BIO-DELIGNIFICATION PRE-TREATMENT OF LIGNOCELLULOSIC BIOMASS, OIL PALM FROND (OPF) AND EMPTY FRUIT BUNCH (EFB): A REVIEW IN BIOFUELS AND BIOGAS PROCESSING

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ABSTRAK

Kajian ini memberi tumpuan kepada penentuan keputusan-keputusan selari dengan 3 objektif kaji semula. Yang pertama, berkait rapat dengan ciri-ciri biojisim lignoselulosik untuk pelepah kelapa sawit dan sisa buah kelapa sawit. Kemudian jenis "pre-treatment" yang tersedia ada dan perbandingan sesama mereka dari segi proses hydrolysis terhadap sisa-sisa biojisim. Akhir sekali adalah mekanisme yang terlibat dalam proses "pre-treatment" dalam mengurangkan kandungan lignin dengan menggunakan kulat (white-rot fungi). Kajian ini dilaksanakan dengan merujuk cara-cara disertasi SLR. Ciri-ciri biojisim lignoselulosik boleh dipamerkan melalui struktur biojisim iaitu cellulose, hemicellulose dan lignin. Impak-impak terhadap proses hydrolysis pula boleh didapati daripada kajian lepas dimana mereka rekod kesan-kesan tersebut melalui peratusan penyingkiran lignin ataupun melalui hasil hydrolysis. Mekanisme kulat yang terlibat dalam pengurangan lignin dalam biomass lignoselulosik seperti pelepah kelapa sawit dan sisa buah kelapa sawit dapat dibahagikan kepada dua kategori, yang pertama delignifikasi memilih dan yang kedua delignifikasi tidak memilih.

ABSTRACT

This study focuses in determining results in relation to three review objectives. Firstly is regarding to lignocellulosic biomass characteristics for both oil palm frond (OPF) and empty fruit bunch (EFB). Afterwards is type of pre-treatment available and their comparison between each other in terms of hydrolysis process of lignocellulosic biomass. Lastly is mechanism for bio-delignification of OPF and EFB using by using fungi. The dissertation is carried out in a systematic literature format (SLR). Lignocellulosic biomass characteristics is determined by signifying the structural content in agricultural biomass for instance cellulose, hemicellulose and lignin composition. Effect of hydrolysis process is determined from past studies where it stated as lignin removal percentages or hydrolysis yield. Mechanism involved in bio-delignification of EFB and OPF through the use fungi (white-rot fungi) is divided into two, selective delignification and non-selective delignification.

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CHAPTER 1

INTRODUCTION

1.1 Background

The palm oil industry since the 1990s has undergone significant development where countries of concern are Malaysia and Indonesia. Oil palm (*Elaeis guineensis*) is cultivated primarily for its palm oil, besides other by-products from the harvest can also be of use for instance palm press fibre, palm kernel and palm oil sludge. Harvesting of fruit bunch from the trees has led to the increase of fibrous waste production where the waste by-products include oil palm fronds (OPF) and empty fruit bunches (EFB) (Dahlan, 2000).

Cultivating practice of palm oil tree in Malaysia are carried as such where firstly cutting of OPF. This activity to some can be called as pruning. Process of pruning is advised to be conducted at regular intervals (better if scheduled periodically), however when harvesting season come by it is not obligatory to carry out pruning. Before fresh fruit bunches (FFB) becomes EFB, it must undergo oil extraction where they are collected together then proceed transporting them to palm oil mills (K. O, Lim et., 2000).

From the palm oil cultivation, waste by-products that are unwanted (high content of lignocellulosic biomass) are left to be burned out in the open air but this issue raises environmental concern particularly on global warming. This practice however is banned and later the wastes produced from oil palm cultivation are left to decompose acting as fertilizer for the ground. Upon agreement from the world community, countries involved in the Kyoto Protocol in December in 1997 have recognised the potential danger that is

global warming and promised to reduce air pollution caused by green-house gases such as carbon dioxide, CO_2 (K. O, Lim et., 2000).

Fossil-fuel is limited and continues to diminish as time goes by though the world depends on it, side effects on fossil-fuel use cannot be ignored. Because of this, world governments have started to relocate their focus on other suitable alternatives of energy source. These alternatives are most common to be renewable in nature where various countries have taken account on renewable energy usages into their energy policy such as China and Germany (Shafie *et al.*, 2012). Since Malaysia is rich in plantation residue (such as oil palm frond and empty fruit bunch etc.), biomass should be considered as an alternative energy resource even more so when the world energy utilization is anticipated to grow by 49% from year 2007 to 2035 (Shafie *et al.*, 2012).

