A Study on the utilization of areca nut husk fiber as a natural fibre reinforcement in composite applications: A systematic literature review

Zulhan Insan Makruf*, Wanda Afnison and Bulkia Rahim

Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Padang, **INDONESIA**

Abstract: This paper presents a systematic literature review of published research on the use of areca nut bark fibres as a reinforcing material in polymer composites. A total of 22 research articles published in Scopus-indexed journals were identified and analysed in depth. In addition, this article presents current issues related to areca nut husk fibre (ANHF) as a reinforcement in composites using the VOSviewer tool. In this article, the authors explains the processing stages of ANHF before it is used as a reinforcement in composites. The chemical treatments carried out are also summarised in this article. Not all types of resins available on the market have been used as matrix in the manufacture of areca nut shell fibre composites. The use of additives derived from natural materials has also been found to be effective in improving the quality of ANHF composites. This article also highlights the need for further research to improve the quality of areca nut husk fibre composites and discusses the unanswered aspects of the published research.

Keywords: ANHF; Mechanical properties; NaOH and KOH; Hand lay-up

*Corresponding Author: zulhaninsan@gmail.com

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1. Introduction

Composites are combined materials between two or more constituent materials (Raja & Sivaganesan, 2021). Generally, there are two main components in composites, which are reinforcement and matrix. Various industrial products have been made using composite materials because they have the advantages of being lighter, stronger and cheaper to manufacture. In general, the fibres that are widely used by industry to make a composite product are synthetic fibres. The use of synthetic fibres is due to their resistance to moisture and good mechanical properties (Ali et al., 2018). However, synthetic fibres have several disadvantages such as the relatively high cost required, non-biodegradability and the potential to generate waste (Gokarneshan et al., 2023).

Natural fibres are believed to be able to solve this problem as they have several advantages, namely easy to obtain, economical, lightweight, biodegradable, non-toxic and environmentally friendly (Mahyudin et al., 2020). One of the natural materials that has the potential to be used as an alternative to synthetic fibres is the fibre found in Areca Nut Husk Fibers (ANHF). ANHF are one of the most abundant agricultural wastes. ANHF are generally underutilised as a product with high economic value. Total world production of areca nut in 2020 will be 1.8 MT (*Areca Nut Production and Top Producing Countries*, n.d.). Each areca nut shell contains ± 40% fibre (Deshmukh et al., 2019), based on which there was 0.72 MT of areca nut shell fibre in 2020. Therefore, ANHF has great potential for use as reinforcement in polymer composites.

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A search of the Scopus database identified five literature review articles related to the use of ANHF for reinforcement in composites. One of the literature review articles comprehensively investigated the effective maturity level of areca nut shell, the effect of treatment on the fibre surface, the type of matrix used, and the mechanical, thermal, and acoustic properties (Kamath et al., 2017). Another study presents the effect of bio-softening, adhesion, fibre length and chemical treatment on fibres and the effect of mercerisation on tensile strength (Ashok et al., 2018). There is also a literature review that discusses the comparison of physical and mechanical properties of areca nut fibre composites with coconut and palm fibres (Loganathan et al., 2020). A literature review was reported on the fibre properties of areca nut leaves and bark for composite purposes instead of woven fabrics (Sunny & Rajan, 2022). A recent review article discussed the effect of pre-treatment of fibres before use with emphasis on strength, stiffness, tensile strength, impact strength and flexural strength (Roopashree et al., 2023). Although the literature review covered various aspects of research, there was no thorough study of the processing of areca nut fibre into composites, and there is no trend in research topics related to areca nut fibre. The methods used in the literature review were also not explained in sufficient detail. Therefore, a literature review article with a systematic approach is needed to strengthen the foundation for future research in this area.

This article examines the development of research into the use of ANHF as a reinforcement in composite materials. The articles reviewed are research findings published in Scopus-indexed journals. This is to ensure that the information presented comes from reliable and responsible sources. This study also analyses the most common and current research topics. The structure of the study on the use of ANHF as reinforcement in composites is based on the stages of the process, from preparation, manufacturing process, fraction fibres, type of matrix, addictive substances used and mechanical properties.

This approach is expected to provide a systematic and comprehensive view of the development of research into the use of ANHF as a reinforcement in composite materials. In addition, the results of the review are expected to contribute to further research by providing an overview of what has been achieved, identifying the gaps that still exist, and providing inspiration for innovation and improvement in future research.

