AN ABSTRACT OF THE DISSERTATION OF

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Title: Data Mining in Food Science Research and Technical Functionality of Wheat Straw-Derived Fibers.

Abstract approved:

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Michael H. Penner

This dissertation focused on data mining in food science research and on the technical functional properties of wheat straw-derived biorefinery-byproduct fiber preparations as related to potential applications as food ingredients. This first study evaluated the importance of electronic bibliographic database selection and multiple database usage during the information retrieval phase of research in the food sciences. Recommended databases for information retrieval in the "food sciences" subject field were Academic Search Premier (ASP), AGRICOLA, Biological Abstract, CAB Direct, Food Science and Technology Abstract (FSTA), PubMed, SciFinder, Scopus, and Web of Science (WoS). Out of nine, six recommended databases were compared with respect to overall journal coverage and journal overlap. Databases were also evaluated with respect to coverage of food science-based journals and the extent of article coverage therein. A case study approach, focused on bile acid/dietary fiber interactions, was used to illustrate the ramifications of database selection/usage when dealing with specific research topics. Databases differed with respect to the breadth of disciplines covered, the total number of journals indexed, the number of food science

discipline-specific journals indexed, and the number of articles cited per indexed journal. All of the databases contained citations that were unique to the given database. The data resulting from the case study provide an example of the extent to which relevant information may be missed if pertinent databases are not mined. In the present case over half of the articles retrieved on the focus research topic were unique to a single database. The combined data from this study point to the importance of thoughtful database selection and multiple database usage when comprehensively assessing knowledge in the food sciences.

The second study focused on comparing the performance of the six commonly recommended bibliographic databases in the food sciences; ASP, AGRICOLA, CAB Direct, FSTA, PubMed and WoS when searching for studies on *in vitro* bile acid associations with a dietary fiber, lignin. Search strategies were created for six commonly used bibliographic databases in the food sciences to gather citations for a systematic review. The databases' performance was evaluated using sensitivity, precision, and number needed to read (NNR). Results showed that electronic databases retrieved 361 citations, of which seventeen were relevant to the review. Additionally, two relevant citations were included from other non-electronic sources. The highest number of citations was retrieved from WoS (222), followed by CAB Direct (135), PubMed (124), FSTA (89), AGRICOLA (85), and lastly ASP (69). However, of the nineteen citations that met eligibility criteria for the review; WoS retrieved 10, followed by CAB Direct (9), FSTA (7), AGRICOLA (6), PubMed (6), and ASP (3). Considering electronic databases alone (17), almost ~18 % were identified uniquely by WoS (3), ~6% by PubMed (1), CAB Direct (1), and ASP (1), and no unique identification was found by FSTA and AGRICOLA. Approximately 65% of the relevant articles included were identified by two or more databases. WoS had the highest yield retrieving about ~53% of the relevant citations. FSTA was the most precise with ~7.9% of screened citations included. NNR was higher for ASP (23), WoS (~22), and PubMed (~21), while generally similar for CAB Direct (15), AGRICOLA (~14), and FSTA (~13). This study provides evidence not only that multiple database usage is important to retrieve all relevant citations, but it also confirms the need to extend the search to other sources in a systematic review. Of the bibliographic databases used, WoS has higher sensitivity than the other five databases. This study also highlights the importance of well-designed database-specific search strategies.

The aim of third study was to determine the potential of fiber preparations derived from alkali processed and/or enzyme saccharified wheat straw as potential food ingredients based on their technical properties, including hydration properties, emulsion and antioxidant capacities. A process based on an alkali pretreatment was applied to fractionate wheat straw into byproducts likely to be generated via biochemicals platform processing under optimal conditions for each fraction. Also, an enzyme saccaharification procedure was followed to obtain a fiber preparation. The composition and technical properties (water- and oil-holding capacities, swelling activities, solubility, emulsion capacities and antioxidant properties) of each fraction were analyzed. Alkali extracted hemicellulose (AEHC) exhibited higher water-holding capacity (10.3 g water/ g dry weight (DW)), swelling ability (18.7 mL/g DW), and oil holding capacity (10.6 g oil/g DW) than alkali lignin (AL) and alkali

treated/enzyme saccharified residue (ATESR). Among all tested fiber preparations, the solubility of AL was increased at higher pHs (>5) and lower ionic strength of buffer. High emulsifying activity was exhibited by AEHC (92.3%), compared to AL (61.6%) and ATESR (57.3%), though the latter had 95.7 % emulsification stability. AL had highest antioxidant capacity as determined by the ABTS method. The differences in the functional properties of the tested fibers can be rationalized based on their compositions. This study demonstrates the potential of using AL as fiber rich antioxidant functional ingredient that can be selectively utilized in various food applications. These results highlight the great potential of these fiber fractions to incorporate in the formulation of low-calorie, high-fiber foods as a valuable source of dietary fiber ingredients.

Data Mining in Food Science Research and

Technical Functionality of Wheat Straw-Derived Fibers

by

Tuba Karaarslan Urhan

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Tuba Karaarslan Urhan, Author

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CONTRIBUTION OF AUTHORS

Hannah Gascho Rempel participated in the design of the study, provided guidance pertaining to practical aspects of information retrieval, and participated in the manuscript revisions for Chapter 2 and 3. Dr. Lisbeth Muinier-Goddik contributed to the design of the study and participated in the manuscript revisions. Dr. Michael H. Penner conceived the study, directed parts of the experimental work, contributed to data analysis and participated in the manuscript revisions. Tuba Karaarslan Urhan contributed to the design of study, collected data, contributed to data analysis, prepared the first draft of manuscripts and participate in the manuscript revisions.

