifications with respect to fibre type and form. Sisal, palm varieties (particularly date palm), alfa, jute and members of the Musaceae family (i.e., banana, plantain and enset) were found to be the most used African-sourced fibres. This study is a step to creating a more extensive global natural fibre database that seeks to provide more precise knowledge, enhance research efficiency, and ensure the utilization of local materials in creating more sustainable composites.

Highlights

- The use of local materials is a key component of sustainable development
- A natural fibre database can foster sustainability in the composite industry
- Egypt, Morocco, and Tunisia are leading Africa's composite research
- Research prioritizes composite material science over practical applications
- Sisal, date palm, alfa and jute are the most used natural fibres in Africa

KEYWORDS
Africa, bibliometric analysis, composites, natural fibre, polymer-matrix composites

1 | INTRODUCTION

A composite material is one that is comprised of two or more materials combined at a macroscopic level through a specialized process. The individual components come with distinct physical and chemical properties that when combined result in a material with unique properties superior to that of the individual elements.[1] A composite material primarily consists of two phases; a continuous phase (matrix) and a discontinous phase (reinforcement) which are insoluble to each other.[2] The matrix provides the rigidity and form of the composite, while the reinforcing material typically determines the strength and stiffness of the composite.[3] With respect to the nature of the matrix phase, there are mainly three types of composites used in Engineering applications: polymer matrix composites (PMC), metal matrix composites (MMC), and ceramic matrix composites (CMC); PMCs dominate the market.[4] Carbon, glass, and aramid fibres have established themselves as reinforcement choice in PMCs due to their exceptional strength-to-weight ratios, rendering them indispensable across various sectors.[5] While synthetic fibres offer significant value, they also present a multitude of sustainability challenges, including dependence on fossil fuels,[6] high embodied energy,[7] and challenges in recycling.[8]

The growing awareness of climate change has made it imperative to integrate sustainable development into all sectors as humanity strives to prevent more environmental harm. Sustainability has also become a global phenomenon with the introduction of the Sustainable Development Goals.[9] This trend is also evident in the engineering field, where there is a growing emphasis on adopting more environmentally friendly materials as opposed to traditional synthetic options. Specifically, goal nine calls for sustainable industrialization and encourages innovation, and goal twelve seeks to ensure sustainable consumption and production patterns, calling for the more efficient use of our natural resources, reduction in waste generation and the use of circular economic principles in waste management.[9] Hence, the environmental impact of engineering materials from manufacture to disposal is a significant consideration in material development. As such, researchers and engineers are now navigating toward leveraging the potential of natural fibres in developing engineering composites in place of synthetic options across various industries: construction, sports and leisure, consumer goods, pipes and small-scale wind energy.[10] Using natural fibre composites (NFCs) across these industries is a promising option to address current environmental concerns, lower energy demands, and potentially diminish carbon footprints.[11] Natural fibres from plant and animal origins offer attributes that resonate with certain sustainable principles. These fibres often have lower embodied energy, are biodegradable, can be sourced from renewable agricultural resources, and have lower costs than synthetic fibres.[12] They also boast of low density and good mechanical and thermal properties, making them suitable for developing engineering composites.[13] These advantages have led to the rise in demand for natural fibres in recent years. The global natural fibre market was valued at US$4.5 billion in 2022 and is projected to be US$9.2 billion by 2031.[14]

Despite noticeable growth in the natural fibre industry, many regions globally still underutilise their available natural fibre resources, presenting an opportunity to leverage them to develop more sustainable composites.[15] A review of the production of some of the most used natural fibres—Abaca, coir, cotton, flax, jute, kenaf, ramie, sisal and hemp from 2010 to 2022 showed that Asia currently leads the world production with 61.5% followed by South America, North America, Africa, Europe and Oceania with 17.6%, 10.5%, 5.0%, 3.5% and 2.0% respectively.[16] While Europe's share in global natural fibre production is comparatively modest, it boasts the largest market for NFCs,[17] primarily driven by government policies around a circular economy. In addition to government policies and standardization, Laasri advocates for a global digital NFC management model to catalogue natural fibres according to geographic regions to create awareness of multiple supply points, ensuring the security of natural fibre supply.[18] Some authors have considered a natural fibre database concept but at local levels. Karimah et al. advocated for Indonesia's natural fibre database.[19] Hayajneh et al. evaluated the physical and mechanical properties of fifteen different natural fibres as potential raw material sources for biomaterials as a seed step to creating a database for Jordan.[20] Balakrishnan et al. created a process for selecting natural fibres found in Malaysia using an analytical hierarchy process.[21] Their study acknowledged the importance of the local availability of natural fibres in the material development process and considered it a selection criterion.

The merits of the NFC industry concerning sustainability are well established in the literature. Consequently, many studies seek to create and evaluate the properties of the developed sustainable composites. However, only a few studies actively point researchers to which natural fibres should be considered raw materials for composite development based on their geography. Economic viability is crucial in selecting and accepting raw materials.[22] Opting for locally sourced materials reduces carbon emissions linked to transportation and the associated costs. As the natural fibre industry employs about 4% of the world's population, its sustained use will help alleviate poverty and, with some plants, contribute to food security.[23] Given this, there is a need to understand the global distribution of natural fibres, providing researchers with valuable guidance to appropriate raw material selection. This paper seeks to answer the question, "What natural fibres have been used to develop polymer composites in Africa?". It aims to review Africa's natural fibre landscape through the lens of polymer composites by (1) retrieving available studies on polymer composites composed of natural fibres with African affiliation to carry out bibliometric mapping of the research field, understanding the collaborations and knowledge flow, and (2) identifying the natural fibres sourced from Africa used to develop polymer composites in view of the fibre types and forms. The rest of this paper is organized as follows. Section 2 presents the research methodology and the literature retrieval strategy. It also presents a method for merging bibliometric data from Scopus and Web of Science (WoS) databases into a unified .csv file. The result of the bibliometric analysis is presented in Section 3. Section 4 presents the results of the meta-analysis. Sections 5 and 6 outline the implications and conclusions of the study.

2 | RESEARCH METHODOLOGY

A two-step process was employed to identify studies that utilized fibres sourced from within Africa. The first step entailed identifying studies that had fabricated natural fibre polymer composites with an African affiliation. This process was done systematically, guided by the PRISMA 2020 statement.[24] This rigorous approach was done to prevent selection bias and accurately capture the existing knowledge.[25] Subsequently, a comprehensive bibliometric analysis of the retrieved articles was conducted, serving as a crucial tool to identify the prominent contributors and contributions within the field. This step facilitated an objective mapping of the knowledge area and the identification of key research themes, enhancing our understanding of the broader landscape. In the second step, a deeper exploration of initially the identified documents was conducted to isolate studies that used fibres specifically sourced within Africa. The resulting dataset was then presented using descriptive statistics and discussed, shedding light on the utilization of African fibre sources and the forms in which they were used to develop polymer composites for use across different industries. Figure 1 delineates the research design.

The main sources of articles for conducting literature reviews are Elsevier's Scopus and Thomson Reuters' Web of Science. Sánchez et al.[26] recommended combining Scopus and WoS bibliometric data, highlighting their distinct coverage profiles and the notable portion of exclusive articles present in each, thus advocating for a comprehensive approach. However, Echchakoui[27] highlights that the difficulties arising from manually integrating data across diverse databases due to varying tag field formats lead many researchers to choose a single database. Authors, such as Boumaaza et al.,[13] opted to analyze results independently. Following this observation, Echchakoui[27] proposed a method to merge datasets from different databases for bibliometric analysis using some software coding with R software and VBA code in Excel. Building on this, Caputo and Kargina[28] offered a simplified approach using Microsoft Excel tailored for integration into the open-source Bibliometrix software. This study builds on the methods of the mentioned authors and presents a process of merging Scopus and WoS data for use in any bibliometric software reliant on the .csv file format.