2. Material and methods

This study used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Moher et al., 2009). This systematic literature review was conducted using the Scopus database with the search terms 'areca nut composite fibre'. This approach was designed to ensure that the documents identified were relevant to the topic under review. As stated in the introduction, the focus of this literature review was on the use of areca nut shell fibres for the production of composite fibres. After the successful collection of various articles, the next step was to determine the suitability of each article to the topic under discussion. Articles that did not fit the scope of the review were excluded, and the subsequent process involved a thorough examination of the full text of the articles that met the criteria.

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The full-text articles were then imported into Mendeley, where they were categorised and bibliographic data extracted in RIS file format. An analysis of the most common and recent topics was carried out using VOSviewer software.

3. Results and discussion

An overview of the systematic stages of the literature review using the PRISMA flowchart in this study is shown in Fig. 1. Based on the search results in the Scopus database, we found a total of 49 documents (research articles and review articles). At the screening stage, eight articles were not related to ANHF, leaving 27 articles to be assessed for eligibility. At the eligibility stage, 22 articles were research articles and five articles were review articles. In accordance with the research objectives described in the introduction, in the final stage (inclusion) we identified 22 research articles for in-depth review.

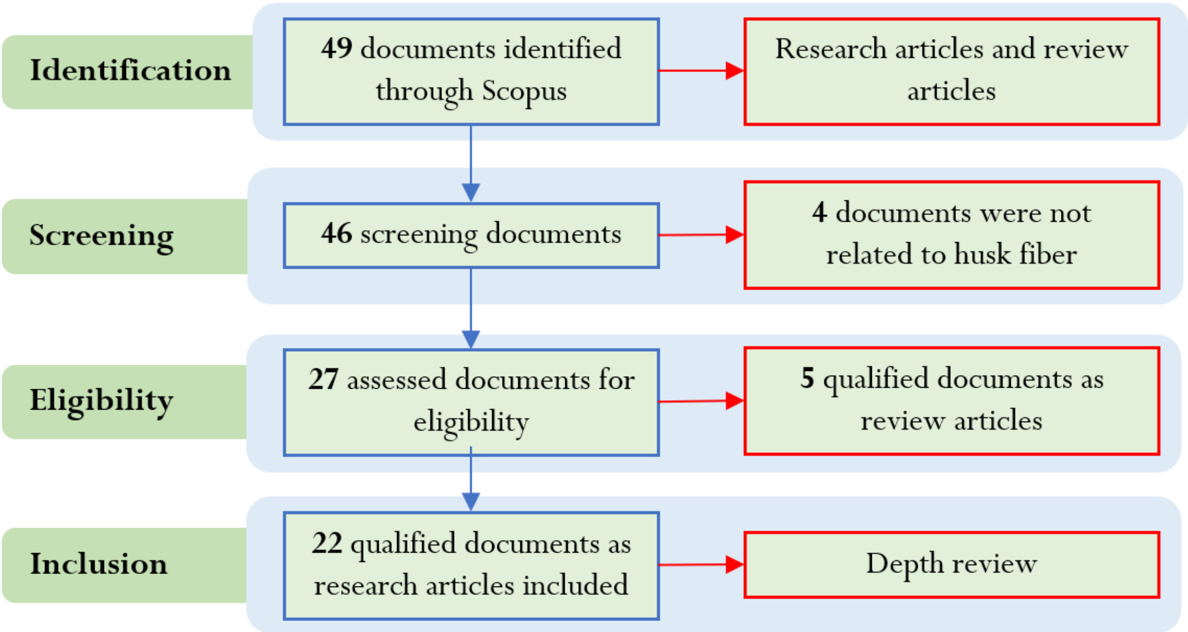

Figure 1. Four phases flow diagram (adapted from (Moher et al., 2009))

3.1 Constructing and visualizing bibliometric networks

Based on the analysis results using the VOSviewer tool, the most frequently discussed keywords of areca fibre as reinforcement in composite materials are keywords about tensile strength and its network shows related to reinforcement, aerospace industry, natural fibre, epoxy, biodegradation, areca fibre bonding, chopped and biodegradable (red colour in Fig. 2). In terms of time, the most recent discussions are about reinforcement, biocomposites, fibre composites, bonding, chopped and biodegradable (yellow colour in Fig. 3).