To make use of lignocellulosic biomass from plantation harvesting, best venture into biofuel production and processing industry so that can better utilize them as an energy source. It is said that last two years (from 2019) main energy usage throughout the world was contributed 80% by prevalent fuels even so, alternatives such as biofuels started to have increase in demand (Haldar and Purkait, 2020). Biofuels can be further grouped into four types, they include bioethanol, biogas, biodiesel and bio-hydrogen. They are organized as such because all different forms of biofuel comes from separate derivation (Correa *et al.*, 2019).

In Malaysia, produced biomass originate from multiple sources of plantation cultivation and they are high in nutrients suitable for biofuel fabrication (OPFs and EFBs included) (Rezania *et al.*, 2020). Challenges may come about particularly in the

degradation process for palm oil mill biomass (OPF and EFB) prior to the anaerobic digestion or temperature phase anaerobic digestion. Methods of pre-treatment is introduced so that it can improve the degradation process where inoculant of interest is fungi. Further research is required on the topic of bio-delignification as a method of pre-treatment to promote hydrolysis in lignocellulosic biomass. Beside, best to further understand biomass characteristic of EFB and OPF so that it may contribute in a review for biofuels and biogas processing.

1.2 Review Questions

The aim of this study is to answer the following review questions:

RQ1. What are the lignocellulosic biomass characteristics specifically on oil palm frond (OPF) and empty fruit bunch (EFB)?

RQ2. What are the types of pre-treatment methods and their effects in hydrolysis process of lignocellulosic biomass with comparison between each other for biofuels and biogas production?

RQ3. What are the possible crucial parameters/conditions in different types of pre-treatment for lignocellulosic biomass?

RQ4. How does the experimental investigations or studies have been carried out in determining pre-treatment process for palm oil waste by-products?

RQ5. What are the processes (possibly including mechanisms) involved in bio-delignification pre-treatment process of OPF and EFB using fungi?

1.3 Objectives of the Systematic Review

The objectives for this study are as follows:

RO1. To determine lignocellulosic biomass characteristics solely focus on oil palm frond (OPF) and empty fruit bunch (EFB).

RO2. To compare the effect of pre-treatment methods in the hydrolysis process of lignocellulosic biomass for biofuels and biogas production.

RO3. To examine the bio-delignification pre-treatment process of OPF and EFB using fungi.

1.4 Scope of the Systematic Review

Experimental studies regarding pre-treatment of lignocellulosic biomass such as OPF and EFB including their possible use in biofuels and biogas processing will be studied using a systematic review method. By doing so, able to justify the stated review objectives through this study. Dissertation of systematic literature review (SLR) type have its own protocol and can be divided into five succession stages. SLR protocol should also further define the course of action required to heed during the review process.

The SLR protocol begins by with identifying the review questions for the topic of interest. It is important for the review questions to be associated with the review objectives. Part of this study also include assemble multiple previous studies that involve with the chosen topic of study where for this occasion, bio-delignification pre-treatment of lignocellulosic biomass, OPF and EFB with a review in biofuels and biogas processing. Afterwards followed by defining searching strategy by pinpointing main keywords from both review questions and review objectives so that it helps in acquiring research articles. The process must undergo the following steps, identification, screening and eligibility.

After collecting relevant research articles, required to define data extraction. The following phase can be interpret as such, fully read each identified article so that

afterwards to be added in the systematic literature review and extract applicable data using a uniform data extraction table/form. SLR protocol ends with by defining data synthesis where the collective of data obtained from the review articles will aid in effort to reach conclusions with the addition of supportive evidences.

1.5 Significance of the Systematic Review

The expected outcome for this project will be a cultivated systematic review from past experimental studies that fulfill the review objectives such as characteristics of biomass particularly OPF and EFB, use of fungi and its effect in enhancing degradation process, comparison between pre-treatment methods for lignocellulosic biomass and their crucial parameters (possibly also the conditions). Through this course of action, it can bring further attention in improving biomass treatment and also review waste by-products such as from palm oil mill in biofuels and biogas production to serve as renewable energy source.

CHAPTER 2

SYSTEMATIC LITERATURE REVIEW (SLR): A METHODOLOGY

2.1 Introduction

This chapter will outline the methodology implemented in this thesis where it gives attention to previous experimental studies collected to be reviewed regarding topics related to bio-delignification of lignocellulosic biomass, OPF and EFB in addition a review in biofuels and biogas production. Moreover, the following research methodology/protocol defined such as Figure 2.1 can help in answering the review questions for this SLR.

