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Exploring Anti-Ballistic Technology Development through Bibliometric Analysis of Scopus Database Records

Fattah Maulana [1], Ubaidillah [1, 2*], Bhre W. Lenggana [1, 3], Dody Ariawan [1], Zainal Arifin [1]

[1] *Mechanical Engineering Department, Faculty of Engineering, Universitas Sebelas Maret, Surakarta 57126, Indonesia.*

[2] *Mechanical Engineering Department, Islamic University of Madinah, Madinah Al Munawwarah, 42351, Kingdom of Saudi Arabia.*

[3] *PT. Bengawan Teknologi Terpadu, Karanganyar, Indonesia.*

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Abstract

Anti-ballistics technology's significance in safeguarding national defense and security has intensified amid rising threats and insurgencies. While prior studies have investigated advancements in anti-ballistic technologies, a noticeable gap persists in discussions involving anti-ballistics through bibliometric analysis and cutting-edge evaluations. This scarcity of research originates from the sensitivity surrounding weapon-related discourse. This article aims to bridge this gap by unveiling an exhaustive bibliometric analysis and contemporary assessment of anti-ballistics research spanning 47 years. The analysis's distinctiveness lies in its approach to addressing this research void within the anti-ballistics domain, achieved through meticulous scrutiny of existing research via bibliometric analysis techniques. The analysis was facilitated by employing Biblioshiny software integrated with RStudio and VOSviewer. Data processing encompassed keyword searches within the Scopus database, with outcomes presented in CSV format. Notably, the study's findings highlight the United States as the frontrunner in reference count and publication output within the anti-ballistics realm. The National Institute of Standards and Technology stands out with 89 articles. Furthermore, a systematic categorization of anti-ballistic materials based on their developmental applications was conducted. Temporal assessment revealed shifting research trends, transitioning from "ceramic materials" in 2016 to "nonmetallic matrix composites" in 2020, particularly for body armor applications. This endeavor involves recognizing notable contributors, categorizing diverse materials under study, and tracking research trend shifts over time. The analysis offers indispensable insights to guide diverse stakeholders' decision-making. It's noteworthy that this bibliometric analysis holds particular value for novices or those entering the field for the first time. Our study significantly enriches the anti-ballistics domain through contributions to library studies and research mapping. By presenting a comprehensive overview of anti-ballistics research trends, our analysis enhances comprehension and empowers informed decision-making for researchers, practitioners, and policymakers alike.

Keywords: Bibliometric Analysis; Anti-Ballistic; Bulletproof Vest; Anti-Ballistic Development; Anti-Ballistic Materials.

1. Introduction

The technique known as anti-ballistics is employed to safeguard individuals from potential harm, such as injuries, wounds, or hazardous circumstances, commonly encountered by military personnel. This technology aims to mitigate or minimize the damage inflicted by ballistic projectiles on the thoracic and abdominal regions. Thoracic injuries

* Corresponding author: ubaidillah_ft@staff.uns.ac.id

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encompass a spectrum of severity, spanning from mild skin abrasions (as classified by the abridged injury scale [AIS] as level 1) to more serious sternal fractures (categorized as AIS 3+). These injuries correlate with impact velocity and bone mineral density [1]. Historically, vests have been associated with safeguarding the human body against potential harm or damage. Nevertheless, it is crucial to note that donning a jacket does not guarantee complete protection from gunfire; it may mitigate the likelihood of sustaining an injury. Since the inception of anti-ballistics equipment in the mid-1970s, the prevailing menace encountered by law enforcement agents has been gunshot injuries [2, 3].

Ballistic hazards encompass the potential dangers arising from the propulsion of airborne objects at significant velocities, including shrapnel and similar projectiles. These hazards are particularly relevant in the context of military operations. The extent of injury resulting from a bullet impacting a person is contingent upon the specific location of the impact and subsequent penetration within the body. Multiple designs of vests exist to protect against ballistic risks. The vests have been specifically engineered to offer both benefits and drawbacks in safeguarding the crucial organs of the human body against ballistic harm. The variation in vest design is contingent upon the wearer's specific characteristics and the threat level they face. Some modifications need to be implemented to prevent errors in the utilization, creation, and upkeep of anti-ballistic measures. The protected area must be shielded by an array of protective panels in front and back [4]. Testing procedure discussion is frequently undertaken to fulfill the requisite anti-ballistic criteria within the relevant field [5]. The typical practice follows national and global norms and adheres to the principles of esteemed worldwide entities specializing in anti-ballistics, such as the National Institute of Justice (NIJ).

Several aspects are commonly examined in anti-ballistic investigations, including historical perspectives [2], materials used [6–8], design considerations [9], and testing methodologies [5]. Many researchers highly regard the creation of anti-ballistic materials. Since 1887, Dr. George E. has conducted experiments involving silk fibers to create vests [10]. Developing and enhancing anti-ballistic materials has increased weight reduction and flexibility regarding their physical morphology. Anti-ballistic materials typically have rigid, high-strength structures with excellent tensile properties, offering enhanced protection against ballistic threats. The soft body armor layer is composed of stacked, dry ballistic materials. The primary application of this innovation is incorporating body armor layers designed for low levels of ballistic risk, specifically those classified under the National Institute of Justice (NIJ) levels I, IIA, and II.

Furthermore, this innovation exhibits commendable flexibility in accommodating various bodily movements [9]. Moreover, these resources are available in diverse formats and can be customized to suit the specific requirements of those working in the respective domain. In the past, the utilization of metal materials was predominant. However, there has been a shift towards using both fiber and metal components, hence modifying the functionalities of the resulting products to cater to the changing requirements.

The field of body armor research has made significant advancements by exploring various types of fibers and designs. These include silk fiber [10], conventional woven fabrics or treated woven fabrics [11], as well as more complex 3D fabrics [12]. Other materials, such as Fiberglass/Polyester Bi-Panels [13], HGM Fiber Carbon Composites [14], Aramid, and unidirectional or multi-axial non-crimp fabrics, have also been investigated. The primary applications of aramid-fiber-based composites in the anti-ballistics field mostly revolve around using such materials to produce soft body armor. Some research has examined the mechanical properties of aramid and its ballistic effects on this material [15–17]. Several scholarly articles have discussed using a ceramic matrix polymer-coated layer to produce anti-ballistic soft body armor. This research has focused on manufacturing armor materials by implementing ceramic-based sandwich structures, also known as hybrid composites, employing the vacuum method [18]. Another notion within the field of material development is the creation of a composite target plate through the combination of SiC ceramics and Dyneema fibers. The integration of silicon carbide (SiC) ceramics with Dyneema material has the potential to produce a target plate that is both lightweight and capable of meeting the level four (NIJ IV) criteria set by the US National Institute of Justice [19]. It has been asserted that SiC ceramics reinforced with Dyneema fibers have superior strength compared to alloys composed of CrFeCoNi, CrMnFeCoNi, and CrFeCoNiMnx (where x represents varying values of 0, 0.3, and 0.6). The plates possess a limited capacity to endure the highest achievable velocity of projectiles, estimated to be around 840 m/s, and are categorized solely as armor-level type III [20–22]. Every solution is subjected to simulation using a designated model and evaluated for a specific threat afterward.

Furthermore, it is common to categorize anti-ballistic materials into two distinct classes: hard body armor and soft body armor. Research has been conducted on developing soft body armor utilizing natural and synthetic fibers. One of the objectives is to maximize waste management efficiency or use resources with poor intrinsic worth. Incorporating abundant natural fibers such as hemp, water hyacinth, wood debris, banana stems, and others into anti-ballistic materials is a viable proposition. Bamboo is a viable option among the various material mixes that can be utilized in developing anti-ballistic technology. According to the NIJ standards, bamboo can withstand a 7.62×51 mm caliber projectile, meeting the criteria for class III designation [23]. Acquiring optimal performance is of utmost importance, particularly in bulletproof panels that exhibit enhanced flexibility and safer structural characteristics.

Conversely, hard body armor is combined with soft body armor in situations with an elevated ballistic threat. Anti-ballistic armor can be manufactured using various materials, including metals, composites, and ceramics. These specialist body armor suits have been designed and implemented for highly specific tasks. Nevertheless, to effectively counter explosive weapons, armor systems must provide full-body coverage and be constructed with pliable armor materials that facilitate unrestricted mobility [24]. Chen et al. endeavored to create a helmet shell array featuring subtle reinforcement textures, which yielded intriguing findings, including enhanced impact protection [25, 26].

Moreover, there has been an increased focus on fiber-based ballistic composites in many military applications because of the advantageous properties exhibited by this material. Fiber-based composites provide exceptional mechanical qualities concerning high-speed impacts while also providing advantages like weight reduction and increased payload capacity. These entities possess characteristics that align with environmental sustainability, exhibit excellent quality, and demonstrate notable speed capabilities. One illustration involves the utilization of composites in vehicle reinforcing strategies aimed at safeguarding medium-bore guns with a bore diameter of 12.7 mm. Fiber-based composite materials are characterized by complex material structures, with numerous factors influencing their mechanical properties and response to ballistic impacts. These factors include the types of fibers used, the resins employed, and the interfaces between the resin and fibers. This is particularly relevant in fortification material development [27].