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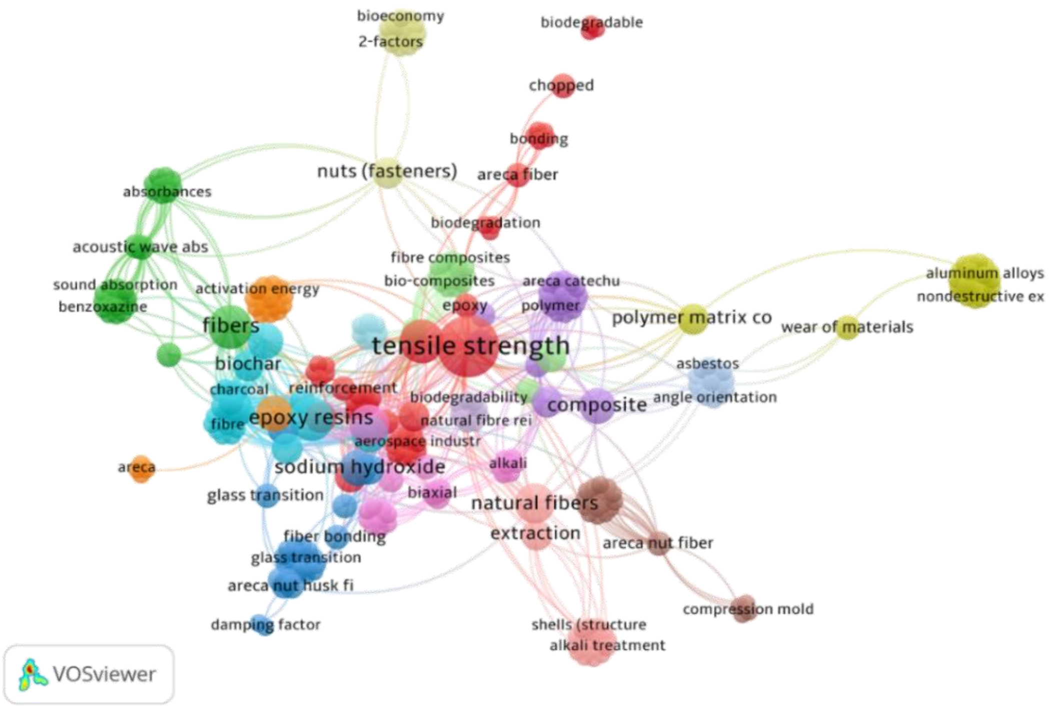

Figure 2. Network visualization

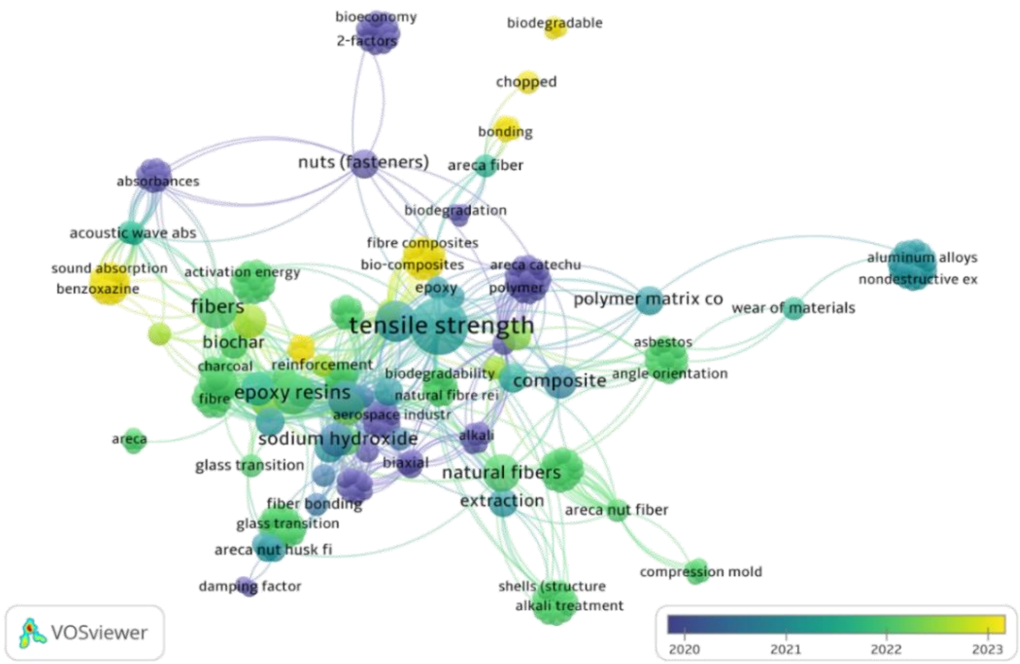

Figure 3. Overlay visualization

3.2 Stages in the production of ANHF composites

Based on an in-depth study of 22 articles, we have classified areca fibre into two main stages, namely the preparation and manufacturing stages of the composite producation.