It is to be noted that for this study, three main methodological processes are involved. Initially, the main intention is to determine as the title for this study implies bio-delignification of lignocellulosic biomass focusing on OPF and EFB, their characteristics, parameters and conditions involved, use of fungi as inoculant and ends with review for both biomasses in biofuels and biogas processing.

Secondly, through SLR able execute the experimental studies on the bio-delignification on lignocellulosic biomass by reviewing them. Lastly, from the systematic literature review dissertation able to pin down the missing links in current knowledge regarding on bio-delignification process on OPF and EFB and their potential use as a renewable energy source.

2.2 Planning of SLR

The end goal for the proposed research methodology is to examine and analyze in detailed manner for the collected experimental studies that are related to the research title, bio-delignification pre-treatment of lignocellulosic biomass. Systematic literature review will be used through the dissertation. A brief overview on the nature of SLR is that this type of dissertation must carry out classifying, analyzing and synthesize from at hand evidence for a particular study/technology in a well-defined and methodological manner. This is solely for clarification of the current status of research, but also contributing background information on research obstacles (BA and Charters, 2007).

SLR review protocol will be implemented along with its required steps for the purpose to identify current literature on experimental studies that are within the scope of the research study, bio-delignification pre-treatment of lignocellulosic biomass, OPF and EFB. Reviewed literatures must also answer the defined review questions and achieve all of the review objectives and they are biomass characteristics of OPF and EFB, comparison between different pre-treatments of lignocellulosic biomass, significant parameters and conditions for pre-treatment, usefulness of fungi as inoculant in pre-treatment.

2.3 Review Protocol

It is equally important in developing protocol in systematic literature review operation as shown in Figure 1. The protocol serve a purpose in laying out the steps and procedures that researchers will use in their analysis to lessen the risk of validity and negate author bias. Noticeable differences between SLR and traditional literature reviews

is their review protocol. An independent reviewer has checked the protocol used in this work.

Figure 2.1: SLR Protocol

The protocol starts with distinguishing of the review questions, later proceed in defining searching strategies for the databases. The inclusion and exclusion criteria are then developed in order to provide a systematic method of choosing between specified primary studies. Finally, data elements extracted from primary studies are established to assist in answering research questions.

2.3.1 Formulation of Review Questions

Proposed review questions should be noted that they must be admissible for respective researchers including with fellow practitioners. The following are the addressed review questions for this SLR:

RQ1. What are the lignocellulosic biomass characteristics specifically on oil palm frond (OPF) and empty fruit bunch (EFB)?

RQ2. What are the types of pre-treatment methods and their effects in hydrolysis process of lignocellulosic biomass with comparison between each other for biofuels and biogas production?

RQ3. What are the crucial parameters possibly conditions also in different types of pre-treatment for lignocellulosic biomass?

RQ4. How does the experimental investigations or studies have been carried out in determining pre-treatment process for palm oil waste by-products?

RQ5. What are the processes (possibly including mechanisms) involved in bio-delignification pre-treatment process of OPF and EFB using fungi?

RQ1 brings up the need to address the lignocellulosic biomass characteristics both for OPF and EFB. The review question may touch upon the biological, physical or even the chemical characteristics of the biomass. RQ2 however will help in determining available pre-treatments for lignocellulosic biomass and later compare with one another in terms of the hydrolysis process.

RQ3 can serve as better discussion for RQ2, RQ4 and RQ5 because it stresses on the important parameters and conditions (if there is any) that are affecting different type of pre-treatment process for lignocellulosic biomass. RQ4 and RQ5 should clumped together because they question on how the experimental studies carried out and the influence of fungi in bio-delignification pre-treatment for both OPF and EFB. It is to be noted that with RQ5, it should help in clarifying the mechanisms or processes involved for the pre-treatment.

2.3.2 Systematic Searching Strategy

This phase included a search and distribution strategy. The search strategy assists in determining the required search string and categorizing the appropriate databases to collect the relevant documents. Identification, screening, and eligibility are the three sub-processes of systematic searching strategies.

The first sub-process is identification, which searches for synonyms, similar terms, and keyword variations. It intends to provide more options for the chosen database to search for more relevant research articles. The appropriate keywords are first identified, with the process based on an online thesaurus, keywords used in previous research, keywords suggested by Scopus and keywords nominated by professionals. Selected leading and supporting databases will be explored for the searching of articles by make use of the main and enriched keywords. The following keywords will be implemented in advanced searching system where may include with the use of Boolean operator, phrase searching, truncation, wild card or even separate code functions. Another alternative is by merging all of the searching method into a finalized searching string.