2.1 | Data set retrieval and filtration

Documents were retrieved from Scopus and WoS core collection databases. Using the search string, "natural AND (fibre OR fiber) AND (composite OR biocomposite) AND (polymer OR plastic)", both databases were explored (accessed on 13th November 2023), yielding 13,014 and 7904 outcomes from Scopus and WoS, respectively. Subsequently, a more precise refinement was done, restricting the source to include journal articles and documents with an African affiliation. After applying these criteria, the result yielded 553 and 533 documents from Scopus and WoS, respectively, deemed eligible for subsequent screening. Subsequently, the bibliometric data of the qualifying documents was exported to MS Excel to identify duplicate entries within both the Scopus and WoS datasets. This task was accomplished with the "highlight cell rules-duplicate values" conditional formatting feature, revealing 320 duplicate records.

Additionally, it was determined that certain instances marked by minute deviations in punctuation or the inclusion of specialized characters within article titles had eluded initial detection as duplicate entries. Some examples of this are presented in Table 1. In response, a secondary manual inspection was done, unveiling an additional 35 duplicate records. Upon successfully identifying duplicate documents, the revised tally of documents eligible for further screening stood at 731 records. The titles and abstracts of these entries were then scrutinized, and only studies with fabricated polymer composites reinforced with natural fibres from plant and animal sources were considered for further analysis. Studies on carbon, glass, and basalt fibres, as well as those solely on fibre characterization without concurrent polymer composite development, were excluded. Following this filtration, 467 documents were considered for the bibliometric analysis.

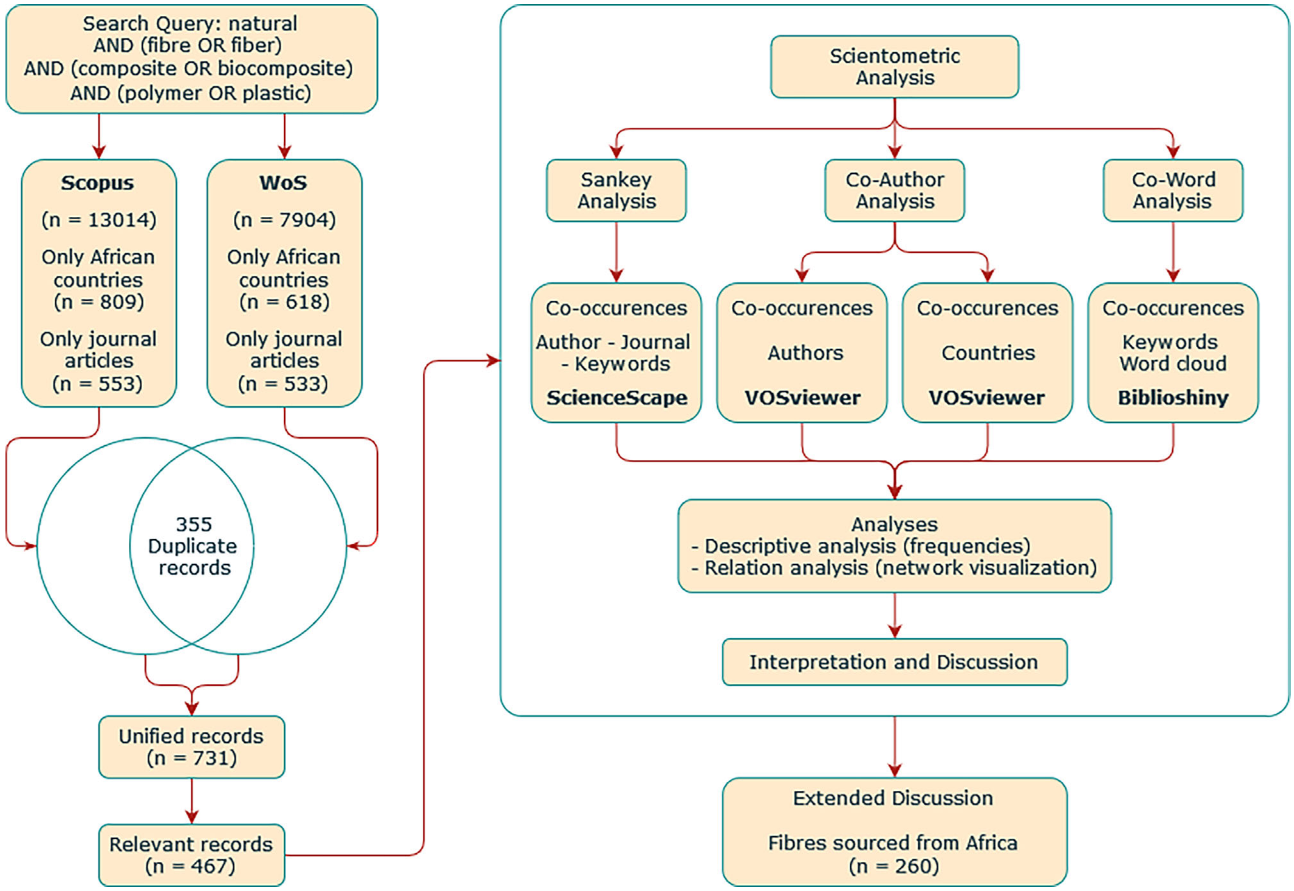

FIGURE 1 Research design.

TABLE 1 Article title discrepancies from Scopus and WoS.

Scopus	Web of science
Hybrid polyester composites reinforced with curauá fibres and nanoclays	Hybrid polyester composites reinforced with curaua fibres and nanoclays
Exploration of mechanical properties of enset–sisal hybrid polymer composite	Exploration of mechanical properties of enset–sisal hybrid polymer composite
Biocomposites of alfa fibers dispersed in the Mater-Bi® type bioplastic: Morphology, mechanical and thermal properties	Biocomposites of alfa fibers dispersed in the Mater-Bi **(R)** type bioplastic: Morphology, mechanical and thermal properties

2.2 | Analytical tools

The analysis and graphical representation of the bibliometric data was conducted using VOSviewer (version 1.6.19),[29] the online scientometrics tool, ScienceScape[30] by médialab Sciences Po and Biblioshiny, a web application from the open source R package, Bibliometrix.[31]

2.3 | Merging Scopus and WoS data

The bibliometric data from Scopus and WoS were combined using the methodology delineated by Caputo and Kargina,[28] albeit with certain adaptations to accommodate the unique attributes of VOSviewer. The bibliographic entries were extracted and saved as ".csv" files from their respective databases. The Scopus file was chosen as the reference format since it returned more articles (553) than that of WoS (533). The duplicate records identified earlier were removed from the WoS records. The remaining records were then copied into the Scopus file for a unified global file. Although the column headings from WoS are largely like those from Scopus, adjustments were made to restructure the WoS columns to align with the sequence of the Scopus columns.

Certain entries required modifications to conform to the Scopus format. Specifically, adjustments were made to the author format within the WoS dataset, transitioning from the WoS format (i.e., Attia, MM; Ahmed, O; Kobesy, O; Malek, AS) to the Scopus format (i.e., Attia M.M., Ahmed O., Kobesy O., Malek A.S.). Also, the publication source column titled "source title" was scanned to ensure a uniform presentation of titles; for instance, "adsorption science & technology" in WoS was changed to its Scopus equivalent, "adsorption science and technology". It was also noted that the "affiliations" column entries in WoS did not include the countries, impacting the co-authorship country network generated by VOSviewer. To address this, entries under the "addresses" column were copied to the "affiliations" column, and the authors' names were removed after that so as not to disrupt the bibliometric networks generated. Entries from the WoS "addresses" column found their place under the "authors with affiliations" heading in Scopus. A practical illustration of this revision is shown in Table 2.