3.2.1 Preparation process

The preparation stage consisted of areca nut shell selection, water retting, areca nut shell fibre extraction, chemical treatment and drying of the ANHF (Fig. 4).

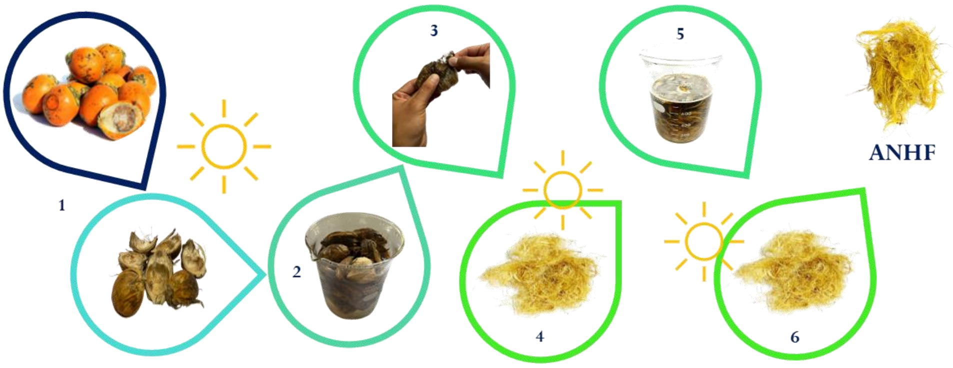

Figure 4. Preparation process

1. Areca nul shell selection

Mature areca nuts were used. The tensile strength of the mature areca fibre was better at 166.03 MPa compared to the young areca fibre at 128.79 MPa (Yusriah et al., 2014). The areca nut shell is separated from the seeds and dried in the sun.

2. Water retting

Soaking of areca nut shells aims to loosen the fibres present in the shells. Three articles reported the duration of soaking, namely 24 hours (Borah & Dutta, 2018), 3 days (Mathapati et al., 2022) and 7 days (Muralidhar et al., 2019). From the literature studied, no one has studied the effect of soaking duration on areca nut peel fibre quality.

3. Extracting fibre from areca nut shells

The fibre is extracted from the areca nut shell and the extraction process can be done by machine or by hand. However, mechanical stripping is quicker and easier.

4. ANHF sun drying

Areca nut shell fibre is dried in the sun. Based on the literature, some people dry the fibres for two environmental days (Mahyudin et al., 2020) and some for 2-4 days (Madnasri et al., 2022). However, there are no reports on the water content limit required to proceed to the next stage.

5. Chemical treatment

Chemical treatment was performed on the extracted (ANHF) fibres, as chemical treatment of intact areca nut shells did not significantly affect the tensile strength of the fibres (Deshmukh et al., 2019). A summary of the type of material, concentration, treatment time and temperature used for chemical treatment is presented in Table 1.

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Tabel 1. Chemical treatment

Chemical	Consentration	Duration of treatment (Hours)	Temperature (°C)	Ref.
NaOH	20%	1		(Chakrabarty et al., 2012; Hegde et al., 2018)
NaOH	10%	36	30	(Ramakrishnan et al., 2022)
NaOH	6%	24	26 ± 2	(Aishwarya et al., 2022; Muralidhar, Vadivuchezhian, Arumugam, & Reddy, 2020; Poornima et al., 2022)
NaOH	5 %	2	Room temperature	(Borah & Dutta, 2018; Mahyudin et al., 2020)
NaOH	5%	1	80	(Srinivasan et al., 2023)
NaOH	5%	0.5	Room temperature	(Lazim et al., 2014)
NaOH	0.5	0.166	Room temperature	(Babu et al., 2019)
KOH	2,5%	24	Room temperature	(Deshmukh et al., 2019)
KOH	6%	Not specified	28 C to 125 C, heating rate of 3 C per minute	(Mathapati et al., 2022)

The chemical treatment aims to remove substances that can damage the fibre bond with the matrix, resulting in better mechanical properties of the composite material. Hemicellulose, lignin and ash contents were most degraded by this chemical treatment of areca nut shell fibre composition, while the effect on cellulose was less significant (Lazim et al., 2014). The most commonly used chemical is NaOH. Based on the literature review, no one has focused on discussing in depth the percentage of NaOH used, the duration of treatment and the temperature used. Further research is needed to find the most optimal. The chemically soaked ANHF are thoroughly rinsed with running water to remove any residual chemical solution still adhering to the ANHF.