Hence, to achieve enhanced anti-ballistic capabilities, explore innovative materials such as Kevlar, S glass plastic, polycarbonate, metal mesh, ceramics, and magnetorheological substances [28]. Kevlar, a synthetic fabric of polymer compounds, has molecules that arrange themselves into elongated chains, characterized by their parallel alignment and dense interweaving. Joining special plastic sheets involves pressing and laminating them together, utilizing various materials such as fiberglass, cotton, paper, and other substances. These materials are immersed in plastic resin and then crushed into thin, firm, and malleable sheets [29]. Polycarbonate is a thermoplastic material that contains carbon as an integral component within its molecular structure [30]. Metal mesh refers to a structural element or partition consisting of numerous interlinked metal filaments, which may manifest as a meshwork or a sheet, contingent upon its specific configuration. Metal meshes can undergo various manufacturing processes to achieve different formats, including expansion, etching, weaving, knitting, and welding [31]. Ceramic, also known as keramik, is an inorganic, non-metallic solid material formed by shaping and hardening through exposure to elevated temperatures. Typically, ceramics exhibit intricate structures, possess resistance against corrosion, and display brittleness [32]. Magneto-rheological (MR) or magneto-restrictive fluid refers to a pliable medium infused with nanoparticles, which can be rendered rigid through electrical stimulation [33].

Utilizing robust, lightweight, and pleasant anti-ballistic materials is paramount for individuals. Due to ongoing advancements and enhancements, personal protective equipment may be acquired with enhanced safety, security, and comfort. Numerous researchers have conducted diverse innovations in anti-ballistics, emphasizing improving security measures while impacting multiple interconnected parts. Different components can be categorized with an anti-ballistic categorization of a specific level, exhibiting variations in their anti-ballistic visual appeal, patterns, forms, and weight, contingent upon the intended recipient. The comprehensive comprehension and depiction of ballistic impacts often need to be revised when relying solely on exploratory, experimental, numerical, or analytical methodologies. Some scholars have employed a blend of exploratory [34–36], quantitative [37], applied, and explanatory research approaches to enhance the understanding and analysis of significant data within the context of ballistic impact systems [38–40]. Ballistic testing is imperative to present novel solutions, understand the intricate nature of penetration, and ascertain the crucial parameters that influence impact resistance for body armor [41–43] and armor plates [44]. Typically, scholars in this advancement employ experimental or Finite Element approaches (FEM) [45–47] to acquire the intended outcomes.

Nevertheless, many individuals continue to uphold faith in the experimental approach, particularly in assessing the dynamic reaction of anti-ballistic impact [48]. However, now, a wide range of models and simulations are available, encompassing macroscopic [49, 50], mesoscopic [51, 52], microscopic [53, 54], and even nanoscale [55] approaches, all of which strive to represent the dynamics of ballistic collisions [56, 57] accurately. The final stage in evaluating the efficacy of new materials for protective systems is typically experimental work. Multiple tests have demonstrated alterations in the behavior of materials when subjected to high deformation velocities [58–60]. When considering an alternative viewpoint, it becomes apparent that the process and production costs are significant and warrant careful consideration.

The efficacy of anti-ballistic technology has been extensively assessed to discover any deficiencies and strive for optimal performance. In advancing anti-ballistic technology, it is imperative to incorporate thoughts and data derived from prior research endeavors, typically disseminated through review papers in academic publications. Several review articles explore various aspects of anti-ballistic materials, including their testing methodologies, historical development, and other relevant subjects. Nevertheless, a majority of researchers express a preference for the advancement of anti-ballistic materials. Since as far back as 1887, Dr. George E. has conducted experiments involving silk fibers to create vests [7]. As of February 2023, examining Scopus using the keyword "body armor" yielded 2441 documents. When the search was refined with the keyword "material," the results were limited to 1390 documents. These documents encompass various types, including 861 articles, 339 conference papers, 81 reviews, 70 book chapters, 17 conference reviews, 12 books, 7 notes, 1 letter, 1 short survey, and 1 undefined source. This data indicates a significant volume of scholarly discourse on anti-ballistic materials, accounting for approximately 57% of the documents retrieved.

Moreover, upon examination of the article review, including 81 papers, it is evident that the initial publication on anti-ballistic material was conducted by MacPherson et al. in 1977. The 81 articles reviewed in this study were cited 843 times in 2022, as shown by 739 separate papers. A bibliometric study is essential to assist future scholars in comprehensively mapping the issue, given the extensive research and citation of several works.

Of the 81 Article reviews on anti-ballistic materials, the average discusses details and clearly about the state-of-the-art materials. However, this paper will present an exciting discussion about; (1) the main contributors leading countries, institutions, research groups, authors, and research fields; (2) the most productive journals on the historical map of the topic; (3) the significant articles with the highest number of citations; and (4) research interests and perspectives. The uniqueness of this analysis lies in its approach to filling a gap in the study of anti-ballistics. It achieves this by conducting a detailed examination of existing research using bibliometric analysis techniques. This involves not only identifying major contributors to the field but also categorizing the types of materials being researched and tracking how research trends have changed over time. Additionally, the analysis offers valuable insights that can guide decision-making for various stakeholders. It's important to note that this bibliometric analysis is particularly useful for newcomers or those new to the field.

2. State of the Art

Body armor made from metal material has been around for hundreds of years. Larger objects, such as vehicles, are called "weight protection." Also, so-called "weight protection" protects larger objects, such as vehicles. However, only a few decades ago, at the end of World War II, a lighter solution emerged, especially for military personnel, in the form of nylon ballistic vests. However, it does not come close to the ballistic protection offered by the aramid fibers, threads, and fabrics in personal armor. Another advantage of ultra-fine polymer filaments (not just aramid [13, 61, 62]) is that they offer an incredibly flexible material, which supports a high level of comfort for the wearer. To make it easier to understand, see Figure 1.

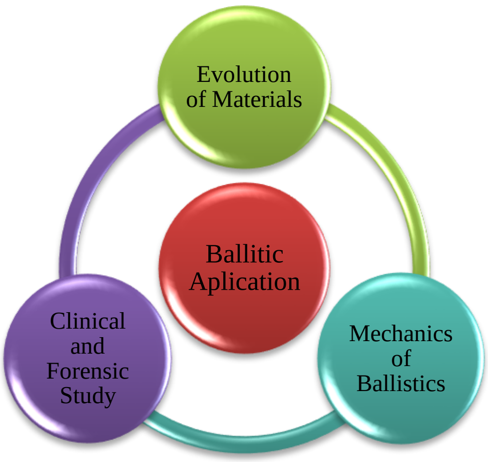

Figure 1. Applications of ballistics

Soft body armor is the primary application for composites made from aramid fibers in ballistics. Several studies have examined the mechanical properties of aramid and the impact of ballistic forces on fabrics and their composites [63–65]. These investigations have employed experimental techniques and the finite element method (FEM) [66–68]. The findings have provided insights into the efficacy of ballistic protection systems and the level of protection offered by bulletproof vests [46, 69]. Recent literature analyses on ballistic protection [8, 31, 70, 71] provide insightful commentary on failure processes and the utilization of highly specialized solutions that effectively combine various materials to counter diverse threats. Various research investigations have been conducted on aramid fibers exhibiting diverse topologies, ranging from conventional or modified forms [72] to three-dimensional fabric structures [51, 73]. Both unidirectional and multiaxial non-wrinkle materials are being investigated for hazards while being simulated under specified model settings. The authors' documentation led them to conclude that each solution needed to be tested experimentally. The failure mechanism exhibits a resilient statistical reliability design before its deployment in combat scenarios. In the context of anti-ballistic materials, it is imperative to ascertain their appropriate application. Following established material usage regulations, we have developed anti-ballistic materials and their corresponding applications, including anti-ballistic helmets, military vehicles, body armor, and panels. In order to enhance comprehension, the schematic representation is presented in Figure 2.

Based on Figure 2, the conclusion is that there are many types of anti-ballistic materials. The selection of appropriate materials is mandatory in order to meet the needs of users. Based on the demands of weapons development, defense development must be adjusted. Therefore, military defense tool producers must know what loads will be faced and how to select materials that can withstand the loads faced. Some options can be selected for some materials, such as UHMWPE, Aramid, hybrid thermoplastic, ceramic, E-glass, and titanium. To make science more accessible, the first scientists need to know the function of the science they will learn. After knowing the use of science, the second step is understanding the source of knowledge or its basis. Scientists also need to know the developments so far so they can contribute to the development of science.