The created search strings are then 'paste' into the selected databases, which are the leading database on Scopus and the supporting database on Science Direct, to search for relevant articles. The corresponding author can also use manual searching methods such as hand-picking, snowballing, and e-mailing.

Table 2.1: Enriching main keywords for review objectives and review questions

Section	Main Keywords	Enriched Keywords
RO1 To determine lignocellulosic biomass characteristics solely focus on oil palm frond (OPF) and empty fruit bunch (EFB)	Lignocellulosic biomass Characteristics Oil palm frond (OPF) Empty fruit bunch (EFB)	Waste biomass, energy crops Properties, structure, composition, (biological, chemical, physical) Palm oil waste/Oil palm waste
RO2 To compare the effect of pre-treatment	Compare Effect Pre-treatment	Contrast, correlate, Result, outcome -

methods in the hydrolysis process of lignocellulosic biomass for biofuels and biogas production.	Hydrolysis Process Lignocellulosic biomass Biofuels Biogas Production	- Procedure, mechanism Waste biomass - - Processing, manufacturing

RO3 To examine the bio-delignification pre-treatment process of OPF and EFB using fungi.	Examine Bio-delignification Pre-treatment Process OPF and EFB Fungi	Investigate, inspect - - Method, procedure Waste biomass, palm oil waste/oil palm waste Inoculant, microbe
RQ1 What are the lignocellulosic biomass characteristics specifically on oil palm frond (OPF) and empty fruit bunch (EFB)?	Lignocellulosic biomass Characteristics Oil palm frond Empty fruit bunch	Waste biomass, energy crops Attribute, aspect, qualities, composition, properties, (biological, chemical, physical) Palm oil waste/oil palm waste
RQ2 What are the types of pre-treatment methods and their effects in hydrolysis process of lignocellulosic biomass with comparison between each other for biofuels and biogas production?	Types Pre-treatment Methods Effect Hydrolysis Lignocellulosic biomass Comparison Biofuels Biogas Production	Category, group - Approach, mechanism, technique Outcome - Waste biomass, energy crops Correlation, contrast - - Manufacturing, processing
RQ3 What are the crucial parameters possibly conditions also in different types of pre-treatment for lignocellulosic biomass?	Crucial Parameters Conditions Different Pre-treatment Lignocellulosic biomass	Essential, significant - - Contrasting - Waste biomass, energy crops

RQ4 How does the experimental investigations or studies have been carried out in determining pre-treatment process for palm oil waste by-products?	Experimental investigations Determining Pre-treatment Process Palm oil waste By-products	- Deduce, certify - Procedure, method Oil palm frond (OPF), empty fruit bunch (EFB) Leftover, derivative
RQ5 What are the processes (possibly including mechanisms) involved in bio-delignification pre-treatment process of OPF and EFB using fungi?	Process Mechanism Bio-delignification Pre-treatment Oil palm frond (OPF) Empty fruit bunch (EFB) Fungi	Procedure, method Operation - - Palm oil waste Inoculant, microbe

Table 2.2: Full search string for review objective 1

Database	Search string
Scopus	TITLE-ABS-KEY (("lignocellulosic biomass" OR "waste biomass" OR "energy crop") AND ("characteristics" OR "properties" OR "composition" OR "biological" OR "chemical" OR "physical") AND ("oil palm frond" OR "empty fruit bunch" OR "palm oil waste" OR "oil palm waste"))
Science Direct	("lignocellulosic biomass") AND ("characteristics" OR "properties" OR "composition") AND ("oil palm frond" OR "empty fruit bunch" OR "palm oil waste" OR "oil palm waste")

Table 2.3: Full search string for review objective 2

Database	Search string
Scopus	TITLE-ABS-KEY (("compare" OR "contrast" OR "correlate" OR "differentiate") AND ("effect" OR "result" OR "outcome") AND ("pre-treatment") AND ("hydrolysis") AND ("process" OR "procedure" OR "mechanism") AND ("lignocellulosic biomass" OR "waste biomass") AND ("biogas") AND ("biofuel") AND ("production" OR "processing" OR "manufacturing"))
Science Direct	("compare" OR "correlate") AND ("effect") AND ("pre-treatment") AND ("hydrolysis") AND ("process" OR "procedure") AND ("lignocellulosic biomass")