3 | RESULTS OF BIBLIOMETRIC ANALYSIS

A bibliometric review is a quantitative approach that uses the bibliometric data from selected studies, including citation patterns, publication and authorship patterns, to map the intellectual structure of a research field, track research trends over time, and identify emerging areas of interest.[25,32–34] Though the reviewed studies were limited to those with an African affiliation, the bibliometric analysis offered some insights into the broader natural fibre composite research domain.

3.1 | Publication output

Figure 2 presents the annual output trend across the 467 documents under consideration in this investigation. The graphical representation delineates publication outputs from both Scopus and WoS databases, in conjunction with a "Global" dataset, integrating the outputs from both sources while disregarding duplicate records. The labels on the graph correspond to the number of articles in the global dataset. The graph shows an increasing interest in the

TABLE 2 Sample of WoS data fields modified to Scopus format.

Original WoS format		Modified to Scopus format	
Affiliations	**Addresses**	**Affiliations**	**Authors with affiliations**
Durban University of Technology	[Krishna, K. Venkata; Kanny, K.] Durban Univ of Technol, Dept Mech Engn, Composites Res Grp, ZA-4000 Durban, South Africa	Durban Univ Of Technol, Dept Mech Engn, Composites Res Grp, ZA-4000 Durban, South Africa	[Krishna, K. Venkata; Kanny, K.] Durban Univ of Technol, Dept Mech Engn, Composites Res Grp, ZA-4000 Durban, South Africa

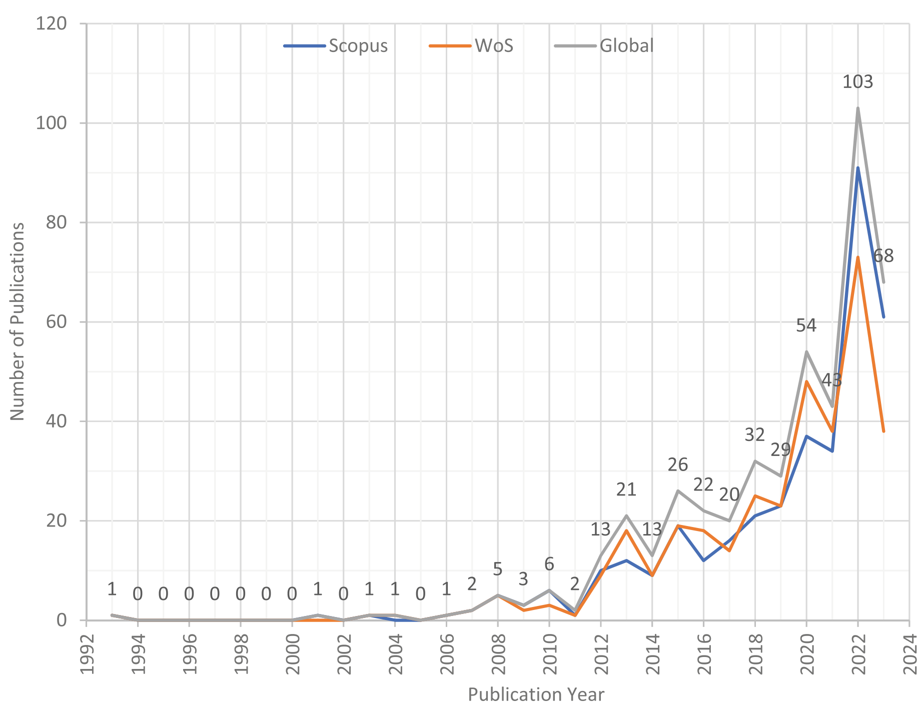

FIGURE 2 Annual publication in sales force literature in Scopus, WoS, and merged databases.

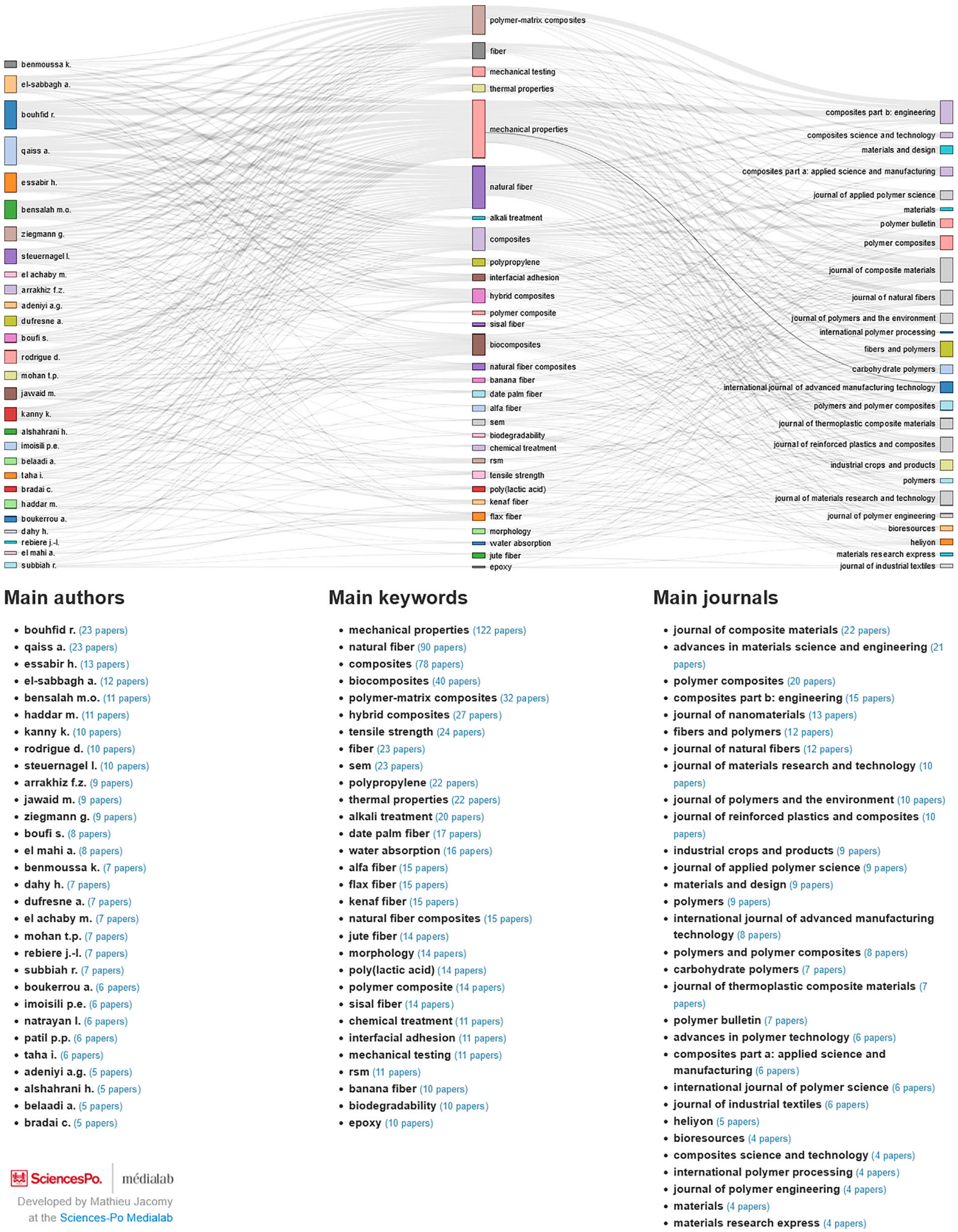

FIGURE 3 Relationships between the top authors (left), main keywords (middle) and top document sources (right)

subject, particularly over the past decade. Notably, the inaugural study by Bisanda[35] presented a sisal/natural resin biocomposite for the production of roofing panels proposed as an economical housing solution in Tanzania. However, research in this sphere across Africa encountered a phase of little productivity until 2008, which saw the publication of five studies. It is also noted that the publication trajectory peaked at 103 documents in 2022, about 91% more than the previous peak in 2020. The exponential growth in research output shows the increasing interest in this field. It is important to acknowledge that the current year, 2023, is represented as a partial year within the data scope, implying that not all anticipated documents for this timeframe have been published yet. A three-field Sankey diagram (Figure 3) was used to show the relationships between the top authors (left), main keywords (middle) and top document sources (right) and was prepared using ScienceScape. The 467 records considered in this study were sourced from 174 journals. The Journal of Composite Materials, published by Sage, Advances in Materials Science and Engineering, published by Hindawi, and Polymer Composites, published by Wiley, had the most publications in the research area.