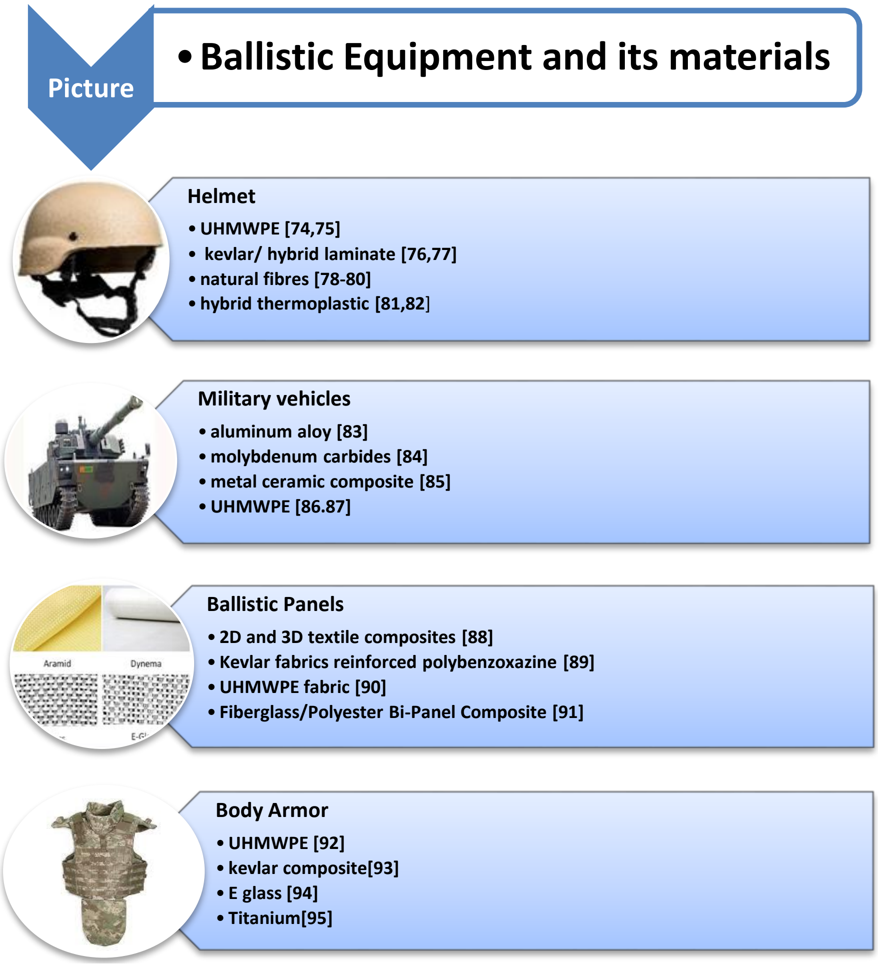

Figure 2. Rundown anti-ballistic material and product application

Recently, there has been a notable surge in studies about anti-ballistics, with a particular emphasis on investigating various target locations. The ceramic and Kevlar-29 composites with honeycomb structures were investigated by Goda and Girardot [96] by applying cylindrical ballistics. The findings from the numerical analysis indicate that the ballistic impact performance is significantly affected by the characteristics of the cohesive material, the woven fabric material, and the arrangement of layers. The performance of titanium sandwich panels against impact loads from hemispherical projectiles was investigated by Rahimijonoush and Bayat [97]. The study's findings indicate that the primary mechanism for absorbing impact energy in the symmetrical sandwich panel was through the back-face sheet. The ballistic limit exhibited a linear relationship with the increase in thickness of either the rear or front face sheet on a specimen of identical weight. In their study, Chatterjee et al. (1998) analyzed the performance of composite sandwich panels when subjected to 9-mm bullet projectile loads, which were propelled at an average velocity of 400 m/s [98]. The presence of liquid dilatants in the SCP led to the observation of the composite sandwich. The hollow composite material was found to absorb 43.96% less impact compared to the material under consideration. The observed change in energy absorption per unit mass increase was 22.43%. It is plausible that the SCP was purposefully designed and built to cater to various applications that necessitate heightened energy dissipation capabilities. The study undertaken by Yu et al. (1999) [99] involved research on anti-ballistic measures utilizing blunt-shaped projectiles with a Y-shaped core sandwich model. The findings and analysis indicate that the impact resistance of composite sandwich constructions, including Y-shaped cores, surpasses that of laminates. In their study, Khare et al. [100] investigated the ballistic load resistance of cylindrical sandwiches with honeycomb cores when subjected to cone-nosed projectiles. This study's findings indicate variations in the cell thickness and skin thickness per wall, ranging from 0.7 to 2.0 mm and 0.03 to 0.09 mm, respectively. Additionally, it was observed that the ballistic limit experienced an increase of 72.2 and 10.9 m/s.

Nevertheless, when the magnitude of the side length was altered from 3.2 to 9.2 millimeters, there was a discernible reduction of 9.9 meters per second in the ballistic limit. The study conducted by Wu et al. [101] examined the properties and performance of an aramid-carbon hybrid fiber-reinforced polymer (FRP) material specifically designed for applications in composite armor systems. The laminate composite structure underwent exposure to ballistic loads originating from AP 7.62 M61 bullets. The primary failure modes observed in FRP laminates, as indicated by the findings of their study on laminate composites, are fiber compression failure and tensile matrix failure. Changes in the fiber-reinforced polymer (FRP) laminate stacking sequence can also impact both factors. The lowest areas of fiber compression and matrix tensile failure occur when carbon fiber is layered on top of the FRP laminate.

In their research, Yang et al. (year) investigated shipbuilding constructions, focusing on a double-arrow composite hemispherical projectile auxetic design [102]. According to the results obtained from the Missouri Educational Component Test (METC), it was observed that the auxetic structure had a relative density of 16.66, representing a 23.06% increase compared to the auxetic design, which had a relative density of 9.08%. The ballistics had a rise of 35.56% and 54.89%, respectively. The observed phenomenon can be attributed to the significant increase in relative density, as confirmed by experimental data, from 9.08 to 16.66 and 23.06%, respectively. In their research, Vescovi et al. [103] investigated a composite structure by employing interacting hybrid composites composed of woven Kevlar and S2 glass subjected to milling with 0.357 Magnum FMJ ammunition. The present investigation acquired the deviation observed at the ballistic limit. The observed value consistently remained below 5.33%, with a peak of 3.87% occurring at an impact velocity of 430 m/s, which closely approximates the ballistic limit.

Furthermore, it is worth noting that the numerical ballistic curve exhibited a relatively seamless transition to the linear segment, closely resembling the experimental curve. The research undertaken by Mohammad et al. [104] pertains to anti-ballistics. The findings indicate that the monolithic shell target saw a decline in ballistic performance of 6.49% as a result of the anti-ballistic measures. When comparing the two marks, it was observed that the multilayer target exhibited a reduction of 3.88% in its ability to resist hits from oblique angles. In their study, Han et al. [105] examined the disparities between the projected ballistic limit velocities of targets measuring 2, 4, 4.82, 8, and 9.94 mm and the corresponding experimental values. The deviations in the simulated values were 12.3, 0.1, 0.0, 4.2, and 4.9%, while the experimental results showed variations of 9.0, 17.5, 21.5, 24.2, and 26.3%, respectively. According to Savage G. [106], ceramic materials possess exceptional toughness and low weight, rendering them highly suitable for utilization as armor materials.

The surface is affected by several ceramic elements, including fracturing, blunting, erosion of the shot, and the dynamic preservation of the vivid energy resulting from the contact. Composite protective coatings often utilize tiles to enhance the impact resistance of their surfaces. According to Tam et al. [107], ceramic fibers possess a considerable diameter. Therefore, it is common for the prepreg bands to exhibit a unidirectional (UD) orientation similar to that of the threads. Ceramic fibers are well-suited for the high-temperature solidification state of titanium and ceramic composites. The annual production of ceramic fibers is restricted to a finite amount.

Nevertheless, the capacity for their manufacture may be rapidly expanded to accommodate emerging demands. The material's rigidity is another crucial criterion for a ballistic protection layer. The rigidity of single Ultra High Molecular Weight Polyethylene (UHMWPE) must be improved, necessitating the incorporation of auxiliary components to enhance its capabilities. Thermoplastics are widely utilized in many applications due to their advantageous characteristics, including non-toxicity, ease of manufacture, low density, and exceptional toughness [108, 109]. To promote environmental sustainability, it is imperative for advancements in anti-ballistic materials to prioritize the utilization of natural fibers, thereby reducing reliance on synthetic fibers. Typically, bio-fibers possess key characteristics such as bio-sustainability and environmental compatibility, which may confer certain advantages over synthetic fibers such as glass, aramid, and carbon [110, 111]. Significant progress has been made in ballistic fiber performance by creating analytical, numerical, and constitutive models spanning micromechanical to micromechanical scales.

Numerous researchers have formulated various constitutive models intending to estimate transversely isotropic materials' post-failure mechanisms, deformation patterns, and energy absorption capabilities. Moreover, the extent of harm inflicted by a penetrating projectile is contingent upon the magnitude of the impact energy, the energy level of the tissue collision, the velocity at which it transpires, and the specific tissue region affected by the projectile's penetration. The tissue areas exhibit localized responses that indicate the presence of significant energy-induced cavitation effects. The considerable energy transfer is correlated with an increased risk of infectious complications. The diverse range of ballistic injury patterns arises from the intricate interplay between projectiles and various tissues. Understanding the underlying mechanisms contributing to tissue failure, such as bullet deformation and deceleration, is crucial for recognizing typical injuries and appreciating the significant energy transfer associated with more severe cases.

3. Material and Methods

This paper uses a bibliometric analysis method based on publications related to "anti-ballistics" published from 1975 to 2022. The literature was obtained from the Scopus database by entering the keyword “body armor”, which yielded the results of 1,255,339 related documents. In the final step, we used the keyword "composite," which yielded 1,328 documents from associated fields. The search results from 1975 to 2022 showed only 937 documents from the Scopus dataset after limiting document types to "article" and "review" only. Then, the documents were processed in CSV format. The process involved a bibliometric analysis using biblioshiny software integrated with RStudio and VOSviewer to produce graphical images and data. The flowchart of the whole process is illustrated in Figure 3.