Table 2.4: Full search string for review objective 3

Database	Search string
Scopus	TITLE-ABS-KEY (("examine" OR "investigate" OR "inspect") AND ("bio-delignification") AND ("pre-treatment") AND ("process" OR "method" OR "procedure") AND ("oil palm frond" OR "empty fruit bunch" OR "waste biomass" OR "palm oil waste" OR "oil palm waste") AND ("fungi" OR "inoculant" OR "microbe"))
Science Direct	("examine") AND ("bio-delignification") AND ("pre-treatment") AND ("process") AND ("oil palm frond" OR "empty fruit bunch") AND ("fungi" OR "inoculant" OR "microbe")

Table 2.5: Full search string for review question 1

Database	Search string
Scopus	TITLE-ABS-KEY(("lignocellulosic biomass" OR "waste biomass" OR "energy crops") AND ("characteristics" OR "attribute" OR "properties") AND ("biological" OR "chemical" OR "physical") AND ("oil palm frond" OR "empty fruit bunch" OR " palm oil waste" OR "oil palm waste"))
Science Direct	("lignocellulosic biomass") AND ("characteristics" OR "properties") AND ("biological" OR "chemical" OR "physical") AND ("oil palm frond" OR "empty fruit bunch")

Table 2.6: Full search string for review question 2

Database	Search string
Scopus	TITLE-ABS-KEY(("types") AND ("pre-treatment") AND ("methods OR technique") AND ("effect") AND ("hydrolysis") AND ("lignocellulosic biomass") AND ("comparison") AND ("biofuel" OR "biogas") AND ("production"))
Science Direct	("types") AND ("pre-treatment") AND ("methods OR technique") AND ("effect") AND ("hydrolysis") AND ("lignocellulosic biomass") AND ("comparison") AND ("biofuel" OR "biogas") AND ("production")

Table 2.7: Full search string for review question 3

Database	Search string
Scopus	TITLE-ABS-KEY(("crucial" OR "essential" OR "significant") AND ("parameters") AND ("conditions") AND ("different") AND ("pre-treatment") AND ("lignocellulosic biomass"))
Science Direct	("crucial" OR "essential" OR "significant") AND ("parameters") AND ("conditions") AND ("different") AND ("pre-treatment") AND ("lignocellulosic biomass")

Table 2.8: Full search string for review question 4

Database	Search string
Scopus	TITLE-ABS-KEY(("experimental investigations") AND ("determining" OR "deduce") AND ("pre-treatment") AND ("process" OR "procedure" OR "method") AND ("palm oil waste" OR "oil palm frond" OR "empty fruit bunch") AND ("by-products" OR "leftover" OR "derivative"))
Science Direct	("experimental investigations") AND ("determining") AND ("pre-treatment") AND ("process" OR "method") AND ("palm oil waste" OR "oil palm frond" OR "empty fruit bunch") AND ("by-products")

Table 2.9: Full search string for review question 5

Database	Search string
Scopus	TITLE-ABS-KEY(("process" OR "procedure" OR "method") AND ("mechanism" OR "operation") AND ("bio-delignification") AND ("pre-treatment") AND ("oil palm frond' OR "empty fruit bunch" OR "palm oil waste") AND ("fungi" OR "inoculant" OR "microbe"))
Science Direct	(("pre-treatment") AND ("process") AND ("biomass" OR "oil palm frond" OR "empty fruit bunch") AND ("fungi"))

Next sub-process in the systematic searching strategy process is screening, which establishes the inclusion and exclusion criteria (where articles comply with the criteria or rejected by it) for the articles to be evaluated. All of the articles to be reviewed must be screened using inclusion and exclusion criteria. This type of work can be performed via the sorting feature provided from the selected databases. Timelines, publication type and language are among the requirements considered for the inclusion and exclusion criteria.

It is noted that timeline is among the inclusion criteria, it is not practical however for researchers to conduct SLR type dissertation to review all available published papers, (Okoli, 2015) the alternative is to encourage researchers alike to focus solely on timeline range that must be reviewed. According to the “Cochrane Handbook for Systematic Reviews of Interventions”, limitations on timeline publications should only be implemented when similar studies are published during the same time (Higgins & Green, 2020). Furthermore, to ensure the quality of the analysis, only articles with empirical evidence and published in journals, research articles, or review articles are included. On top of that, for this study papers published to be reviewed is limited only to English written papers (or Bahasa Malaysia if relevant).