3.2 | Publication domains

Figure 4 presents the classification of the retrieved document by different subject areas obtained from both Scopus and WoS. This classification was done to identify the industries for which polymer composites were developed. The largest sectors, 39% and 21%, were attributed to the Material Science and Engineering sectors. The other affiliated areas were closely related to the science around polymer composite material development and little to the sectors related to the industrial application of these polymer composites. This implies that the research on polymer composites is mainly focused on material development with physical, mechanical and chemical characterization rather than the application of the developed composites.

Upon closer scrutiny of the 467 examined documents, only a few studies revealed composites designed explicitly for targeted applications, as outlined in Table 3. Additionally, other studies explored the development of composites for potential applications, including wind turbine blades,[36,37] automobile body parts,[38–40] ballistic armour components,[41,42] non-structural building panels,[43,44] pressure vessels,[45] electric circuit boards,[46] and composite film for packaging applications.[47,48]

3.3 | Co-author analysis

In bibliometric analysis, mapping co-authorship relationships can present valuable insights regarding collaborations within a field. This section presents a co-authorship network and a network of co-authors' countries.

3.3.1 | Co-authorship network

The co-authorship network helps identify the leading authors and their networks in a research field. The

TABLE 3 Natural fibre polymer composites applications.

S/N	Application	Source
1.	Architecture: small-scale furniture	Chair/stool[49–54]; telephone stand[55]
2.	Structural building materials	Structural retrofitting[56–61]; rebar[62–64]
3.	Non-structural building materials	Tiles[65,66]; roofing panel[35]; composite panels[67,68]; particle board[69]
4.	Automotive components	Car window regulator handle[70]; break pad[71]

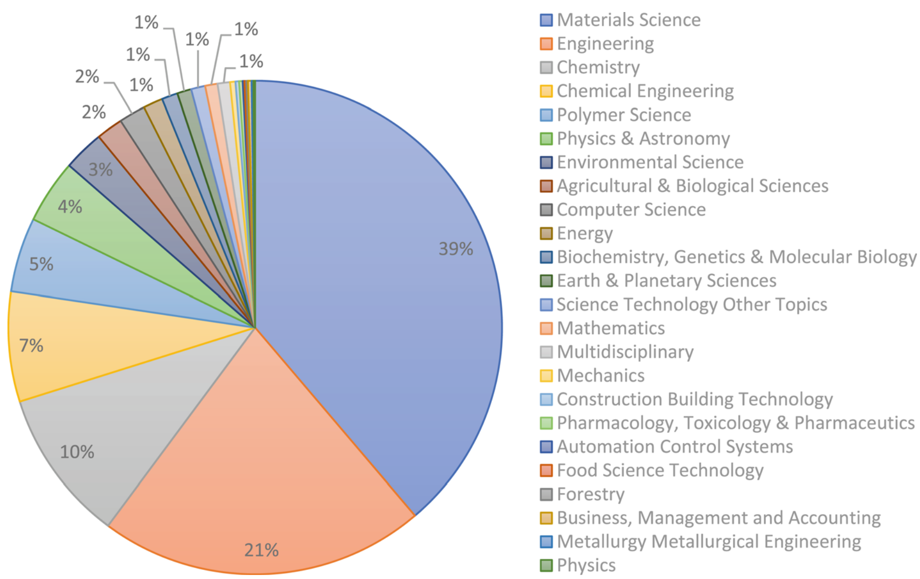

FIGURE 4 Domain classification of studies.

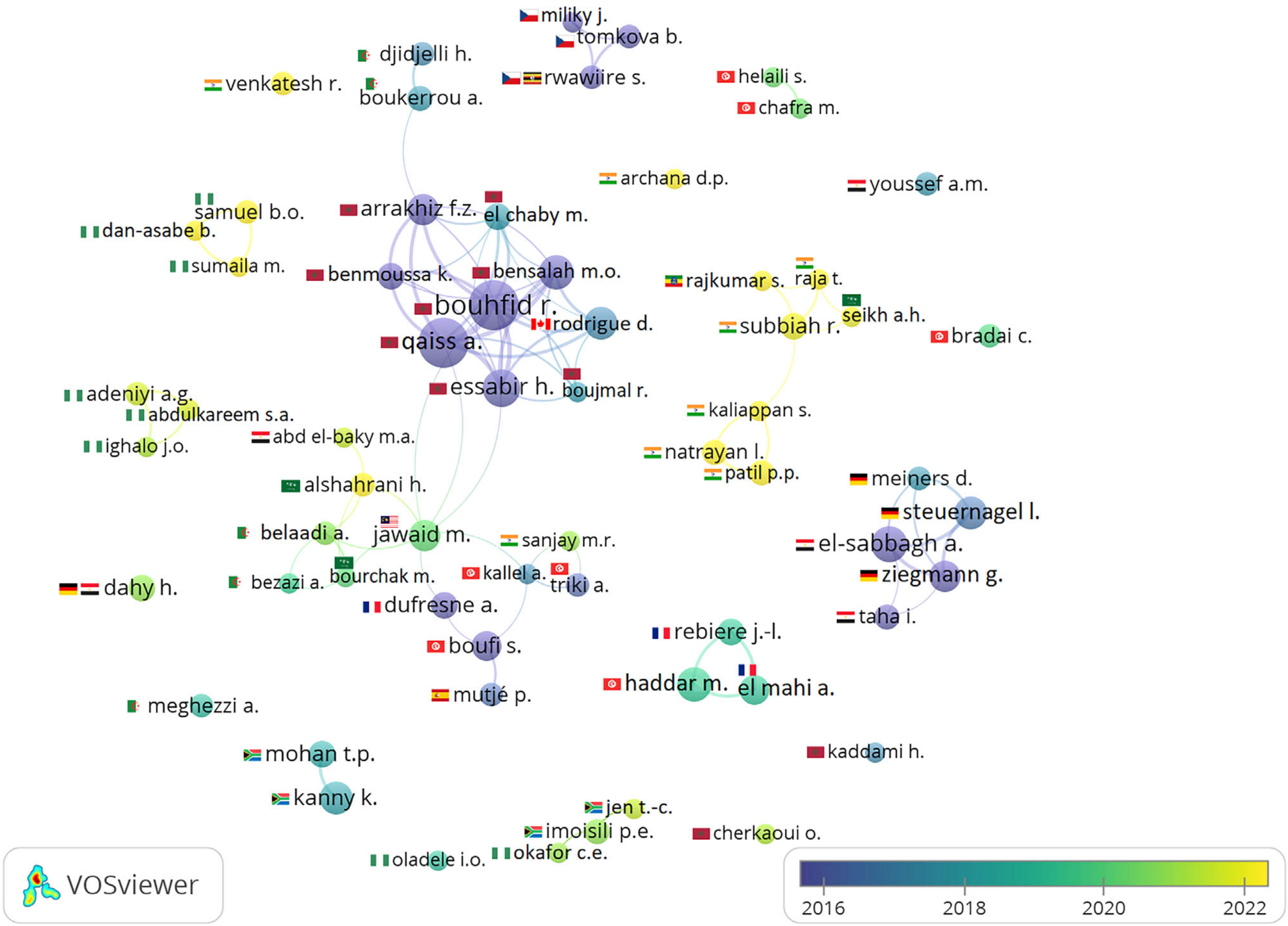

FIGURE 5 Co-authorship network.

bibliometric data was cleaned to prevent separate calculations of author names with different representations (i.e., Achaby M.E. was the same author as El Achaby M.). This cleaning saw the number of authors go from 1631 to 1605. The co-authorship network, which presents data from the merged dataset, is presented in Figure 5. For this network, the minimum number of author occurrences was set to four; of the 1605 authors recognized, 63 met the threshold. The colours depict the average publication year, and the size of the bubbles corresponds to the number of documents per author. The author-affiliated countries were also manually included to better understand the network links. The largest network was that of Bouhfid R., Qaiss A., and six other authors from Morocco.