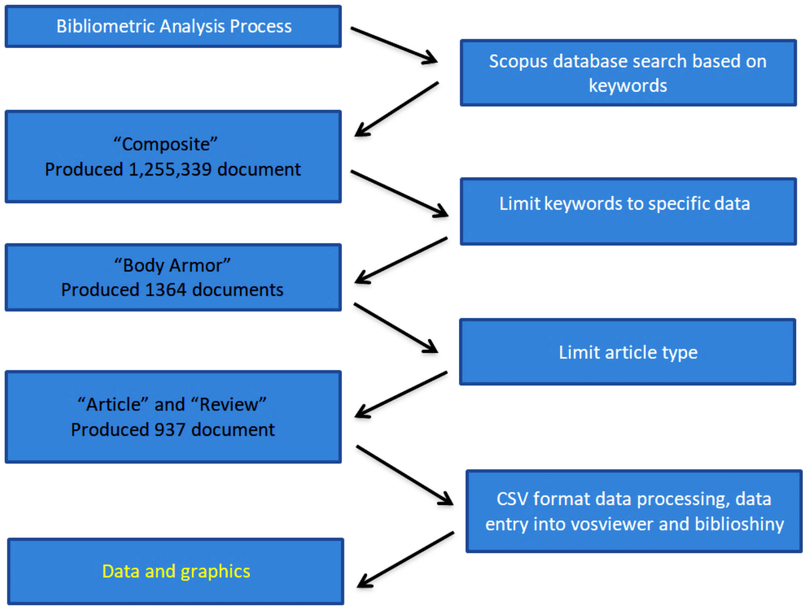

Figure 3. Flowchart of the data analysis process

4. Result

The collection of information related to articles published from 1975 to 2022 is described in Table 1. However, there were many associated papers published in the Scopus database in this period, i.e., 937 articles.

Table 1. Main information

Description	Results
Main Information about Data	
Timespan	1975:2022
Sources (Journals, Books, etc)	373
Documents	937
Average years from publication	7,04
Average citations per documents	23,76
Average citations per year per doc	2,74
References	38129
Document Types	
Article	857
Review	80
Document Contents	
Keywords Plus (ID)	5914
Author's Keywords (DE)	2329
Authors	
Authors	2659
Author Appearances	4203
Authors of single-authored documents	61
Authors of multi-authored documents	2598
Authors Collaboration	
Single-authored documents	82
Documents per Author	0,352
Authors per Document	2,84
Co-Authors per Documents	4,49
Collaboration Index	3,04

Based on Table 1 upper, the bibliometric analysis results show that 44 countries have contributed to the field of anti-ballistics research, with 937 documents created by 2659 authors, in the form of 857 articles and 80 reviews. For easier understanding, data is presented in the discussion below.

4.1. The Main Contributors Leading Countries, Institutions, Research Groups, Authors, and Research Fields

Before conducting research, it is important that a researcher be familiar with those who have contributed significantly to the topic that will be studied or developed. For this reason, we present Figure 4, which lists the authors with the most anti-ballistics publications.

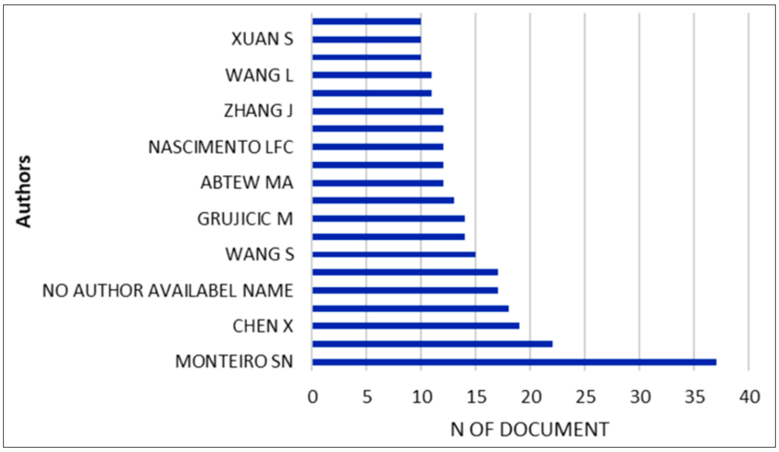

Figure 4. Most relevant authors

As a result, the authors who write and produce the most articles and are most relevant to the field of anti-ballistics are as follows: In first position, the most relevant author is Montero SN, the second is Wang Y, the third is Chen X, the fourth is Majumdar A, the fifth is No Author Name, and the sixth is Gong X, with more than fifteen documents. In the seventh position is Wang S, with fifteen documents. Meanwhile, authors in the 8th to 17th order have more than ten documents: Foster Al, Grujicic M, Bosou F, Abtew Ma, Bruniaux P, Nascimento LFC, Oliveria MS, Zhang J, JR, and Whang L. Furthermore, the authors ranked 18th to 20th have the same average number of works. Each has ten documents; they are Butola Bs, Xuan S, and finally Zhang X. Moreover, from the number of citations, the quality of the journal can be determined, which will help future researchers develop their research. More details are shown in Figure 5.

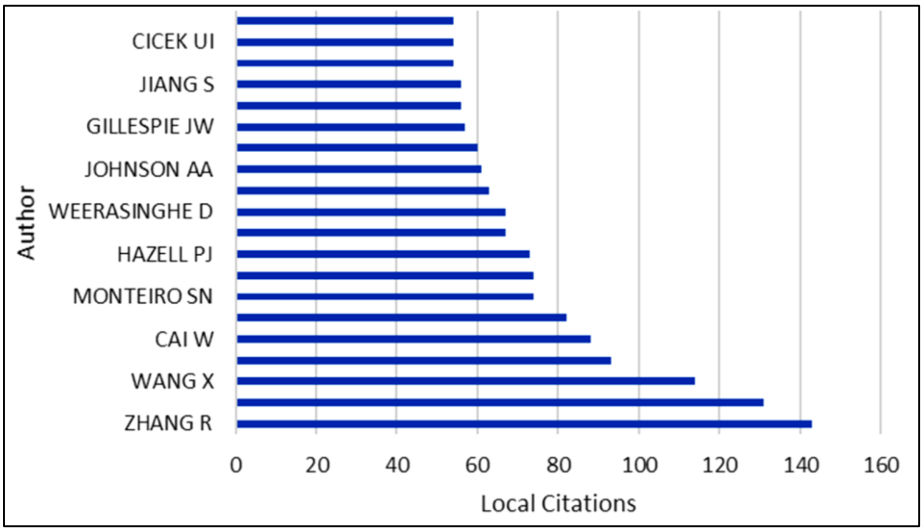

Figure 5. Most locally cited authors

Based on the table above, with the number of documents uploaded, Zhang R was ranked first in the categories of Most Locally Cited, followed by Zhang X in second place, and Bruniaux P in third place, with an overall total of more than 100 citations. However, there is a slight difference in the citation results and the relevant authors. In the 4th to 14th positions, with a total of more than sixty citations each, Forstel AL, Cai W, Majumdar A, Menteiro SN, Wang H, Hazell PJ, Mohotti D, Weerasinghe D, JR, Johnson AA, and Xu Y. The 14th to 20th positions are occupied by Gillespie Jw, Gong X, Jiang S, Chen Y, Cicek UI, and Southee DJ, respectively, with less than 60 total citations. We can obtain the local author impact of each author based on the H index. In general, the authors of the most journals always occupy the highest rankings. Likewise, in this case, the results aren't much different, as shown in Figure 6.

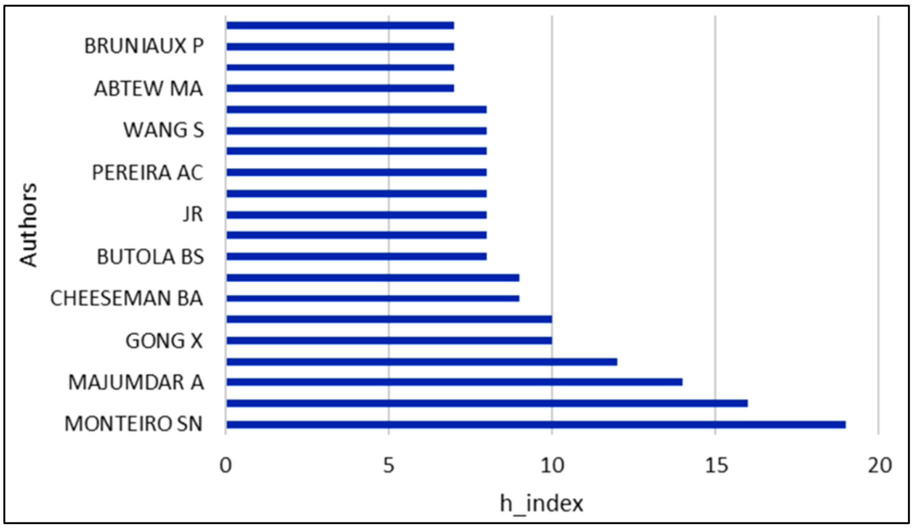

Figure 6. Author local impact by H Index

The highest rank author is Menteiro SN, with an H-Index of 19, followed by Chen X who has H-Indeks 16, and Majumdar A who has H-Indeks 14. Currently, the top 8 local authors, with H-Indeks more than eight, are Wang Y, Gong X, Grujicic M, Ceeseman BA, and Oliveira MS. Local authors with H-Indeks eight each are in the order of 9th to 16th position occupied by Butola BS, Jiang W, JR, Meyers MA,Pereira AC, Wang L, Wang S, an Xuan S. Those in the 16th to 20th positions, with H-Indeks eight each are; Abtew MA, Boussu F, Brunaux P, and Lima XP. In general, the author is associated with an institution, which overshadows and serves as the identity of the author. Thus, it is necessary to discuss the institutions that host the authors with the most publications. Results are presented in Figure 7.