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This dissertation is dedicated to my husband, Oguz S. Urhan and my daughter, Arya S. Urhan for their unconditional love and support.

CHAPTER 1

INTRODUCTION

Information Retrieval in The Food Sciences

Information retrieval is a necessary and critical component of modern research. Online information is available through many platforms, including postings on private/public web pages, social media, blogs, and bibliographic databases (Stanbury & Selman, 2008). Researchers typically prefer to work with peer-reviewed publications and thus their primary sources for information gathering are electronic databases that index such documents. Online database usage is integral to the research process; it is essentially impossible to stay abreast of relevant literature manually. Information retrieval, via "literature searches" done toward the beginning of a research project, is typically aimed at getting an overview of current knowledge, generating problem solving ideas, determining the novelty of experimental approaches, or identifying experts in a given research field. As a research project progresses, literature searches tend to focus more on specific aspects of a project (e.g., alternative analytical methods) or to obtain peripheral supporting information (Hart, 2001).

In most cases researchers aim, at least in the beginning, to perform an overall assessment of the literature pertaining to a particular topic. Literature searches with this objective can be daunting due to the overwhelming amount of information available. Thus, effective use of these databases requires a general understanding of database construction, familiarity with the mechanics of searching databases, and an awareness of approaches for achieving maximum benefit from online database searching (Booth, 2016; Jensen, Saric & Bork, 2006).

Before starting a literature search, researches should be familiar with which databases and how many databases to use when assessing current knowledge in a given field. Although these might take considerable time, they are important steps to consider since many researchers tend to rely on a single preferred database, without giving much consideration to the benefits of accessing additional databases. Food Science and Technology-relevant databases include a number of choices, since this subject area is defined broadly, including food production, storage, processing, distribution, preparation, consumption patterns, nutrition, chemistry, engineering, microbiology, etc. (Duran & McDonald, 2006). On the other hand, there is a lack of information in the literature to address the relevance of database selection and multiple database usage by considering the retrieval of food science-related publications in general. Search concepts are demonstrated through a case study of information retrieval for a specific, currently pertinent, research topic: “in vitro bile acid binding properties of dietary fibers.” This topic is of general interest with regard to the use of dietary fibers as functional food components; bile acid binding is a putative mechanism by which dietary fiber consumption effects cholesterol metabolism (Li, Mense, Brewer, Lau & Shi, 2017; Liu et al., 2016; Kahlon, 2011; Gunness & Gidley, 2010). Although the focus throughout this research is on databases commonly recommended for research in the food sciences, results are presented in the context of common database usage.

Unbiased and complete identification of relevant studies is an important step for researchers to evaluate and design their study. There are several approaches for addressing the comprehensiveness of an information retrieval exercise (Papaioannou, Sutton, Carroll, Booth, & Wong, 2010). These strategies include not only extensive literature searching using multiple databases but also other methods such as following citation trails, either forward or backward, of key papers in the target field of research; essentially asking the extent to which one’s database mining has retrieved articles cited in accessible papers (Papaioannou et al. 2010; Wright, Golder & Rodriguez-Lopez, 2014). However, this approach may yield thousands of citations, and eventually a very small number of these citations may be relevant to the review. It is important to maximize the retrieval of relevant citations while reducing the number of irrelevant ones. Maximizing the retrieval of relevant citations can be done through careful selection of databases that cover the disciplinary field, targeted search strategies that take into consideration sensitivity and precision, the databases' ability to identify unique articles not available in other sources, and time and cost (Wright et al. 2014). The importance of comprehensive search strategies for identifying all relevant studies especially when conducting systematic reviews is well known (Dickersin, Scherer & Lefebvre, 1994). Studies have reported the performance of bibliographic databases in terms of sensitivity and precision after finalizing a systematic review (Betrán, Say, Gülmezoglu, Allen & Hampson 2005; Katchamart, Faulkner, Feldman, Tomlinson & Bombardier, 2011; Wright et al. 2014). On the other hand, assessing the performance of bibliographic databases after a systematic review is fairly novel in the food science discipline. However, systematic reviews have been widely conducted in food science and have explored topics such as the effects of food constituents on health and diseases (Ho et al. 2016), food safety (Thaivalappil, Waddell, Greig, Meldrum, & Young 2018), food security (Abiad and Meho, 2018), food microbial contamination (Park et al. 2012), and other related issues, e.g., method development (Woolnough, Monro, Brennan, & Bird 2008).

Utilization of Wheat Straw-Derived Fiber Byproducts from Bioethanol Industry as Food Ingredients

A growing global demand for energy, unstable supply of petroleum, and the emergence of global warming have encouraged the development of alternative and renewable energy sources that can replace the use of fossil fuels. Bioethanol is the most common and one of the practically important liquid bio-fuels. According to Renewable Fuels Association in 2017 report, the United States retained its position as the top ethanol producer in the world in 2016, accounting for nearly 60% of global production with estimated production of a records 15.25 billion gallons of ethanol. However, biofuel production generates significant amounts of low-value residues and wastes that are left unused. This results in concern over the sustainability of the biofuel industry and its impact on the environment. But, these residues/wastes can be used as low-cost substrates for conversion to value-added products such as technologically appropriate direct and/or indirect food additives.