Table 2.10: Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Timeline	2005-2021	Before 2005
Publication type	Journal, research article, review article, books, conference proceeding, chapter in books	Newspaper
Language	English (include also Bahasa Malaysia if relevant)	Anything besides English (or Bahasa Malaysia)

Final sub-process for systematic searching strategies is eligibility. After screening, retrieved articles will be further inspect by authors so that all remaining articles meet the established criteria stated previously. The following work can be completed by examine and read the paper's articles and their abstracts.

2.3.3 Data extraction and synthesis

Next course of action is to extract and analyze the data or results of interest from those articles after identifying them for the systematic review. It is noted that there are multiple frameworks for data extraction and data synthesis, the familiar approaches are non-meta-analysis for qualitative analysis while meta-analysis for quantitative analysis. Non-meta-analysis is executed by implementing finding tables to act as a form of summary for our findings. Data pooling and advanced statistical analysis however will be used in meta-analysis.

With recent development in machine learning, electronic texts searches can now be performed whereby this provides further assistance in discovering information within articles (Cochrane Handbook, 2020). In spite of that, data extraction still remains largely manual even with advancements in automating data extraction in systematic reviews via machine learning models.

2.4 Reporting the SLR

At this phase, all procedure carried out should be reported in an orderly manner. Collection of articles retrieved from databases where later undergo identification to screening and lastly eligibility sub-process, likewise should have fitting data record management. Number of articles recovered is shown using the PRISMA flow diagram, as shown in Figure 2.2.

From Figure 2.2, records identified through the databases resulted in having a total of 145 and 1179 for Scopus and Science Direct respectively. By combining previous studies collected from the two databases, we have a total of 1324 studies. However when consider the occurrence of duplicates from full search strings of review questions and review objectives, the outcome after removing duplicates is 662.

Afterwards, records collected are further screened whereby by excluding 99 records this result to a total of 563 records left. After screening, eligibility sub-process play its role whereby accomplished by reading the title and abstract of the recorded studies. When in doubt or unable to fully comprehend, further reading on the research paper contents is required. To conclude, full text articles assessed for eligibility and qualitative analysis come about to 30 to be reviewed.