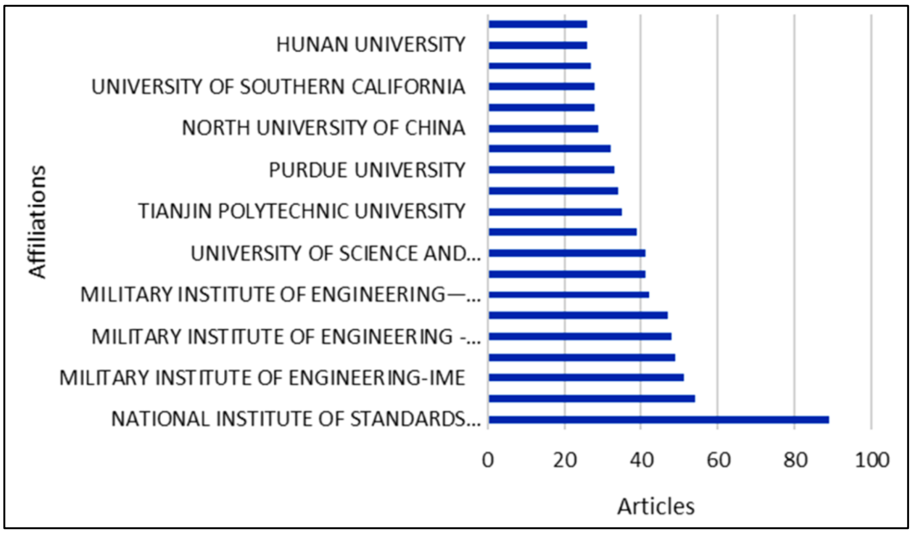

Figure 7. Most relevant affiliations

Based on the Most Relevant Affiliations table above, the National Institute of Standards and Technology ranks first, with 89 articles. Clemson University follows with 54 document articles. The Military Institute of Engineering-IME follows with 54 document articles. Furthermore, the other most relevant affiliates, with more than forty article documents each, are the Indian Institute of Technology Delhi, Military Institute of Engineering - IME, University of Science and Technology of China (USTC), Military Institute of Engineering--IME, University California, and the University of Science and Technology of China. The 10th to 14th in middle positions are occupied by the School of Materials Science and Engineering, Tianjin Polytechnic University, Beijing Institute of Technology, Purdue University, and the Military Institute of Engineering, with more than thirty articles each. The bottom positions, with an average total of more than twenty-five documents each, are the North University of China, Nanjing University of Science and Technology, University of Southern California, Northwestern Polytechnical University, Hunan University, and Massachusetts Institute of Technology. Many countries are interested in anti-ballistics development because it contributes to national defense. Moreover, security strengthens a country, even if only on a small scale. It can be helpful if the development progresses to an extreme stage, such as withstanding 30 mm caliber cannon projectiles (STANAG 4569). We present the countries that are most proactive in conducting research and development in anti-ballistics in Table 2 and Figure 8.

Table 2. The published articles and collaboration by country

Country	Articles	Freq	SCP	MCP	Total Citations	Average Article Citations
USA	179	0.22630	159	20	7021	39.223
CHINA	169	0.21365	145	24	2269	13.426
INDIA	80	0.10114	74	6	2152	26.900
UNITED KINGDOM	50	0.06321	34	16	1318	26.360
BRAZIL	43	0.05436	31	12	966	22.465
AUSTRALIA	28	0.03540	23	5	564	20.143
TURKEY	27	0.03413	25	2	672	24.889
MALAYSIA	24	0.03034	18	6	385	16.042
FRANCE	23	0.02908	9	14	466	20.261
CANADA	19	0.02402	16	3	573	30.158
POLAND	19	0.02402	18	1	122	6.421
KOREA	15	0.01896	13	2	614	40.933
GERMANY	14	0.01770	4	10	843	60.214
ITALY	9	0.01138	2	7	121	13.444
SPAIN	9	0.01138	7	2	648	72.000
SINGAPORE	8	0.01011	6	2	1013	126.625
IRAN	7	0.00885	6	1	324	46.286
ISRAEL	7	0.00885	6	1	184	26.286
PAKISTAN	6	0.00759	2	4	75	12.500
JAPAN	5	0.00632	3	2	29	5.800

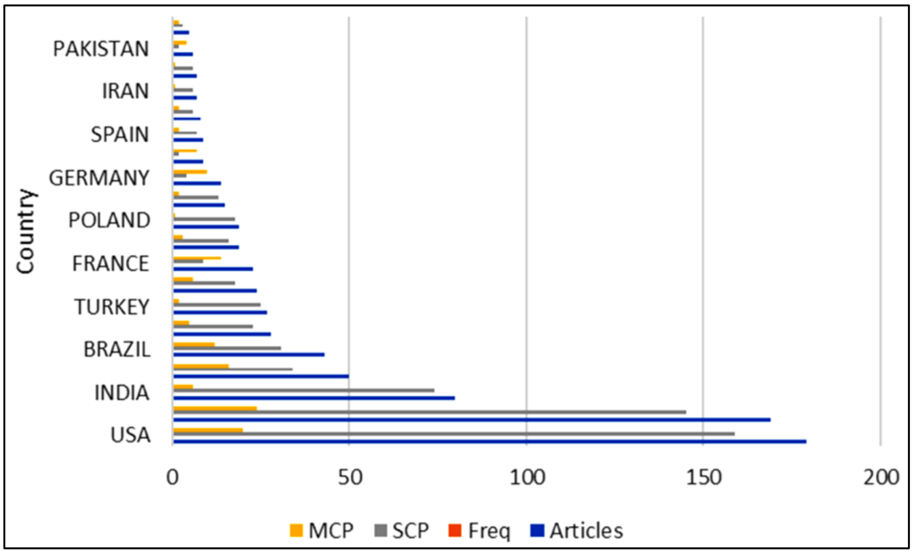

Figure 8. Corresponding authors' countries

Furthermore, in the table above, the USA is the most productive country publishing anti-ballistics research, with 179 documents. It is followed by China, with 169 documents. The third position is India, with 80 documents. Other countries that publish documents on anti-ballistics are the United Kingdom, with fifty documents, and five other countries that published more than thirty documents each, Brazil, Australia, Turkey, Malaysia, and France. The country of Canada also publishes documents regarding anti-ballistics, with a total of twenty-nine documents, as well as Poland, which has published twenty-nine documents as well. Meanwhile, nine other countries have published anti-ballistics documents, with less than sixteen document each: Korea, Germany, Italy, Spain, Singapore, Iran, Israel, Pakistan, and Japan. In the development of anti-ballistic technology, all developers wish to prevent the field from stagnating or regressing. Thus, it is crucial to learn from previous papers so that the direction and purpose of development are clear. More details are shown in Figure 9.

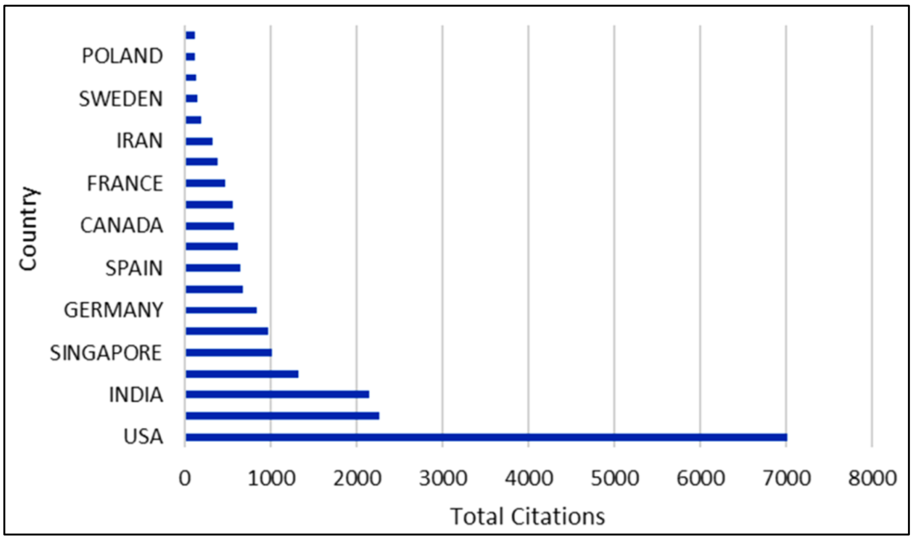

Figure 9. Most cited countries

Every development requires citations from several sources. The following are countries that are a source of inspiration for researchers in the anti-ballistics field. The table above shows the most cited countries, the first being America. America is the reference country in this field, possibly because America is well known for its technological advances. Therefore, America has been cited 7021 times, China was cited 2269 times, and India was cited 2152 times. In addition to these three countries, there are two other countries whose publications have been cited more than 1000 times: The United Kingdom, which has been cited 1318 times, and Singapore, which has been cited 1013 times. In addition, seven countries have publications with more than 500 citations but less than 1000, namely Brazil with 966 citations, Germany with 843 citations, Turkey with 672 citations, Spain with 648 citations, Korea with 614 citations, Canada with 573 citations, and Australia with 564 citations. Meanwhile, three countries have cited more than 200 times: France with 466 citations, Malaysia with 385 citations, and Iran with 324 citations. The fifth countries with the lowest cited were Israel, Sweden, Saudi Arabia, Poland, and Italy.

4.2. The Most Productive Journals on the Historical Map of the Topic

Researchers must continue developing their work due to the increasingly advanced demands of the present era. However, this may be challenging if the researcher lacks knowledge of the history of development or competition in the researched matter. These developments are shown more clearly in Figure 10.