Bioethanol can be produced from a variety of cheap substrates. Lignocellulosic biomass such grass and agricultural residues has received more interest as promising resources for ethanol production considering availability, low cost and higher ethanol yields (Irmak, 2017; Saini, Saini, & Tewari, 2015). Straws in general are major sources of lignocellulosic biomass in the Pacific northwest. Wheat straw in particular, is the secondary feedstock for ethanol production after corn stover in the USA. Wheat straw is a good example of a low value, high volume agricultural residue that can be used as a feedstock in a biorefinery concept (Clark et al., 2006)

The cell wall of lignocellulosic biomass consists mostly of three structural organic compounds; cellulose, hemicellulose, and lignin that make up more than 80% of total dry-weight. Cellulose is linear homopolymer of β-1,4 linked D-glucose units and is the most abundant natural polymer in a biomass. It ranges between %18.4-60.4 in agricultural residues (Sun, 2010). Hemicellulose is the second most abundant organic polymer in a biomass. Unlike cellulose, hemicellulose is composed of linear and branched heterogeneous sugar polymers of d-xylose, l-arabinose, d-galactose, d-glucose and d-mannose and it ranges between %14.8-32.8 in agricultural residues (Sun, 2010). Lignin is the third most abundant organic non-carbohydrate polymer after cellulose and hemicellulose. It is a phenolic polymer comprised of phenylpropanoid units which are particularly difficult to biodegrade, and it ranges between %5.9-21.3 in agricultural residues (Sun, 2010)

The presence of lignin in lignocellulosic biomass prevent plant cell destruction from microbial, enzymatic, and chemical interference (Himmel et al., 2007; Li, Pu, & Ragauskas, 2016). This is a limiting factor for the use of lignocellulosic biomass and reduces its economically viable conversion into value-added products (Himmel et al., 2007; Kumar, Barrett, Delwiche, & Stroeve, 2009) Various pretreatment methods have been recognized to overcome the limitations of the utilization of lignocelluloses, e.g physical (milling, extrusion, microwave, freeze pretreatment), chemical (acid, alkali, ionic liquid, organosolv, ozonolysis), physico-chemcial (steam explosion, ammonia fiber explosion, CO_2 explosion and wet oxidation) and biological pretreatments (Mood et al., 2013). The aim of the pretreatment process is to (1) disrupt hydrogen bonds in crystallinity of cellulose, (2) break down cross-linked matrix of hemicellulose and lignin, and (3) increase the porosity and surface area of plant fibers for an enzymatic saccharification (Kumar et al., 2009; Mood et al., 2013; Mosier et al., 2005). Alkali pretreatment is commonly used for the fractionation of lignocellulosic biomass by many industries such as paper and pulping industries, the ruminant animal feed industry and ethanol industries. Among alkali agents including sodium, potassium, calcium, and ammonium hydroxides, sodium hydroxide (NaOH) has been studied the most (Kumar et al., 2009). In NaOH pretreatment operations, nearly all of feedstock cellulose remains in the solid phase, however lignin and hemicellulose are extracted into the liquid phase (Junyusen, 2013). Lignocellulosic biomass processing is usually focused on the utilization of the carbohydrate fraction of these two phases. On the other hand, economically viable processes will likely involve the value-added processing of all major components (Junyusen, 2013).

Lignin is one such major component. Lignin byproducts are available from not only bioethanol industries, but also paper and pulp industries, thus large quantities of lignin will likely be available in the future due to usage in these industries. However, the most of undesirable extracted lignin are directly burned for energy recovery. This is because it is challenging to efficiently and cost effectively to utilize lignin into higher value product due to its complex structure and lack of information about properties of lignin (Lu & Ralph, 1999). But, lignin is a promising ecofriendly renewable material pertinent to many bio- based applications. The conversion of the lignin into higher value products would increase the efficiency utilization of lignin. Lignin-rich byproducts of wheat production/processing was used as starting materials in this study because it is relatively inexpensive, abundant, and have appreciable lignin content; 14% of total dry-weight of wheat straw (Junyusen, 2013). To be economically viable, such process must develop markets for these byproducts. The potential of the application of lignin in the food sector has received relatively little attention.

Although not a carbohydrate, lignin is included in the definition of dietary fiber. Dietary fiber has been defined by American Association of Cereal Chemists (AACC) as “the edible part of plants or analogous carbohydrates that is resistant to digestion and absorption in the human small intestine, with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances" (DeVries et al., 2001).

Consumption of dietary fiber has many benefits to human health and body function due to decreased occurrence of disorders and diseases such as chronic bowel disorders, obesity, diabetes, cardiovascular disease, and cancer (Johnson, 2004; Kris-Etherton et al., 2002). The USDA/DHHS-authored Dietary Guidelines for Americans points to the fact that fiber intake in the United States is sufficiently low to be considered a "public health concern." Fiber intake is low across all segments of the U.S. population; USDA tabulated food intake data suggest that < 3% of Americans meet their recommended intakes (Clemens et al., 2012). Thus, the food industry seeks to increase fiber levels in products for supporting human health. One practical means of increasing the fiber intake of the U.S. population is to substitute non-caloric fiber components for caloric non-fiber components in formulated foods, defined as those foods that are mixtures of ingredients. Incorporation of such fibers into foods is expected to have environmental as well as health promoting benefits since this approach uses byproducts as functionally relevant food extenders.