3.3.2 | Networks of countries

Figure 6 presents a general network of international co-authorships between countries. It provides an overview of collaborations in the field and helps understand the knowledge flow. The colours depict the average publication year, and the size of the bubbles corresponds to the number of documents per author. The connection between two nodes (countries) signifies a collaborative association; the greater the density of link lines, the stronger the collaboration between the respective countries. The study area involved up to 59 countries, and the leading publication output was from India, Ethiopia, Egypt, Nigeria and France. Though the initial document search was limited to African countries, India still recorded the highest publication rate due to the strong collaboration between itself and Ethiopia in recent years. There was also a strong collaboration between France and Tunisia, Egypt and Germany, Nigeria and Malaysia, and France and Algeria. There have been noticeable collaborations generally between African countries and countries in Asia and Europe, but minimal collaboration within African countries.

The citation data was obtained from VOSviewer and overlayed with the publication output network using a simple graphics editor to show the most influential countries in the research area. The red bubbles correspond to the number of citations per country. With this, it can be

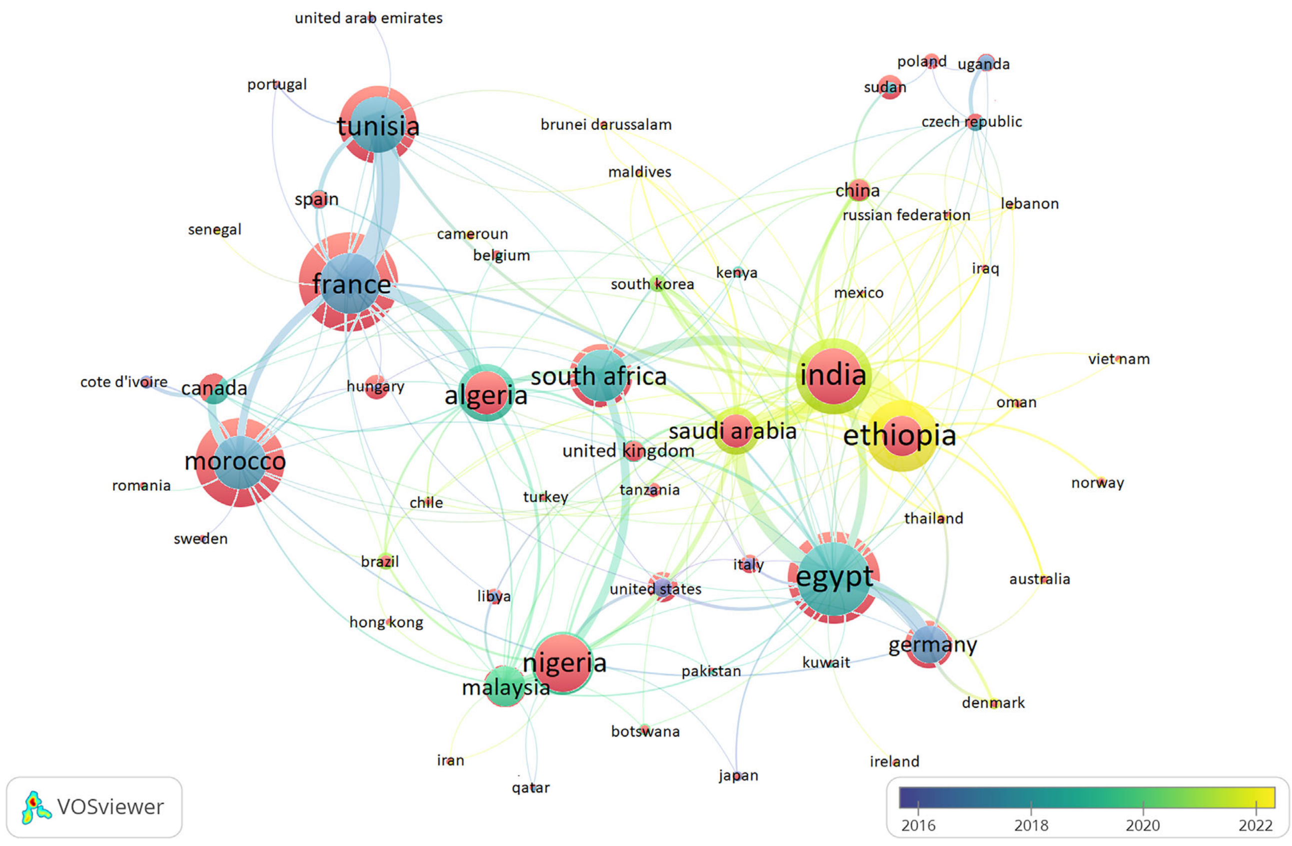

FIGURE 6 Network of co-authors' countries.

observed that France, Egypt, Morocco, Tunisia, South Africa and Nigeria have the most influential work.

3.4 | Keyword analysis

Keyword analysis presents an outlook on the research trend within a study area. There are keywords explicitly listed by the authors and others generated from the vocabulary used in the articles. The second set of keywords is classified as "index keywords" in Scopus and "keywords plus" in WoS. The "author keywords" were used for the keyword analysis because they provide insight into main topics and research trends. Though not every article listed author keywords, the data presented reflects 81.37% of the articles under consideration.

In this study, we addressed the issue of inconsistent keyword data and removed coding errors by "cleaning".[72,73] The keywords were processed to merge various keywords with the same meaning but written in different styles (i.e., alkali treatment, alkali chemical treatment and alkaline treatment were all recoded to alkali treatment, which was the most reoccurring of the three terms). Nonetheless, keywords with only partial similarity were not merged, as they could convey distinct meanings (i.e., interface and interfacial adhesion; polymer composite and polymer matrix). Also, words with different linguistic forms were reconciled to a single form in all instances (i.e., fiber, fibers, fibre and fibres were all recoded to fiber which was the most reoccurring of the three terms). This process saw the number of unique keywords go from 1087 to 758.