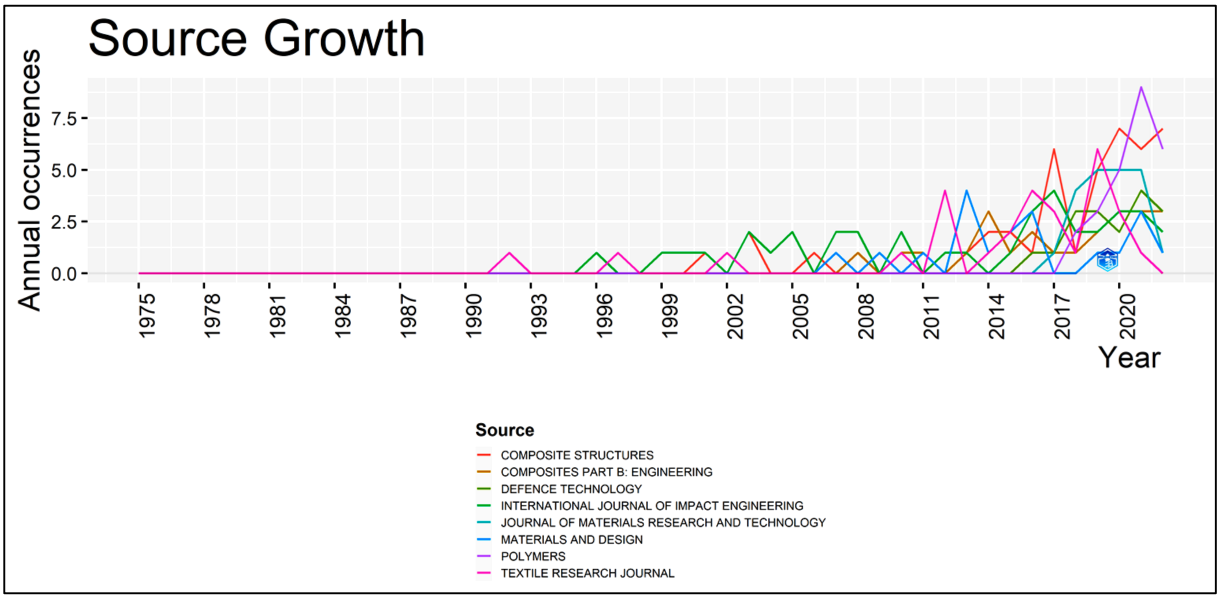

Figure 10. Source growth

Based on the graph of source growth, we can see that Textile Research Journal was the first field to release a journal related to ballistics. In 1996, the competition began when the International Journal of Impact Engineering uploaded one journals. The most intense competition occurred in 2019, when more than two competitors published more than one journal. However, Polymers still hold the highest position, with nine journals uploaded, starting with two journals in 2018.Knowledge of trend topics is essential for every significant journal author. Because the publication of research is expected to bring about changes in current or emerging trends, the author needs to know which trends will be the most relevant. We thus present Figure 11 below, which might help to determine the next topics of interest.

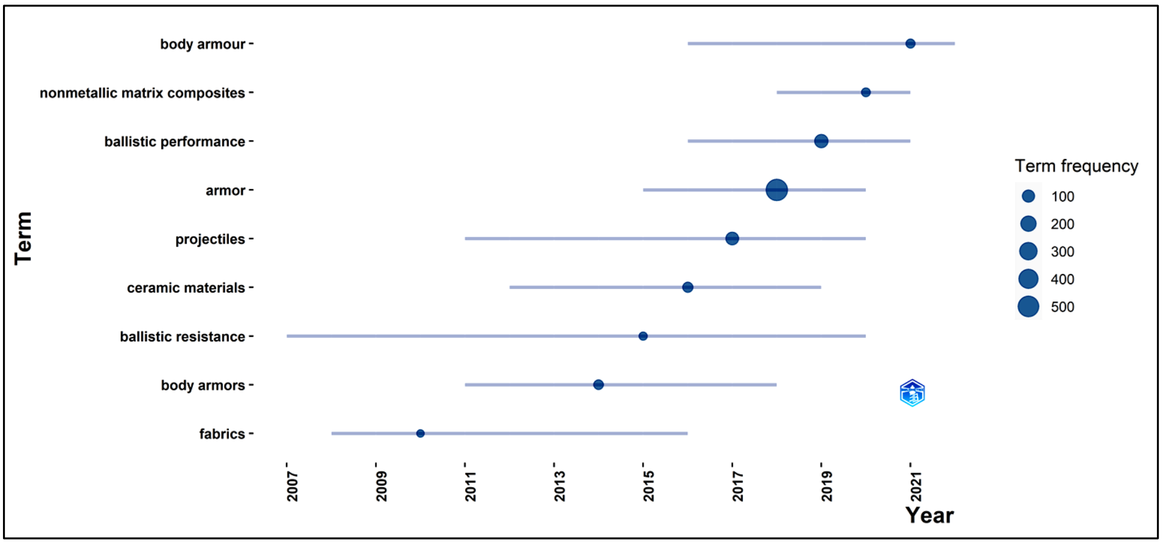

Figure 11. Trend topics

The trend topics from year to year began to change. Although they did not change entirely, sometimes there was a changing focus. In 2010, the trending topic was fabrics, and it continued to develop into other trends, namely the topic of body armor in 2014. Moreover, in 2015, the trending topic was ballistic resistance, and it continued to develop into other trends, namely the topic of ceramic resistance in 2016. Meanwhile, in 2017, the trending topic was projectile, and it continued to develop into different trends, namely the topic of armor in 2018. Furthermore, in 2019 the trending topic was ballistic performance, but it was moved to nonmetallic matrix composites in 2020. In 2021 the most famous was body armor. However, the first position topic trended to occupy is armor with 549 term frequency. The following discussion identifies many relationships between authors, authors who use citations, and authors who are renowned. This is known as the Historical Direct Citation Network. For convenience, results are shown in Figure 12.

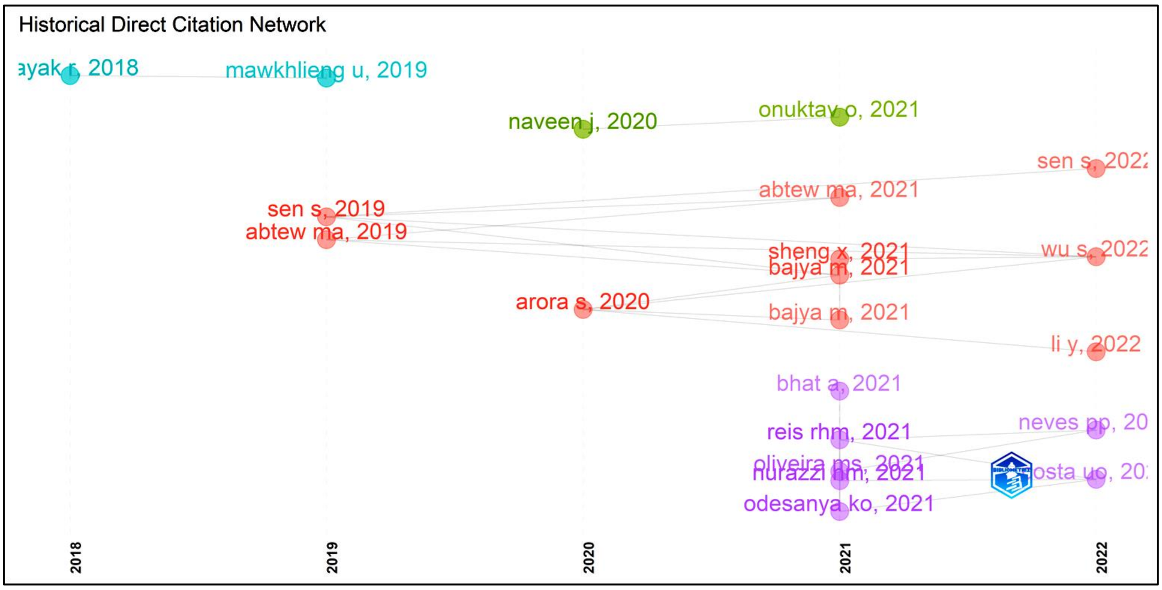

Figure 12. Historical Direct Citation Network

The Historical Direct Citation Network above shows many links in research, namely from the writings of several authors who are used as references by other authors or quoted directly. Moreover, as he often appears in the anti-ballistic bibliometrics, Abtew Ma is a reference source by writers on related topics. On the other hand, regarding the year, Abtew Ma only became well known in 2019, and before that year, Vinson JR had been widely cited since 1975. It is possible that Abtew Ma also cited some statements from Vinson JR. However, Vinson JR was also cited by Naveen J, Sen S, Mawkhlieng U, Yang J, Hut Ap, and several other authors. The following figure shows the correlations between countries that produce journals or articles related to ballistics or bulletproof materials. This figure is very useful for those who wish to develop or even realize the technology developed by several countries. More details are shown in Figure 13.