On the other hand, huge quantities of agricultural by-products are generated and not utilized. These byproducts contain valuable compounds that could be optimized to make high-value food products. If these by-products could be used as a dietary fiber source, it would reduce pollution and add value to industry. The dietary fibers of agricultural wastes have gained much attention, as a new source of dietary fibers that attributed to the development of new applications and value-added food products that can be used as ingredients in the food industry. Dietary fiber can be added to a number of products, e.g bread, breakfast cereals, pasta, jam and marmalades, beverages, dairy products, meat products, and others (Cardador-Martínez, Espino-Sevilla, del Campo, & Alonzo-Macías, 2017). The incorporation of dietary fibers as a food ingredient can offer several technological properties to food, including hydration properties (solubility, water holding capacities, swelling ability), oil-binding capacity and antioxidant properties (Elleuch et al., 2011; Quirós-Sauceda et al., 2014; Xie, Wang, Wu, & Wang, 2016). Fibers can be used as anti-caking and anti-sticking agents due to their hydration and oil holding properties that help to retard staling, control moisture and ice crystal formation, reducing syneresis and increasing stabilization of high fat foods products and emulsion (Elleuch et al., 2011; Lecumberri et al., 2007). Fibres that pose high antioxidant activities allow the stabilization of fatty foodstuffs, thereby improving their oxidative stability and prolonging their shelf life (Elleuch et al., 2011). Moreover, the use of dietary fiber as a food supplements are likely to increase in near future not only because of the technological properties provided to food but also its physiological functionalities such as laxative, reduction of blood cholesterol and glucose, reduction of risk of chronic disorder (Elleuch et al., 2011; Quirós-Sauceda et al., 2014).

Objectives

This dissertation has focused on database mining in dietary fiber studies and technical properties of wheat straw-derived biorefinery-byproduct fiber preparations. This first study evaluated the importance of electronic bibliographic database selection and multiple database usage during the information retrieval phase of research in the food sciences. The second study focused on comparing the performance of the bibliographic databases Web of Science (WoS), PubMed, AGRICultural OnLine Access (AGRICOLA), Food Science and Technology Abstracts (FSTA), CAB Direct and Academic Search Premier (ASP) when searching for studies on in vitro bile acid associations with a dietary fiber, lignin. The aim of third study was to determine the potential of using fiber preparations derived from alkali processed wheat straw as potential food ingredients based on their technical properties, including hydration properties, emulsion and antioxidant capacities.

CHAPTER 2

INFORMATION RETRIEVAL IN FOOD SCIENCE RESEARCH: A BIBLIOGRAPHIC DATABASE ANALYSIS

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2.1 ABSTRACT

The aim of the present research was to ascertain the importance of electronic bibliographic database selection and multiple database usage during the information retrieval phase of research in the food sciences. Six commonly recommended databases were compared with respect to overall journal coverage and journal overlap. Databases were also evaluated with respect to coverage of food science-based journals and the extent of article coverage therein. A case study approach, focused on bile acid/dietary fiber interactions, was used to illustrate the ramifications of database selection/usage when dealing with specific research topics. Databases differed with respect to the breadth of disciplines covered, the total number of journals indexed, the number of food science discipline-specific journals indexed, and the number of articles included per indexed journal. All of the databases contained citations that were unique to the given database. The data resulting from the case study provide an example of the extent to which relevant information may be missed if pertinent databases are not mined. In the present case over half of the articles retrieved on the focus research topic were unique to a single database. The combined data from this study point to the importance of thoughtful database selection and multiple database usage when comprehensively assessing knowledge in the food sciences.

KEY WORDS: food sciences, research, databases, information retrieval, dietary fiber

PRACTICAL APPLICATION: This paper provides insights into article database usage for food science-relevant information retrieval. Online information retrieval is an efficient way to assess current knowledge in any of the food science disciplines. Acquired knowledge in turn is the underpinning of effective problem solving; whether it be private sector- or academic/government-based research.

2.2 INTRODUCTION

Information retrieval is a necessary and critical component of modern research. Online information is available through many platforms, including postings on private/public web pages, social media, blogs, and bibliographic databases (Stanbury & Selman, 2008). Researchers typically prefer to work with peer-reviewed publications and thus their primary sources for information gathering are electronic databases that index such documents. Online database usage is thus integral to the research process; it is essentially impossible to stay abreast of relevant literature manually. Information retrieval, via "literature searches" done toward the beginning of a research project, is typically aimed at getting an overview of current knowledge, generating problem solving ideas, determining the novelty of experimental approaches, or identifying experts in a given research field. As a research project progresses, literature searches tend to focus more on specific aspects of a project (e.g., alternative analytical methods) or to obtain peripheral supporting information (Hart, 2001).

In most cases researchers aim, at least in the beginning, to perform an overall assessment of the literature pertaining to a particular topic. Literature searches with this objective can be daunting due to the overwhelming amount of information available. A 2016 online ranking of journals covering most academic disciplines listed 23,226 journals (see Scimago; www.scimagojr.com). Those journals combined contained over 2.3 million documents in 2016 alone. When the subject area was narrowed to "Food Science," the same survey listed 260 journals; those journals included 32,755 documents in 2016. The amount of published information pertaining to the food sciences is obviously staggering, particularly if one includes the more fundamental subject areas upon which the food sciences are based. Harnessing this information requires thorough and efficient information gathering, which is enabled by electronic bibliographic databases. These databases are valuable links between authors, who have generated knowledge, and information seekers who are trying to access such knowledge. Effective use of these databases requires a general understanding of database construction, familiarity with the mechanics of searching databases, and an awareness of approaches for achieving maximum benefit from online database searching (Booth, 2016; Jensen, Saric & Bork, 2006).