6. Drying of ANHF after chemical treatment

ANFH that has been washed with water is then dried in the sun for 24 hours or until the areca fibre is completely dry and no water is present in the areca fibre. The drying process of the areca fibre has a great influence on the strength of the areca fibre itself, as fibres that are still wet can disrupt the bond between the fibre and the matrix in the composite. This weak bond can result in poor mechanical properties of the areca nut shell fibre composite.

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3.2.2 Manufacturing process

Of the various studies on the use of ANHF for reinforcement in composites, the most commonly used method is hand lay-up (Aishwarya et al., 2022; Haque et al., 2021; Mathapati et al., 2022; Poornima et al., 2022). In addition, another method that has been applied in the manufacture of ANHF composites is compression moulding (Borah & Dutta, 2018).

3.3 Fraction, matrix, additives and mechanical properties

Based on the review of these research articles, it was found that different fractions, types of matrix and additives have been added to make ANHF composites. The authors summarises them in Table 2 and presents their mechanical properties. From published research reports it is known that the fibre fraction, matrix type and additives used affect the mechanical properties of the composites. The range of fibre fractions used was from 3 to 65 wt.%. The most commonly used matrix type is epoxy, with seven studies using this matrix type. In addition, two studies used polypropylene matrix type, one study used polyester and one study used dropoxy. The additives used are 2% papaya biochar, 2% orange peel biochar and 20% sponge gourd.

In terms of mechanical properties, the best combination was found with a fibre fraction composition of 40 wt.% using an epoxy type matrix coupled with 2% papaya biochar (Lakshmana & Erko, 2022). While for the polypropylene matrix type, high tensile strength was achieved with a fibre fraction composition of 30 wt.% (Chakrabarty et al., 2012). In contrast, based on matrix type, the lowest tensile strength was achieved with polypropylene at 3 wt.% fibre fraction (Mahyudin et al., 2020).

Tabel 2. Constituents and mechanical properties

Constituents			Mechanical Properties			
Fibre fractions (wt. %)	**Matrix type**	**Addictive substances**	**Tensile Strength (MPa)**	**Flexural strength (MPa)**	**Impact (J)**	**Ref.**
40	Epoxy	2% Papaya biochar	178	282	5,42	(Lakshmana & Erko, 2022)
40	Epoxy	2% Orange peel biochar	178	188	-	(Alshahrani & Prakash, 2024)
20	Epoxy	-	28,24	52,11	-	(Sankarathil et al., 2023)
30	Polypropylene	-	27	63	-	(Chakrabarty et al., 2012)
65	Epoxy	-	25,9733	-	-	(Babu et al., 2019)
20	Polyester	20% sponge gourd	22,06	40,1	-	(Haque et al., 2021)

5	Dropoxy	-	15,6	-		(Borah & Dutta, 2018)
15	Epoxy	-	15,1	73	6	(Muralidhar et al., 2019; Muralidhar, Vadivuchezhian, Arumugam, & Srinivasula Reddy, 2020)
60	Epoxy	-	-	74,613	-	(Thamba et al., 2019)
3 7	Polypropylene	-	11	-	0,0739	(Mahyudin et al., 2020)
15	Epoxy	-	9,19	-	-	(Hegde et al., 2018)

4. Conclusion

Based on the search results in the Scopus database, a number of studies have been carried out using ANHF as a reinforcing material in composites. ANHF has the potential to be used as a reinforcement in natural composites. Prior to its use, there are several steps that need to be taken to obtain fibres from areca nut shells. These include shell selection, drying, water retting, fibre extraction, re-drying, chemical treatment and re-drying to ensure that the fibres are of suitable quality for the application.

Various methods of chemical treatment have been used. However, further research is needed to confirm the effectiveness of chemical treatment. Composite manufacturing is generally done by hand lay-up, but further research is also needed to find a more effective method. Based on reported research, fibre fraction, matrix type and additives used influence the mechanical properties of composites. Currently, only four types of resins are commonly used, namely epoxy, polypropylene, polyester and dropoxy. Further research is therefore needed to identify other resin types that can be used. The same applies to natural additives that can improve the quality of composites reinforced with ANHF.

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Declarations

Author contribution

Zulhan Insan Makruf: Resources, Anylisys VosViewer, dept-review and write original articles. Wanda Afnison: Data Curation, Writing - Review & Editing, and Supervision. Bulkia Rahim: Writing - Review & Editing, and Supervision.

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Conflict of interest

There is no conflict of interest in this study.

Ethical clerance

There are no human subjects in this manuscript and informed consent is not applicable.

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