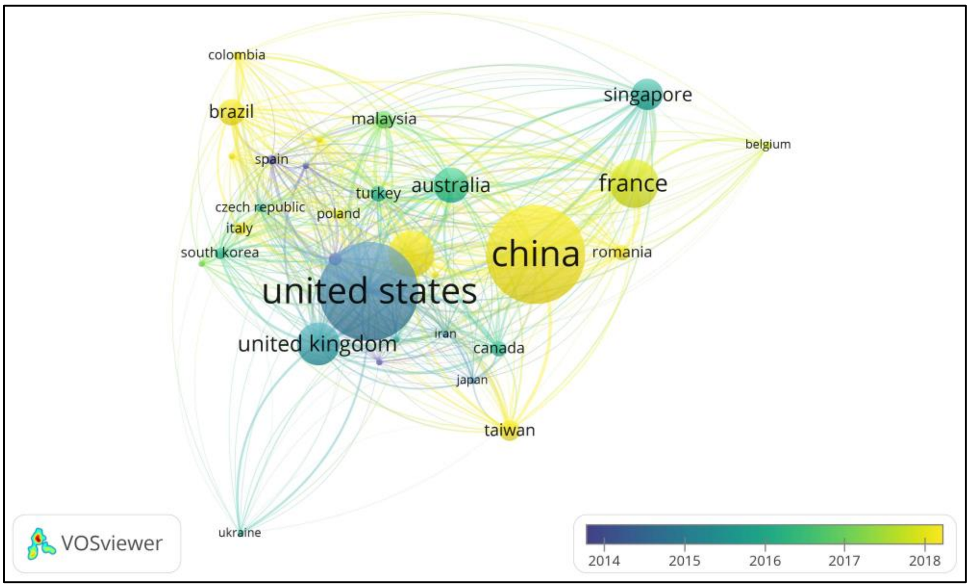

Figure 13. Network collaboration among countries

As already shown in Figure 10, the USA is the country that produces the most publications, and we can see the relationships between USA writers and other writers in figure 10. Based on this, we can generally assume that a large number of publications from the USA is due to the support of another country. France has the largest armed forces in the European Union. According to Credit Suisse, the French Armed Forces are ranked as the sixth strongest military in the world. The UK has a history of worldwide wars for several years, so they are definitely familiar with this field. Regarding China, we can see that China has extensive relationships with other countries because the Chinese themselves are well known for their openness and communication. Furthermore, the USA may develop much military technology; this superpower is already well known for its military technology. Nevertheless, in terms of publicity, this country is inferior to India. It is possible that the results of their research were not published for several reasons.

4.3. The Significant Journals with the Highest Number of Citations

The highest-ranking publication is the Composite Structures, with fourty-one journals published, as shown in Figure14, but higest index H is the International Journal of Impact Engineering. Source notes for journals in the field of Anti-Ballistic shown in Table 3.

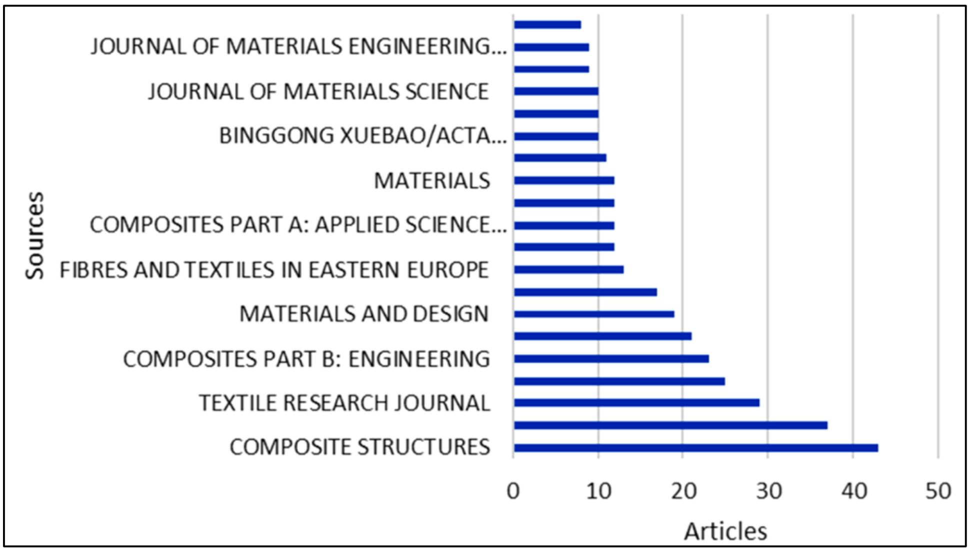

Figure 14. Most relevant sources

Table 3. Source notes for journals in the field of Anti-Ballistic

Element	H_index	Citation	Document	Y start
INTERNATIONAL JOURNAL OF IMPACT ENGINEERING	24	1816	35	1996
COMPOSITE STRUCTURES	21	1856	41	2001
COMPOSITES PART B: ENGINEERING	16	950	22	2008
MATERIALS AND DESIGN	15	852	17	2007
TEXTILE RESEARCH JOURNAL	15	991	28	1992
JOURNAL OF MATERIALS RESEARCH AND TECHNOLOGY	12	372	20	2017
COMPOSITES PART A: APPLIED SCIENCE AND MANUFACTURING	10	510	10	2013
JOURNAL OF THE MECHANICAL BEHAVIOR OF BIOMEDICAL MATERIALS	10	510	12	2011
POLYMERS	10	394	22	2018
DEFENCE TECHNOLOGY	8	260	14	2016
CERAMICS INTERNATIONAL	7	151	10	2017
JOURNAL OF COMPOSITE MATERIALS	7	506	9	1996
JOURNAL OF MATERIALS ENGINEERING AND PERFORMANCE	7	309	9	2009
ACTA BIOMATERIALIA	6	229	7	2013
FIBERS AND POLYMERS	6	169	7	2010
FIBRES AND TEXTILES IN EASTERN EUROPE	6	110	13	2010
JOURNAL OF APPLIED POLYMER SCIENCE	6	214	9	2008
JOURNAL OF MATERIALS SCIENCE	6	158	9	2005
COMPOSITES SCIENCE AND TECHNOLOGY	5	532	5	2007
RSC ADVANCES	5	181	5	2016

Other publications that contribute to anti-ballistic research and are second ranking publication is International Journal of Impact Engineering with forty-three journals. The third ranking publication is Textile Research Journal with twenty seven journals. And other journals that did not make it into the top 3 are; Polymers with twenty-fifth journal. Composites part b: Engineering with twenty-three journals. Journal of Materials Research and Technology with twenty-one journals. Materials and Design with nineteen journals. Defense Technology with seventeen journals. Fibres and Textiles in Eastern Europe 13 journals. International Ceramics with twelve journals. Composites Part a: Applied Science and Manufacturing with twelve journals. Journal of Mechanical Behavior of Biomedical Materials with twelve journals. Materials with twelve journals. Advanced Composites Bulletin with eleven journals. Binggong Xuebao/Acta Armamentarii with ten journals. Journal of Composite Materials with ten journals, Journal of Materials Science with ten journals. Journal of Applied Polymer Science with nine journals. Journal of Materials Engineering and Performance with nine journals. Acta Biomaterialia with eight journals.

And other journals that did not make it into the top 3 are; Polymers with twenty-fifth journal. Composites part b: Engineering with twenty-three journals. Journal of Materials Research and Technology with twenty-one journals. Materials and Design with nineteen journals. Defense Technology with seventeen journals. Fibres and Textiles in Eastern Europe 13 journals. International Ceramics with twelve journals. Composites Part a: Applied Science and Manufacturing with twelve journals. Journal of Mechanical Behavior of Biomedical Materials with twelve journals. Materials with twelve journals. Advanced Composites Bulletin with eleven journals. Binggong Xuebao/Acta Armamentarii with ten journals. Journal of Composite Materials with ten journals, Journal of Materials Science with ten journals. Journal of Applied Polymer Science with ninth journals. Journal of Materials Engineering and Performance with ninth journals. Acta Biomaterialia with eight journals. Additionally, core sources on the Bradford law diagram display many sources, which are the basis for identifying journals that discuss the most cited anti-ballistic technology. More details are shown in, see Figure 15.