Primary questions related to information retrieval are "What database(s) is best for finding information pertaining to particular subject areas?" and "To what extent is it necessary to access multiple databases when assessing current knowledge in a given field?" The trivial answer to the latter would be to search all databases, but searching databases is time consuming and, at some point, further searches bring diminishing returns (Stevinson & Lawlor, 2004). Taking both the time commitment and the anticipated diminishing returns into account, it is reasonable to assume that researchers will access multiple databases to the extent they feel it productive. Our informal surveys aimed at verifying this assumption suggest that many doing research in the food sciences tend to rely on a single preferred database, without giving much consideration to the benefits of accessing additional databases; and that the preferred databases differ amongst food science professionals. Recognition of these inconsistencies led to the work outlined in this manuscript. Herein we address the relevance of database selection and multiple database usage by considering the retrieval of food science-related publications in general. Search concepts are then demonstrated through a case study of information retrieval for a specific, currently pertinent, research topic: "in vitro bile acid binding properties of dietary fibers." The focus throughout the manuscript is on databases commonly recommended for research in the food sciences, and results are presented in the context of common database usage.

2.1.1 BACKGROUND

2.2.1.1 The nature of electronic bibliographic databases

A database is a collection of information typically organized for efficient utilization. Electronic databases present data in digital/electronic formats, such that the information can be accessed and manipulated using the appropriate computer software. A bibliographic database contains bibliographic information; for a journal article this commonly includes the paper's title, authors and year of publication, the title of the journal in which it was published, volume and issue of the journal, and page numbers. Bibliographic databases may also include the article's abstract; such databases are formally referred to as abstracting databases. Yet other databases may contain an electronic version of the full text of the article; such databases are formally referred to as full-text databases. Bibliographic databases may also be referred to as indexes. The term index is useful in that it points to the role of these databases, which is to help the user find information that may be distributed in many different sources such as journals, theses, government documents, or conference proceedings – just as a book's index helps the reader find information distributed throughout that book. Bibliographic databases or indexes are thus essential tools for those trying to assess current knowledge in any given subject area.

2.2.1.2 Accessing bibliographic databases

Bibliographic databases can be accessed through online commercial vendors, through major academic, public, or private libraries or directly via the database's website. Some databases are proprietary and thus require a licensing agreement for access. Licensing agreements may be directly between a researcher and the database provider or, more commonly, researchers take advantage of licensing agreements between their library and database providers. Some databases are in the public domain and are thus open access, requiring no license.

Database access, through commercial vendors or through libraries, may be granted for the use of single or multiple databases. Web of Science, for example, can be accessed through the provider's website or via any one of many academic libraries. Once Web of Science is accessed, one can search the databases included in the individual or institutional licensing agreement, which at a minimum, will include the "Core Collection." The Web of Science Core Collection itself includes multiple databases; the most relevant of which to the food sciences is likely Science Citation Index Expanded. EBSCOhost is another online information retrieval system similar to Web of Science in the sense that it can serve as a gateway to many proprietary databases, some of which are compiled by EBSCO itself (e.g., Academic Search Premier). But EBSCO also provides access to content from other database vendors via the EBSCO platform (e.g., Food Science & Technology Abstracts). A food science-relevant example of an open access portal to powerful databases is PubMed; which is developed and maintained by the National Center for Biotechnology Information (NCBI) at the U.S National Library of Medicine (NLM), which is itself a part of the National Institutes of Health (NIH). Within the PubMed umbrella, MEDLINE (NLM's citation/abstract bibliographic database) is the most relevant to the subject matter of this paper.

One can often access impressive numbers of distinct databases when working through academic institutions. Our recent survey of representative U.S. academic libraries indicated Oregon State University (OSU) provides access to 316 bibliographic databases; Cornell University, 733; University of California at Davis, 1,249; and Harvard University, 5,392. These databases cover a wide range of subjects, ranging from the sciences, engineering, and technology to the humanities, business, and law. When considering academic institution-accessible databases, it is important to recognize that some of the databases may be accessible to the general public, either onsite or via the internet, while others will be accessible only to those formally associated with the institution (one typically needs to "login" to access these). For example, of the 316 databases accessible via the OSU Libraries only 83 are "open access" (available to the general public without a subscription fee) and 233 are "OSU restricted." In the latter case, a user must login using an OSU ID to obtain the right to access the databases to which the library has paid subscription fees.

2.2.1.3 Choosing an appropriate bibliographic database(s)

An early step in the information retrieval process is the selection of appropriate databases. That decision can involve consideration of hundreds, or even thousands, of choices. Most researchers are likely to access databases through academic library "database hubs." Such sites will typically provide guidance on making database choices; for example, they may provide a list of the most commonly used databases, or identify databases as "starting points," or provide an opportunity to search available databases based on subject area. The "most common" and "starting point" databases are often multidisciplinary (also referred to as "encyclopedic;" Gasparyan, Ayvazyan & Kitas, 2013); more specific databases are sometimes categorized as "specialized" or "narrow-specialized" (Gasparyan et al., 2016).