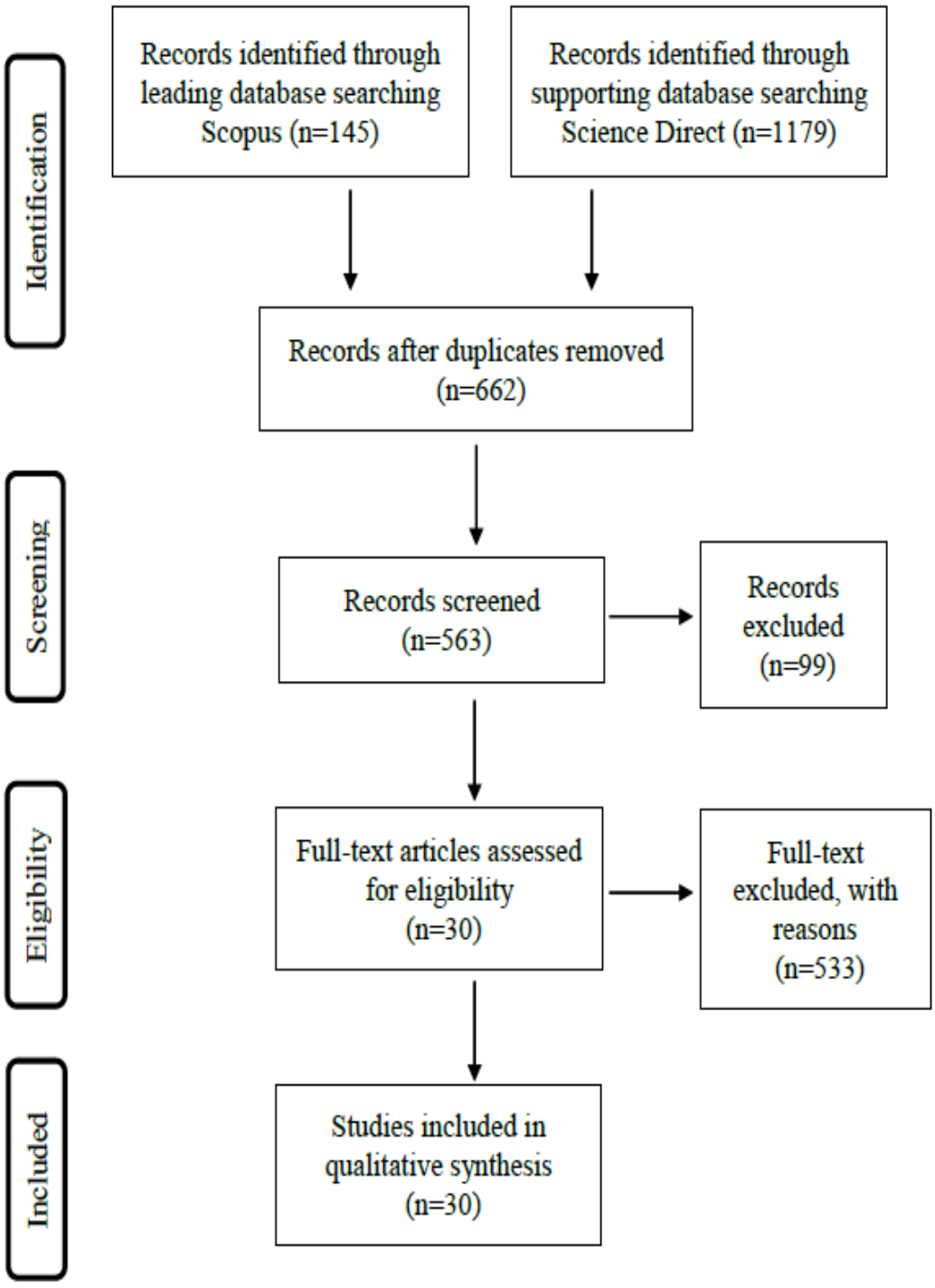

Figure 2.2: Flow diagram of the retrieved articles

CHAPTER 3

DATA EXTRACTION AND SYNTHESIS/ANALYSIS/METHODOLOGY

3.1 Introduction

The extraction and synthesis phase involved categorising the relevant data from the selected articles according to the information and conclusions obtained. The data extraction procedure entailed identifying and extracting relevant data from the selected articles. In addition, synthesized data and extraction of important information with conclusions is to be included in the analysis phase.

To achieve the SLR's goal, the variable of interest was organised based on the general characteristics of the articles and the primary criteria used for evaluation. The papers' general details include the years of publication, the type and scope of the study, and the country or region in which the study was conducted. For the selected papers, Excel spreadsheet will be used to record relevant extracted data and results for processing.

For further study, the categorisation stage entailed the classification and processing of the collected data, where charts and different type of graphs will be make use of to present the final result. Supposedly in the analysis phase, developed review questions previously should have been answered from this work. It is equally important for the analysis phase to incorporate a qualitative summary of the findings, discussion on the results, recommendation for future work and conclusion.

3.2 Data extraction

This step focuses on collecting data from related studies for analysis and comparison of findings sake. When extracting data, proper data management practices

must be followed. Appropriate data management should be implemented best at the very beginning of collecting data. Moreover, data management software such as Mendeley, EndNotes, etc. will help for this particular work where have the ability to choose which information to be kept.

The method of reading the full text of each article chosen for inclusion in the analysis and extracting the relevant data using a standardized data extraction form/table is known as data extraction. For smaller or simpler projects, a data extraction form or table can be created in Excel, Google Spreadsheets, or Word. It is important to use review objectives and review questions as basis in developing the data extraction from or table.

Collecting of qualitative evidence is most often repetitious. Besides, key themes and questions will emerge from the synthesis where review authors will interchange between studying primary papers, data extraction and interpretation (Noyes & Lewin, 2011).

Table 3.1: Example of data extraction table

Author	Year	Objective	Scope	Method	Findings	Design parameters	Limitations

3.3 Data synthesis

Combining of data from a set review articles to come about conclusions about a body of evidence is called data synthesis. Qualitative data synthesis/analysis and quantitative data synthesis/analysis are among the main types of data synthesis/analysis. There are several methods for synthesis/analysis of qualitative data.

The most commonly used ones, however, are chronological and thematic. Analysis of the papers based on the dates they were published is known as chronological approach. This type of approach should only be used when particular research path is established from past research and follow progression in chronological manner.

Instead of following a chronological progression, thematic analysis however revolves around a topic or problems. To explain briefly, aim of thematic analysis is to pin point trends available in the data acquired from primary studies and it is accomplished by sorting by affinity and data significance.

CHAPTER 4

LITERATURE REVIEW: FINDINGS AND DISCUSSION

4.1 The lignocellulosic biomass characteristics of OPF and EFB

To highlight back RQ1, lignocellulosic biomass characteristics needed to be determined and reviewed. Biomass of interest again are EFB and OPF from palm oil waste. Biomass characteristics discussed revolves around properties include physical, biological composition, chemical elements and other attributes if applicable. From reviewing relevant papers, methods in discovering biomass characteristics share similarities in their method of analysis such as Elemental Analysis and Proximate Analysis.