The keyword word cloud in Figure 7 was generated through the "Biblioshiny app" of the "Bibliometrix" software. The visualization was based on the top 62 keywords with a minimum of six occurrences. The themes were around mechanical and physical properties (mechanical properties, tensile strength, SEM, thermal properties, water absorption, morphology, finite element analysis, mechanical testing, flexural properties, RSM, thermal stability, thermogravimetric analysis, rheology, microstructure, thermal analysis, thermal conductivity and wear); natural fibers (natural fiber, fiber, date palm fiber, kenaf fiber, alfa fiber, jute fiber, alkali treatment, flax fiber, sisal fiber, banana fiber, cellulose fiber, glass fiber, hemp fiber, sugarcane bagasse and wood flour); composite design (chemical treatment, interfacial adhesion, optimization, biodegradability, reinforcement, Taguchi, surface treatment); composites (composites, biocomposites, polymer-matrix composites, hybrid composites, natural fiber composites, polymer

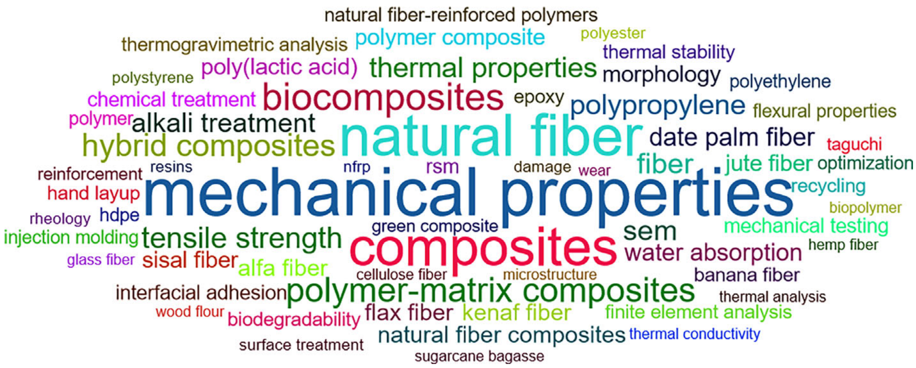

FIGURE 7 Keyword analysis.

composite, recycling, natural fibre-reinforced polymers, hand layup, injection molding, damage, NFRP and green composite) and polymers (polypropylene, poly(lactic acid), epoxy, HDPE, polyethylene, polymer, polystyrene resins, biopolymer and polyester).

4 | FIBRES SOURCED FROM AFRICA

Of the 467 documents considered in this study, 260 were found to have used natural fibres sourced from within Africa. This section focuses on these 260 publications, providing insights into the specific fibre form and type concerning Africa's natural fibre landscape.

4.1 | Fibre form

In an accurate sense, the term fibre refers to a material with a long axis much greater than its diameter. However, in this paper, the term fibre has been used loosely to refer to the reinforcing component of polymer composites, irrespective of its morphology and volume fraction in the composite. It is also noted that short fibres or particles are sometimes regarded as fillers rather than reinforcements in composites.[74] PMCs can be classified based on the architecture of their reinforcing material as fibre-reinforced composites, particle-reinforced composites and consolidated/structural composites (Figure 8). Fibre-reinforced composites can be categorized into two main types: continuous and discontinuous fibres. Continuous fibre composites comprise long, continuous fibres that can be unidirectional, woven, in braid or yarn form within the matrix.[75] Discontinuous fibre, on the other hand, incorporates shorter fibres that may be randomly distributed or aligned within the matrix. Discontinuous fibre composites can have short fibres (1–5 mm) or long fibres (5–50 mm).[76] Particle-reinforced composites are categorised into large particles and dispersion-strengthened

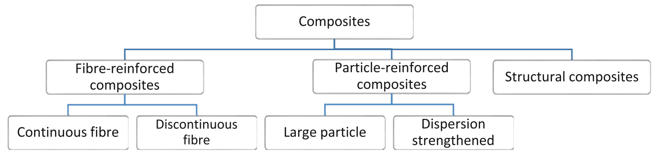

FIGURE 8 Classification of polymer composites based on fibre form.[79]

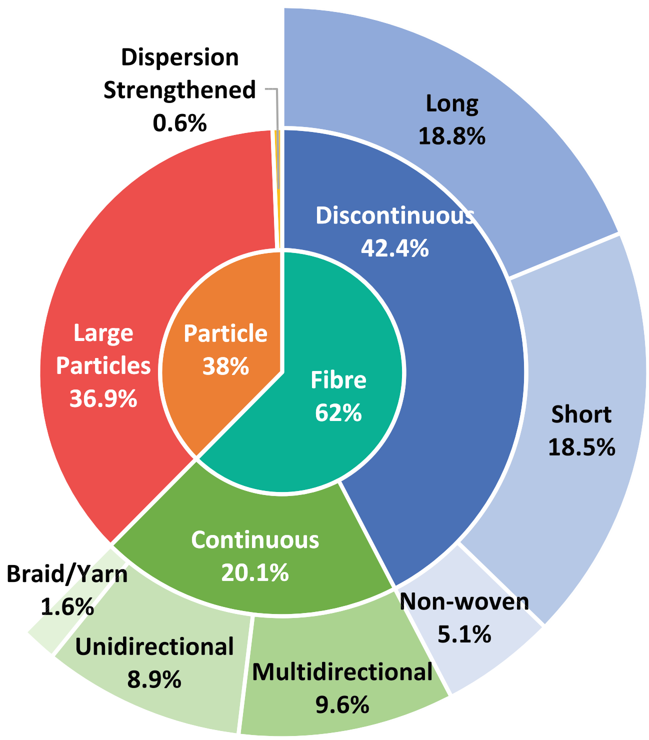

FIGURE 9 Distribution of natural fibre polymer composites based on reinforcement forms.

composites. With the latter, particles are much smaller, having at least one of its dimensions in the nano range (< 100 nm).[77,78] Structural composites can be a combination of composite and homogenous materials, with their

TABLE 4 Natural fibres sourced within Africa to develop polymer composites.

S/N	Fibre	Part	Country
1.	Abutilon straw	Stalk	Sudan[111,112]
2.	Alfa	Stem	Algeria[43,113–121]; Morocco[36,122–127]; Tunisia[57,128–139]
3.	Almond shell	Seed	Nigeria[140]; Tunisia[141]
4.	Argan nut shell	Seed	Morocco[142–144]
5.	Arundo donax L.	Cane	Algeria[145,146]
6.	Bamboo	Cane	Ethiopia[37,147]; Nigeria[148]
7.	Banana	Pseudostem, bunch stalk	Cameroon[149]; Egypt[150–152]; Mauritius[153]; Morocco[154]; Nigeria[70,155,156]; South Africa[157–160]
8.	Bark cloth	Tree bark	Uganda[161–165]
9.	Coconut/coir	Fruit	Cote d'Ivoire[127,166,167]; Nigeria[70,168–170]
10.	Corn	Cob, husk, silk, flour	Algeria[171]; Egypt[172–174]
11.	Cotton	Seed	Morocco[88]; Nigeria[168]; Egypt[152]
12.	Enset (false banana)	Pseudostem	Ethiopia[65,175–179]
13.	Flax	Bast	Algeria[84,180]; Egypt[63,71,80,150,181–183] South Africa[184,185]
14.	Hemp	Bast	Egypt[186]; Ethiopia[187]; Morocco[188]; South Africa[189]
15.	Jute	Bast	Algeria[43,84,180,190–192]; Egypt[63,64,172,193–195]; Ethiopia[37,187]; Morocco[41,81,82,196]; Nigeria[85,168]
16.	Kenaf	Bast	Egypt[197]; Nigeria[59,198,199]; South Africa[200–202]; Sudan[203]
17.	Luffa cylindrical	Fruit	Egypt[131]; Nigeria[204]; Algeria[205]; Morocco[206]
18.	Momordica Augustisepala	Stem	Nigeria[207–209]
19.	Olive	Fruit	Algeria[210–214]; Morocco[215]; Tunisia[216]
20.	Opuntia ficus-indica	Stem	Morocco[167,217–219]; Tunisia[220]
21.	Palm varieties		
	Date palm	Trunk, leaf, fruit, cluster arm	Algeria[103,221–231]; Egypt[150,232–234]; Ethiopia[235]; Nigeria[170]; Tunisia[48,236,237]
	Deleb palm	Fruit	Nigeria[238]
	Desert palm	Leaf	Algeria[239–241]
	Doum palm	Leaf, petiole, fruit	Morocco[242–246]; Nigeria[247]
	Oil palm	Fruit	Cote d'Ivoire[248]; Nigeria[249]
	Raffia palm	Leaf	Nigeria[198]
22.	Pine cone	Cone	Morocco[250,251]
23.	Pineapple leaf	Leaf	Ethiopia[66]; Nigeria[45,252–254]; South Africa[255]
24.	Plantain	Pseudostem, empty fruit bunch	Nigeria[40,256–260] South Africa[261–263]
25.	Rice	Straw, grain husk	Egypt[44,47,67,83,152,264–269]; Kenya[270]; Nigeria[271]
26.	Sisal	Leaf	Algeria[84,180]; Botswana[272]; Cameroon[273]; Egypt[183,274–276] Ethiopia[65,101,147,176,187,277–282]; Kenya[60,283]; Morocco[284,285]; Nigeria[95,168,198,286]; South Africa[287–291]; Tanzania[35,292]; Tunisia[293]
27.	Sorghum	Stalk, grain bran	Egypt[294]; Nigeria[295]
28.	Bagasse	Cane	Egypt[150,152,172,183,264,296–299] Kenya[270]; Morrocco[127,300]; Nigeria[168,301,302]
29.	Typha	Stem, leaf	Senegal[303]; Tunisia[304]
30.	Urena lobata	Bast	Nigeria[305,306]
31.	Wood	Stem	Algeria[307,308]; Egypt[309,310]; Kenya[270] Nigeria[68,311,312]; South Africa[313]; Tunisia[130]