Typically, a library website will have a "search by subject" link that allows filtering of accessible databases based on the user's subject area or topic of interest. Once filtered in this way, the suggested databases may contain a combination of encyclopedic and specialized databases. For example, the Oregon State University Libraries returns fourteen "Best Bet" databases for those seeking information in the area of "Food Science and Technology." That "Food Science and Technology-relevant" databases include a number of choices is not surprising, since this subject area is defined broadly, including food production, storage, processing, distribution, preparation, consumption patterns, nutrition, chemistry, engineering, microbiology, etc. (Duran & McDonald, 2006). Common library-suggested databases for information retrieval in the "food sciences" subject field are listed in Table 2.1 (based on our survey of 10 representative academic libraries; these libraries were chosen based on their campuses having widely recognized academic programs in the food sciences). Some of these databases are only accessible to licensed users, others are open access. All provide bibliographic information, abstracts, and links to open access journals; some provide a gateway to full-text articles that are not open access Seven of the nine databases listed in Table 2.1 are accessible via the authors' campus library (Oregon State University Valley Library); the characteristics of six of those databases are presented in Table 2.2. (although accessible via the authors' campus library, SciFinder Scholar was omitted from subsequent analyses based on our inability to do refined searches this database using methods analogous to those used for the other six databases).

2.3 METHODS

2.3.1 Database journal coverage and extent of journal overlap between databases

The number of journals indexed by specific databases (Table 2.3) was determined based on the number of unique ISSN numbers cited by the databases; the total number of database-declared journals was obtained via the database's website, by direct communication with database personnel, or from information provided by Oregon State University's Valley Library. In some cases, the database's list of indexed documents included bulletins, magazines, patents, reports, conference proceedings, etc.; in such cases all but peer-reviewed journals were eliminated. Extents of journal overlap between databases was determined by comparison of indexed p-ISSN (print-ISSN) numbers. These comparisons were done within Excel files using Statistical Analysis System (SAS) PROC SORT, with the NODUPKEY option.

2.3.2 Database coverage of selected food science-based journals.

Twenty-four well-recognized food science-based journals were included in this phase of the study (journal titles listed in Tables 2.4 & 2.5). Journals were chosen based on being representative of established journals that cover (a) all aspects of food science, (b) specific academic disciplines within the food sciences, or (c) commodity-specific food science research/technology. Whether or not databases index specific journals were determined by searching each online database using journal titles and pISSNs. To determine the number of articles indexed from a given journal for a given year an initial search of each database was done to retrieve all articles from the journal of interest; the retrieved articles were then filtered by year. This evaluation included all 24 journals for the following years: 1976, 1996 and 2016 (a span of 40 years; see Table 2.5). PubMed, Web of Science, and CAB Direct were accessed via their individual database platforms; AGRICOLA, FSTA, and Academic Search Premier were accessed via the EBSCOhost platform.

2.3.3 Case Study

A case-study approach was used to provide an illustrative example of the importance of using multiple databases for information retrieval. The case-study approach allows the focus to be on a specific research topic; the topic chosen for this phase of the study was “in vitro bile acid binding properties of dietary fibers.” The six databases characterized in Table 2.2 were searched in an analogous manner to determine the number of indexed articles each contained that specifically dealt with this research topic. The keyword search protocol for article retrieval from each database, including Boolean operators, is given in Table 2.6. Appropriate keywords were chosen based on preliminary reviews of titles, abstracts, and keywords of pertinent papers. Searches were done via Oregon State University’s Valley Library subscription access during the period October 16 through October 20, 2017. Searches were limited to English text, peer-reviewed, academic, journal articles. Recovered articles were processed using the reference/citation manager software Zotero. Zotero, as a citation management tool, allows the user to initially catalog citations retrieved from databases and then do keyword searches, title comparisons, etc. of cataloged citations (for reference, alternative citation management tools include EndNote and Mendeley).

Overlap between retrieved articles from different databases was determined by doing title comparisons using Zotero and manual inspection. Pairwise comparisons were made based on traditional overlap (TO) and relative overlap (RO); as defined below (Hood & Wilson, 2003).

$$\mathrm{TO}\ (\%) = 100 \text{ x } \left(\frac{|A_{\mathrm{Records}} \cap B_{\mathrm{Records}}|}{|A_{\mathrm{Records}} \cup B_{\mathrm{Records}}|}\right)$$

$$\mathrm{ROA}\ (\%) = 100 \text{ x } \left(\frac{|A_{\mathrm{Records}} \cap B_{\mathrm{Records}}|}{|A_{\mathrm{Records}}|}\right)$$

$$\mathrm{ROB}\ (\%) = 100 \text{ x } \left(\frac{|A_{\mathrm{Records}} \cap B_{\mathrm{Records}}|}{|B_{\mathrm{Records}}|}\right)$$

Where “ARecords” and “BRecords” are the two data sets being compared (i.e., the sets of retrieved articles/records from database A and database B, respectively). Percent TO (%) values indicate the extent of overlap in terms of the combined databases; ROA (%) and ROB (%) values indicate the extent of overlap in terms of (“relative to”) the individual databases, either “A” or “B”. The symbol “∪” denotes the union of two sets; the symbol “∩” denotes the intersection of two sets.