Table 4.1: Lignocellulosic content of EFB

No.	References	Component	Values (%)
1	(Abdullah *et al.*, 2011)	Cellulose	59.70
		Hemicellulose	22.10
		Lignin	18.10
2	(Omar et al., 2011)	Cellulose	23.70
		Hemicellulose	21.60
		Lignin	29.20
3	(Mohammed *et al.*, 2012)	Cellulose	22.24
		Hemicellulose	20.58
		Lignin	30.45
4	(Ruano *et al.*, 2016)	Cellulose	43 - 65
		Hemicellulose	17 - 33
		Lignin	13 - 37
5	(Megashah *et al.*, 2018)	Cellulose	37.1 ± 4.4
		Hemicellulose	39.9 ± 0.75
		Lignin	18.6 ± 1.3
6	(Yang *et al.*, 2020)	Cellulose	37.4 ± 0.6
		Hemicellulose	23.9 ± 0.4
		Lignin	21.2 ± 0.3

Table 4.2: Lignocellulosic content of OPF

No.	References	Component	Values (%)
1	(Srirnachai *et al.*, 2014)	Cellulose	37.68
		Hemicellulose	35.34
		Lignin	25.18
2	(Tan *et al*., 2016)	Cellulose	42.80
		Hemicellulose	14.80
		Lignin	19.70
3	(Ruano *et a*l., 2016)	Cellulose	40 - 50
		Hemicellulose	34 - 38
		Lignin	20 - 21
4	(Megashah et al., 2018)	Cellulose	45.0 ± 0.6
		Hemicellulose	32.0 ± 1.4
		Lignin	16.9 ± 0.4
5	(Omar *et a*l., 2018)	Cellulose	47.3 ± 1.1
		Hemicellulose	27.3 ± 1.9
		Lignin	20.1 ± 2.4

For lignocellulosic content or structural composition analysis, the key components are as follows Cellulose, Hemicellulose and Lignin. Before can proceed for testing, past studies has shown for instance EFB need to be grounded or chopped by hand into little sizes later transfer them to a shredder. To obtain feedstock smaller than 1.0 mm in size, a grinder (FRITSCH, Germany) with a screen size of 1.0 mm was used (Mohammed *et al.*, 2012).

OPF sample preparation can differ from EFB sample preparation for an example OPF received was cut into small pieces and dried for 24 hours at 90 ˚C to remove moisture. It was then ground to a size of 0.2 - 2 mm and soaked in water in a 1:4 ratio for 24 hours. The raw material was then squeezed to collect OPF juice and stored in a refrigerator at 40 degrees Celsius. The solid fraction was dried in an oven at 90 0C for 24 hours before being stored in plastic at room temperature (Srirnachai *et al.*, 2014).

Other exemplar of OPF sample preparation was carried out as such, where only the petiole part was used for characterization. To squeeze and extract the juice from the raw OPF biomass, a Sugarcane Machine Model (SCM), 6.5HP Elephant brand, was used (Tan *et al.*, 2016). Though both EFB and OPF originated from the same plant, their lignocellulosic contents differs between one another where one reason they come from different parts of the plant or from reviewed studies suggest that it also dependent on the location, geographical and soil condition, age including weather (Ruano *et al.*, 2016).

In addition, when observe both Table 4.1 and Table 4.2 comparing findings from past literatures have conflicted values between each other. This is true between the biomass themselves (OPF between OPF and EFB between EFB) but from each reviewed studies, they all share the same pattern where the dominant composition is Cellulose followed by Hemicellulose and lastly Lignin (Ruano *et al.*, 2016). Monomeric sugars are often obtained after hydrolysis of both Cellulose and Hemicellulose (Yang *et al.*, 2020) while Lignin is the protective wall/layer that binds them which may complicate hydrolysis.

Complex carbohydrate polymers that are found in lignocellulosic biomass has their own general ranges like so cellulose (40-50%), hemicellulose (25-35%), and lignin (15-20%) (Srirnachai *et al*., 2014). There are multiple analytical methods from reviewed studies in determining the lignocellulosic content of EFBs and OPFs which include acid detergent fiber (ADF), neutral detergent fiber (NDF), acid detergent lignin (ADL), TAPPI (Technical Association of Pulp and Paper Industry) method or laboratory analytical procedures developed by NREL (National Renewable Energy Laboratory).