(Continues)

TABLE 4 (Continued)

S/N	Fibre	Part	Country
32.	Cow tail	Animal hair	Nigeria[314,315]
33.	Human hair	Animal hair	Nigeria[314,315]
34.	Wool	Animal hair	Egypt[69,232]; Morocco[36,88]; Nigeria[314,315]; Tunisia[137,139]
35.	Shrimp shell (chitin)	Animal shell	Egypt[316]; Morocco[245]; South Africa[317]

properties determined not solely by the characteristics of the individual components but also by the geometric arrangement of the different structural components.[79] Sandwich composites,[43] laminates,[80–83] and honeycomb composites[84] are types of structural composites. These composites can have their reinforcements in the form of fibres, particles, or a combination of different forms.

Figure 9 presents the polymer composite types of the reviewed documents based on reinforcement form. Sixty two percent of the developed composites were fibre-reinforced, while 38% were particle-reinforced composites. Particles for reinforcing polymer composites can be obtained from various natural sources since they will be reduced to powder. These sources range from plant leaves, stems and seeds to animal shells. On the other hand, the reinforcement for fibre-reinforced polymer composites is typically from long fibre sources such as sisal, jute, kenaf, flax banana and plantain fibres.

4.2 | Fibre type

Natural fibres can be classified based on their source as animal, mineral and plant fibres. Plant fibres are primarily used in NFCs, and they can be further broadly classified based on the part of the plant from which the fibres are extracted. These classifications include bast fibres (e.g., jute, flax, hemp, kenaf), leaf fibres (e.g., sisal, pineapple), seed fibres (e.g., cotton), fruit fibres (e.g., coir), stalk fibres (e.g., rice, wheat), and cane fibres (e.g., bamboo). Table 4 overviews the fibres used to fabricate polymer composites within the reviewed documents. This table highlights fibres used in at least two instances across the reviewed documents. Other fibres that were used in only one study include African walnut shell (Nigeria),[85] ampelocissus cavicaulis (Nigeria),[86] cassava cortex (Nigeria),[87] chicken feathers (Morocco),[88] cissus populnea (Nigeria),[89] coffee husk (Ethiopia),[90] combretum dolichopetalum (Nigeria),[91] cyanara cardunculus L. (Algeria),[92] dioscorea alata (Nigeria),[93] diss grass (Algeria),[94] egg shell (Nigeria),[95] el retma (Algeria),[96] eucalyptus capsule (Morocco),[97] grapevine (Tunisia),[98] groundnut shell (Nigeria),[99] Mediterranean saltbush (Algeria),[100] Nacha–hibiscus (Ethiopia),[101] natural cork (Tunisia),[102] orange peels (Algeria),[103] posidonia oceanica (Tunisia),[104] raw pepper (Morocco),[105] reed fibres (Egypt),[106] screwpine (Mauritius),[107] sunflowers trimmings (Egypt),[108] teff straw (Ethiopia),[109] and triumfetta cordifolia (Cameroon).[110]

The reviewed documents featured natural fibres sourced from eighteen African countries, with the most used fibres being sisal, palm varieties, alfa and jute, as shown in Figure 10. Sisal emerged as the most used natural fibre in 10 of the 18 contributing countries. Sisal also the premier crop in Africa's natural fibre polymer research.[35] Its fibres are typically extracted from the sisal plant leaves, whose length varies from 0.6 to 1.5 m.[318] Palm trees are a group of tropical and subtropical plants characterized by long trunks and fan-like leaves. Polymer composites were made with fibres from various palm species, including date palm, deleb palm, doum palm, oil palm, raffia palm and Washingtonia Filifera (desert) palms. It is worth noting that coir, obtained from the coconut tree, is also a palm variety but was classified in its category because of its popularity. Among the various palm varieties that emerged, date palm was the most used, accounting for 62% of all the studies involving the different palm varieties. Date palm is native to North Africa and the Middle East. Though it serves great agricultural and economic importance in the region, 2.8 million tons of biomass are generated annually from date fruit harvesting and palm pruning, leading to serious waste management concerns.[48,233,237] Fibres can be extracted from various parts of the palm tree, such as the leaflets, rachis, petiole, cluster arm, trunk, fruits and seeds. When extracted, these fibres have different physical and mechanical properties.[235] Alfa is a tussock grass that grows to 1 m in height in the dry parts of North Africa and the southern parts of Europe.[114–116] Jute is one of the most commonly used natural fibres for engineered composites. Fibres are typically extracted from the bast of the plant and can get to 2–3.5 m tall.[318] Banana, plantain and enset (also referred to as false banana), all members of the Musaceae family, have also been commonly used. Fibres are typically extracted from their pseudostem but can also be obtained from the fruit bunches.