2.4 RESULTS AND DISCUSSION

In the first inquiry, six of the databases from Table 2.1 were searched in an analogous manner to quantify the number of unique academic journals associated with each database and to determine the extent of journal overlap between databases. The search was based on journal ISSN numbers and refined as described in “Methods.” The numerical values in Table 2.3 demonstrate the disparity in the size of the recommended databases and the extent of journal overlap. The values in the main diagonal (Mi,i) of Table 2.3 indicate the number of journals indexed by the different databases. The sub-diagonal values (Mi,j) correspond to the number of journals common to “i” and “j” databases (i.e., journal overlap). The number of journals covered by WoS approaches 20,000; it was the largest database considered in this study. AGRICOLA was the smallest database considered, at least based on number of journals indexed, with 834. Clearly, the larger databases index many journals not directly dealing with the food sciences. These journals should not be summarily ignored however, because they may contain articles with information germane to food systems. When considering overlap it is useful to question the merit of using a larger diversified database versus a smaller specialized database, e.g. WoS or CAB Direct versus FSTA. The data in Table 2.3 help to answer this question. The overlap in FSTA by WoS is 66% (i.e., 66 percent of the journals indexed in FSTA are also indexed in WoS); the analogous overlap for FSTA by CAB Direct is 74%. The latter example indicates that searching CAB Direct allows access to approximately three-fourths of the journals indexed in FSTA, while simultaneously allowing access to a large number of additional journals that possibly contain articles of interest. Questions like “How important is it to access the journals unique to FSTA?” and “What is the likelihood of missing important papers by searching the specialized database (FSTA) rather than the diversified database (CAB Direct)?” become important when deciding whether to search CAB Direct, FSTA, or both CAB Direct and FSTA – or any of the other databases listed in Table 2.3.

The next phase of the study focused on article overlap between databases. Article overlap in database coverage is important because extents of "journal overlap," without consideration of "article overlap," can be misleading, because journal coverage by a database does not necessarily mean all of the articles from the "covered journal" are cited in the database. If a journal is considered a "core journal" for a particular database, then it is likely that all articles from that journal will be indexed in that particular database. Otherwise, database managers may be selective as to which articles from a "covered journal" are actually cited in their database. Thus, two databases may cover the same journal and yet differ with respect to the articles cited from that journal. This paradox was addressed herein by comparing the extent of article coverage from selected food science-discipline journals in the six major databases previously considered for journal overlap. The "test journals" chosen for this comparison ranged from those covering food science in general (e.g., Journal of Food Science), to those covering an academic discipline within food science (e.g., Food Chemistry), to those covering a specific commodity (e.g., Potato Research). All of the journals considered in this phase of the study are relatively well established. Presumably, these journals are more likely to be covered by major databases than are more obscure journals. Table 2.4 indicates which databases indexed these test journals. The majority of the test journals are covered by a majority of the databases. PubMed indexed the fewest of these journals, only 9 of the 24; ASP indexed the second fewest (16 of 24). The other databases covered all but one journal. The most specialized database, FSTA, was the only database to formally cover the journal Food Structure. Some of the database omissions are somewhat surprising; for example, the lack of coverage of Journal of Agricultural and Food Chemistry in ASP.

The data of Table 2.5 reflect the extent to which databases differ with respect to article coverage for specific journals. The data was collected by searching the databases for articles published in specific journals (those listed in Table 2.4) during selected years (1976, 1996, 2016); thus, the range of coverage spans 40 years. Consideration of a few examples from Table 2.5 is sufficiently informative to make the point that journal coverage cannot be equated with article coverage. The first thing to note is the apparent lack of coverage of early papers as evidenced by the low numbers of database entries for 1976. Low numbers are indicative of the relatively low numbers of papers being published at that time, the relatively low numbers of published papers being indexed at that time, and/or, in some cases, journals not existing at that time (e.g., Journal of Food Processing started in 1977, Journal of Food Engineering in 1982, Postharvest Biology and Technology in 1991, and Food Structure in 2014). Focusing on the more recent 2016 database entries, it can be seen that, in general, coverage of the test journals is similar, but not the same, for the different databases. The numbers of articles indexed in WoS, FSTA, and CAB Direct are within a few percent for the food-specific journals. In contrast, comparison of entries from Journal of Dairy Science in FSTA, WoS, and AGRICOLA shows considerable variability. This variability can be rationalized as WoS indexing more non-food articles than FSTA; the lower number for AGRICOLA appears to indicate a lack of consistent coverage of Journal of Dairy Science. The numbers in Table 2.5 are to be taken as approximate. For example, the relatively high number of articles indexed from Journal of Food Science in ASP for 2016 reflects that this database indexes, in some cases, editorials, content descriptions, etc. Recognize that even minor differences in database content can be important if the articles omitted from a given database are of particular importance to the research question being addressed. The following section presents a case study that illustrates this point.

The data presented in Tables 2.3-2.5 illustrate the uniqueness of databases commonly recommended for information retrieval in the food sciences. A case study approach was used to ascertain the consequences of this uniqueness. Searches in individual and combinations of databases were used to determine the number of peer-reviewed articles published on the “in vitro bile acid binding properties of dietary fibers.” This topic is of general interest with regard to the use of dietary fibers as functional food components; bile acid binding is a putative mechanism by which dietary fiber consumption effects cholesterol metabolism (Li, Mense, Brewer, Lau & Shi, 2017; Liu et al., 2016; Kahlon, 2011; Gunness & Gidley, 2010). The topic is also appropriate for this study because it is sufficiently refined so as to yield manageable numbers of publications in database searches. Searches for English language journal articles dealing with this topic were done using the parameters described in Table 2.6. All databases were searched in an analogous manner. There were four independent searches for each database (S1-S4); searches within a given database differed with respect to the number of search terms required to satisfy the query (see S1, S2, S3 and S4 of Table 2.6).