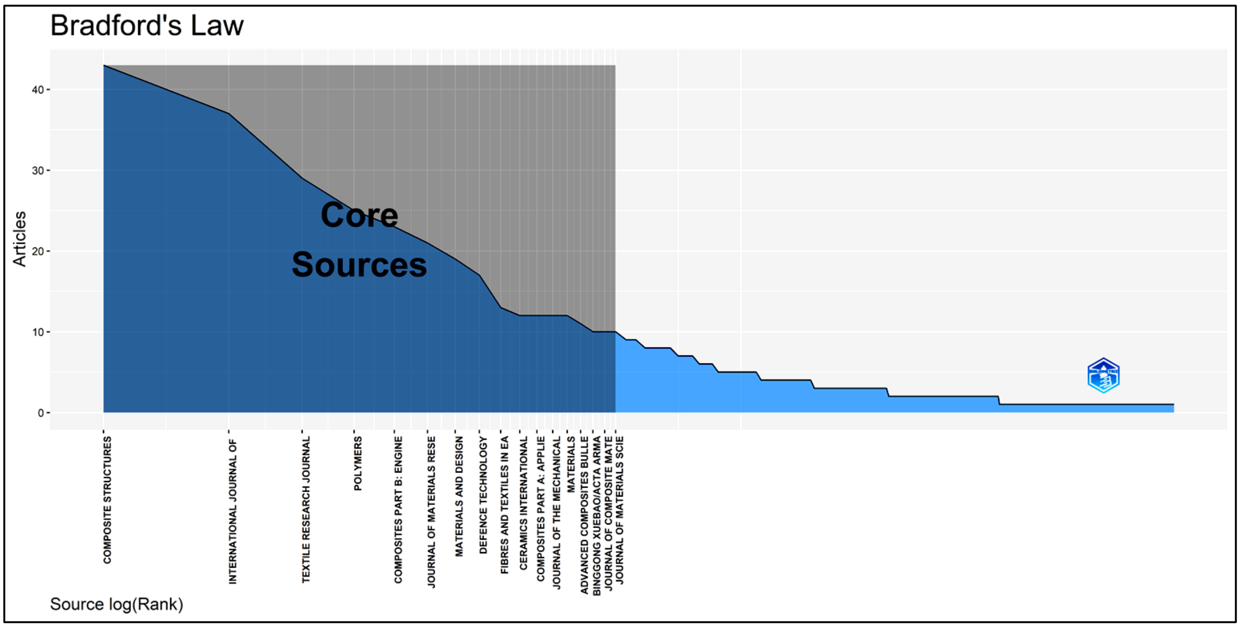

Figure 15. Bradford's Law

The Composite Structures has forty-three core sources based on the data obtained using the Bradford law. Bradford law articles are sourced from thirty-seven journals, namely the International Journals of Impact Engineering. Those under thirty articles are Textile Research Journal with twenty-nine articles. Polymers with twenty-fifth articles. Composites Part B: Engineering with twenty-three articles. Journal of Materials Research and Technology, with twenty-one articles. Materials and Design with nineteen articles. Defence Technology with seventeen articles. Fibres and Textiles in Eastern Europe, with thirteen articles. Ceramics International has twelve articles. Composites Part A: Applied Science and Manufacturing has twelve articles. Journal of the Mechanical Behavior of Biomedical Materials, with twelve articles. Materials with twelve articles. Advanced Composites Bulletin has twelve articles. Binggong Xuebao/Acta Armamentarii has ten articles. Journal of Composite Materials, with ten articles. Journal of Materials Science, with ten articles. Based on the figure diagram, the most common sources of search interest are the journals presented in the figure below. For more details, see Figure 16.

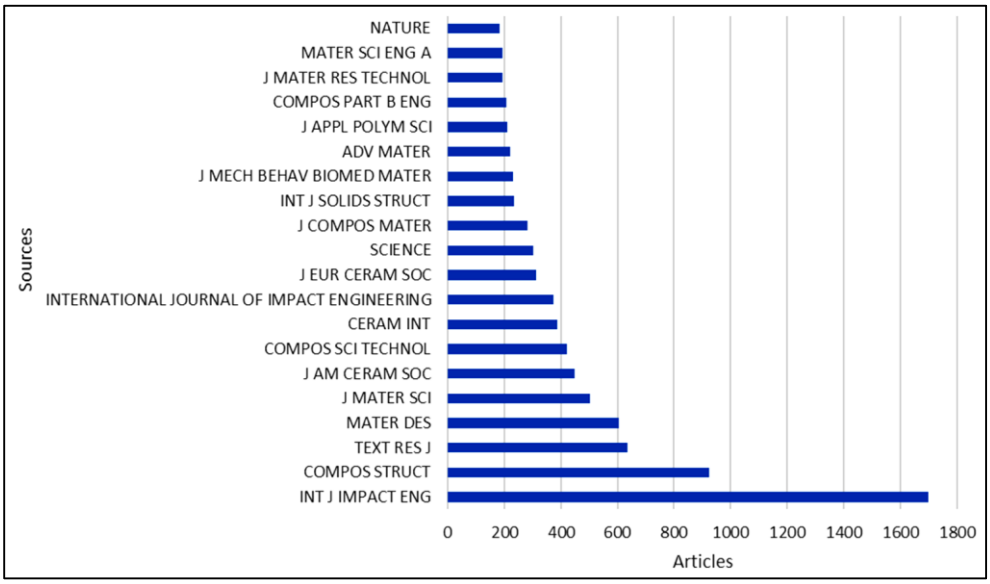

Figure 16. Most locally cited sources

As seen in the figure diagram, the most locally cited sources cited in International J Impact Eng are 1698 local citations, as well as Compos Struct with 924 local citations and Text Res J with as many as 636 local citations. Furthermore, several sources are still cited from other journals, such as Master Des, with as many as 606 local citations; J Master Sci, with as many as 503 local citations; J Am Cream Soc, with as many as 447 local citations; and Compos Sci Technol, with as many as 422 local citations. Meanwhile, other publications that are sourced in local citations that number above ten local citations amounted to 200—namely Composite Part B Eng, with 208 local citations; J Apl Polimer Sci with 210 local citations; Adv Mater with 222 citations; J Mech Behav Biomed Master with 231 citations; Int J Solid Structure with 235 local citations each; J Compos Mater with 282 citations; Science with 303 local citations; J Eur Cream Soc with 313 local citations; International Journal of Impact Engineering with 373 local citations; Ceram Int with 388 local citations. Moreover, the remaining three are under two hundred local citations each, namely J Mater Res Technol, Mater Sci Eng A, and Nature.

4.4. Research Interests and Perspectives

Attack and defense are interrelated things. Anti-ballistics is a technological defense that must keep up with developments. The beginning of the development of anti-ballistics itself began in the 15th century. The first anti-ballistic material is a hard metal material that is quite heavy. However, anti-ballistic is increasingly adjusting to the user's wishes over time. The benchmark in anti-ballistic development is anti-ballistics that are lightweight, comfortable, not hot, or even cheap. Based on the development objectives, the material needed to develop it is an advanced material that is strong but light. The development of armor materials has focused on reducing the weight of existing armor materials because weight reduction can help save energy and increase mobility [112, 113]. On the other hand, aesthetic values must be considered by studying and developing a proportional design to meet user comfort. With the development of thermoplastic polymers and synthetic fibers in recent years, lighter-weight, rugged protection systems have been produced, combining metals or ceramics with polymer fabrics and fiber-reinforced polymer composites.

During the Vietnam War, it was reported that soft armor made of fiberglass and nylon cloth was used for ballistic protection [114]. Some of the commercial fibers used to manufacture armor include aramid (Kevlar or Twaron) [93, 115], nylon fibers [116], polyethylene fibers (SpectruM or Dyneema) [117, 118], and carbon fibers [119, 120]. These fibers must provide the excellent impact resistance required for ballistic armor, have high specific energy absorption, and have the ability to distribute kinetic energy in ballistic impacts [116]. The polymer material commonly used in ballistic applications is low-molecular-weight polyethylene. Very high in UHMWPE (Dyneema) and para-aramid fibers (Kevlar and Twaron). Kevlar has been introduced as an ideal base material for ballistic protection due to its outstanding thermal properties and high tensile strength. Its highly crystalline structure and high orientation toward delicate structures result in the required high modulus [114, 117, 121]. As a result, Kevlar fiber is considered the main reinforcing constituent for ballistic composites. In composite materials, although the individual parent materials (fiber and matrix) cannot provide ballistic resistance properties by themselves, the combination of the two components has been found to exhibit a better degree of ballistic protection.

This paper shows most of the primary materials used in the manufacture of anti-ballistic technology and bibliometric analysis. In some ways, anti-ballistic technology still needs to be developed. Anti-Ballistic Technology can also be applied to other things unrelated to ballistics but having immense added value, such as applications in automotive, shoes, or clothing needed for specialized activities. Anti-ballistic body armor needs to be developed in terms of material design and development, which is still too thick on the market and has yet to be considered in different conditions. Based on the bibliometric analysis, there is no one article that Anti-ballistic vests can absorb water and add weight to the anti-ballistic after absorbing a certain amount of water. Therefore, it is necessary to have an anti-ballistic design that is hydrophobic.

5. Conclusion

This paper has analyzed and obtained the results. The state-of-the-art chapter has reviewed the literature findings to date in the broad field of ballistic composite materials in search of materials that can be applied in the future. This chapter discusses the classification of ballistic protective equipment and the mechanical properties of the different types of ballistic composites shown. This chapter also highlighted the possibility of new materials and technologies for ballistic protection. On the other hand, the results of the bibliometric analysis showcased the global and leading countries working in the field of anti-ballistics or bulletproofing. The information obtained from the bibliometric analysis has raised suspicions, as the United States has the most publications. The general public understands that Germany is indeed a country with a sophisticated mastery of metallurgy, but why is Germany itself not the most prominent publisher? In addition, the number of Indian citations is not significant in the discussion of anti-ballistics [122]. Several sources have been found that are from previous years [123]. There is also a problem with USA research, for which the author's name is often not mentioned. Therefore, it is necessary to question why India is the largest producer of journals, while Germany and the UK produce fewer. A literature search from 1975 to 2022 revealed that articles on anti-ballistics published in 1975 were not the first. Based on the previous discussion, it can be concluded that bibliometric analysis can broadly provide information for those who need it. The information generated includes the name of the country, campus, or individual with knowledge and expertise in anti-ballistics. Future researchers can also refer to this paper in determining research topics that will become trends in the following year based on the trends that have been analyzed. It is possible that future trends in anti-ballistics will include the use of smart materials, biodegradable composites, and anti-heavy technology.

6. Declarations

6.1. Author Contributions

Conceptualization, U., Z.A., and D.A.; methodology, F.M. and B.W.L.; software, F.M.; validation, U., Z.A., and D.A.; formal analysis, F.M. and B.W.L.; investigation, F.M.; resources, B.W.L.; data curation, F.M.; writing—original draft preparation, F.M.; writing—review and editing, U.; visualization, B.W.L.; supervision, U. and D.A.; project administration, Z.A.; funding acquisition, U. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

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6.4. Institutional Review Board Statement

Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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