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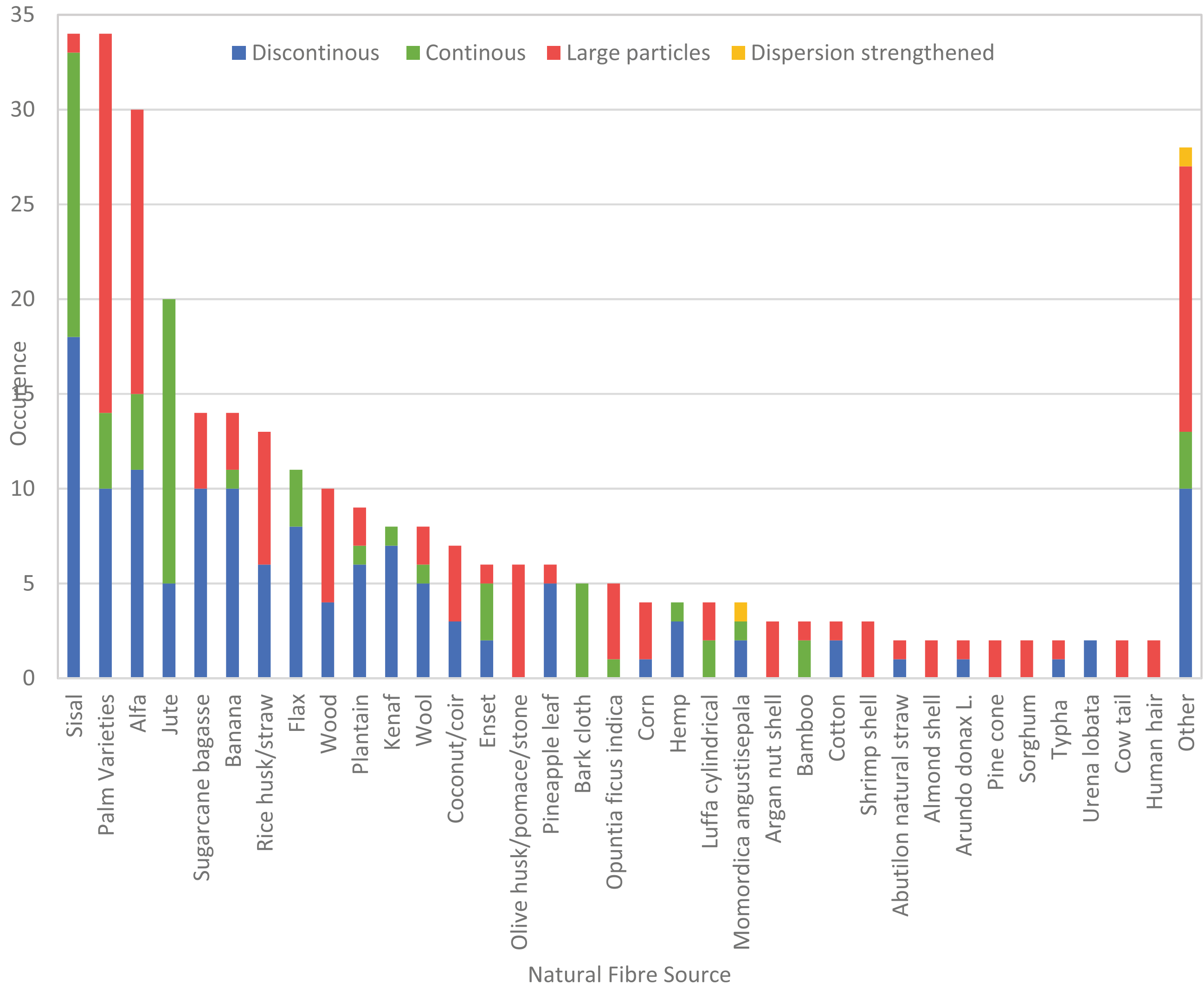

FIGURE 10 Africa's natural fibre sources.

5 | IMPLICATIONS

Table 5 presents the percentage production of selected fibre crops from 2010 to 2021 by the Food and Agriculture Organization of the United Nations.[319] The crops listed were specifically focused on long natural fibre sources since natural fibre particles can be obtained from an endless list of natural sources. It can be observed that Africa's contribution to the production of major fibre crops is low, typically falling below 10%. However, bananas, dates, pineapples, plantains, and sisal are exceptions. Africa can significantly contribute to the global supply chain of natural fibre, focusing on plantain (and other closely related crops), dates, and sisal. Africa has contributed the largest share to plantains with 69.57% and the second largest share of dates and sisal with 42.93% and 30.34%, respectively, since 2010.

For the NFC sector to develop effectively, there is a need for adequate regulation. Regulatory frameworks aimed at promoting research and development for materials for NFCs and ensuring the quality and performance of such materials are maintained. In addition to this, Laasri[18] proposed a framework that ensures the supply of quality fibres, including a global database of the availability of different natural fibres by region. This current study is a step in that direction. Aside from the technological implications of the natural fibre industry, its development can help the economy of local communities and ensure food security.[23]

6 | PERSPECTIVES FOR FUTURE RESEARCH

There is a need to explore more practical industrial applications of engineering composites. While numerous studies have assessed the mechanical properties of natural fibre polymer composites, there remains a considerable

TABLE 5 Total production of major natural fibre source crops by continents from 2010 to 2022.[319]

Plant fibre crop	Total production of plant fibre crops (Million Tonnes)					
	Africa	N. America	S. America	Asia	Europe	Oceania
Bananas	234.28 (17.04%)	136.52 (9.93%)	235.90 (17.16%)	743.13 (54.05%)	5.83 (0.42%)	19.26 (1.40%)
Coir, raw	0.50 (3.49%)	0.00	0.00	13.92 (96.51%)	0.00	0.00
Dates	42.55 (42.93%)	0.57 (0.57%)	0.00 (0.00%)	55.82 (56.31%)	0.18 (0.18%)	0.00
Flax, processed but not spun	0.10 (1.02%)	0.00	0.07 (0.70%)	0.32 (3.32%)	9.01 (94.96%)	0.00
Jute, raw or retted	0.10 (0.25%)	0.00 (0.01%)	0.01 (0.03%)	40.30 (99.72%)	0.00	0.00
Kenaf, and other textile bast fibres, raw or retted	0.20 (6.91%)	0.15 (5.27%)	0.19 (6.69%)	1.76 (60.70%)	0.59 (20.43%)	0.00
Maize (corn)	953.67 (7.55%)	4707.72 (37.29%)	1601.72 (12.69%)	3955.83 (31.33%)	1399.63 (11.09%)	7.35 (0.06%)
Oil palm fruit	245.20 (5.75%)	81.26 (1.91%)	147.16 (3.45%)	3756.50 (88.13%)	0.00	32.46 (0.76%)
Pineapples	57.31 (18.51%)	59.93 (19.36%)	53.61 (17.32%)	137.28 (44.34%)	0.01 (0.00%)	1.46 (0.47%)
Plantains and cooking bananas	310.82 (69.57%)	32.95 (7.37%)	54.59 (12.22%)	48.36 (10.82%)	0.00	0.08 (0.02%)
Rice	390.14 (4.39%)	145.50 (1.64%)	298.16 (3.35%)	8006.53 (89.99%)	49.52 (0.56%)	6.90 (0.08%)
Sisal, raw	0.98 (30.34%)	0.32 (9.98%)	1.74 (54.19%)	0.18 (5.49%)	0.00	0.00
Sugar cane	1116.04 (5.01%)	1939.67 (8.70%)	10040.91 (45.05%)	8795.31 (39.46%)	0.05 (0.00%)	395.37 (1.77%)
True hemp, raw or retted	0.00	0.00	0.05 (2.18%)	0.83 (35.38%)	1.47 (62.44%)	0.00
Total	(7.25%)	(14.24%)	(24.36%)	(50.02%)	(3.19%)	(0.94%)

Note: Values in parenthesis represent the percent production of each continent.

gap in developing prototypes suitable for real-world applications across diverse industries.

Additionally, further research is needed to establish more comprehensive natural fibre mappings for other regions to ensure more efficient utilization of locally available fibres on a global scale.

7 | CONCLUSIONS

The bibliometric analysis revealed Africa's growing interest in natural fibre polymer composites, especially over the past decade. The research domains revealed a strong emphasis on the science of composite material development over practical industrial applications. Within the continent, Ethiopia, Egypt, Nigeria, Tunisia, and Algeria are leading in terms of research output, while Egypt and Morocco have the most influential work in terms of citation count. The collaboration networks highlighted partnerships between African countries and international counterparts, notably France, Germany, Malaysia, and in more recent years, India. However, intra-African collaboration remains limited. The keyword analysis saw the major themes around mechanical and physical properties, various natural fibre types, composite design, composite types, fabrication techniques, and polymer types.

From the 467 documents considered for the review, 260 studies were identified to have developed polymer composites with natural fibres sourced from within Africa. Natural fibre polymer composites have been developed as fibre-reinforced, particle-reinforced, and structural composites. Thirty-five types of natural fibres found in Africa have been used to develop polymer composites. Sisal, date palm, alfa, jute, and the Musaceae family (including banana, plantain, and enset) are the most used fibres in the region. This paper is a valuable resource for researchers, engineers, and policymakers interested in advancing sustainable material development. It provides a natural fibre catalogue to help select appropriate, locally sourced raw materials to create more sustainable polymer composites.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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