The data in Table 2.7 summarizes the number of articles retrieved from databases using different search term scenarios. The inverse correlation between the number of articles retrieved from any given database and the number of search terms required for recognition is obvious when reading across rows from S1 to S4. Under the most refined search scenario (i.e., S4), Web of Science returned the most articles (261) and Academic Search Premier the least (80); the difference in number of articles retrieved being over 3-fold. These values represent approximately 61% and 19% of the total number of articles retrieved by a combined search of all six databases (the total number of records retrieved from searching all six databases, after accounting for replicates, was 425). The number of articles “unique” to each database provides further insight into the amount of information that would be “missed” by not searching a given database, assuming the other five databases were searched (Table 2.7). These values can be unsettling because they point to the fact that a number of potentially relevant articles can be missed even if one searches multiple databases. An alternative way to think about the number of articles unique to different databases is to consider the percent they represent relative to the total number of records retrieved from a combined search of all six databases. These values are presented visually in Figure 2.1. The data shows that the percent of articles missed by not including FSTA, AGICOLA, ASP, or CAB Direct in such a search is approximately 20%. One may be tempting to conclude that the numbers of articles unique to some of these databases are acceptably low such that those databases need not be included in searches. The difficulty in this rationale is that the importance of articles unique to different databases, no matter how few they may be, is generally not known until the articles have been examined. Clearly, one would not want to exclude all of these lower yielding databases (i.e., FSTA, AGRICOLA, ASP and CAB Direct) in the present case because they account for nearly one-fifth of the total publications retrieved. When considering the absolute numbers of papers retrieved in this study (Table 7) it is important to keep in mind that these values are strictly dependent on the combinations of keywords used to in the searches. The expectation is that adding additional permissible keywords (when using the “or” Boolean operator) or reducing the number of “required” keywords is likely to increase the number of papers recovered and, thus, broaden the overall search.

A pairwise comparison of the numbers of articles retrieved from the different databases is presented in Table 2.8. Pairwise comparisons are useful when considering database similarity and prioritizing databases for searches. In the present case, it is apparent that the database pair generating the most articles in response to the specified query is WoS and PubMed, and that both databases contributed substantially to that total (~ 67% of the 261 articles retrieved from WoS were not indexed in PubMed; ~ 48% of the 163 articles retrieved from PubMed were not indexed in WoS). "Relative overlap" is defined for a pair of databases as the number of articles, excluding replicates, indexed by both databases divided by the total number of articles indexed in the one database of the pair for which the overlap is relative to (see "Methods" for the equation). Relative overlap is thus a measure of the percentage of the retrieved articles from one database that are also indexed in the other database of the pair. For example, the data of Table 2.8 shows that nearly 80% of the articles retrieved from AGRICOLA were also indexed in WoS. This database pair provides an instructive example of why overlap is best considered relative to both databases; note that only ~31% of the articles retrieved from WoS are indexed in AGRICOLA. In some cases the relative overlap is strikingly low, for example only ~ 15% of the articles retrieved from PubMed were indexed in ASP. These relative values are particularly useful when considering the likelihood that a database will contribute articles that are distinctive to the combined retrieval list. The traditional overlap values of Table 2.8 provide a general picture of the overall similarity of databases (Gluck, 1990). It is not particularly surprising that the two most specialized databases, FSTA and AGRICOLA, were among those databases with the highest traditional overlap.

The combined results from this study are helpful when considering the design of literature searches. The productivity of initial searches is typically evaluated based on the number of relevant articles recovered. Assuming this criterion, the results of the case study suggests the Web of Science database is a logical place to start. Over half of the total citations retrieved in the case study were accessible through Web of Science. In many situations, an initial search in a single database will provide access to sufficient information to answer a researcher's question(s) and thus no further data mining is necessary. However, in those cases where reproducible, in-depth surveys of the literature are required, such as for systematic reviews and meta-analyses, one would certainly want to continue mining other databases. The need to search multiple databases to obtain a thorough representation of the literature on a given topic is obvious from the number of unique citations found in each database for the case study. There will eventually be a point of diminishing returns where further searches will yield few additional citations. The study reported herein focused on the use of abstracting and indexing databases for information retrieval. These are "curated" (or "purposefully managed") databases in the sense that they are selective as to what is indexed; the goal is not to include all scholarly activity in these databases. Their selectivity is a result of each database having unique quality guidelines and topical constraints. Database-specific guidelines and constraints account for the differences in the numbers and types of articles included in the databases. An alternative approach to using controlled abstracting and indexing databases is to search for information using an academic web search engine, such as Google Scholar or Microsoft Academic (Halevi, Moed, & Bar-Ilan., 2017; Thelwall, 2017). These search engines contain web crawler-derived data. The advantage of using an academic web search engine is that they typically access far more data than do abstracting and indexing services. A major reason for the higher numbers of citations retrieved by academic web search engines is that they do not filter source materials to the same extent as the abstracting and indexing services. Some of the data included comes from traditional journal sources, but other sources of quasi-scholarly materials may also be retrieved. Thus, the sources retrieved by these services will not have undergone the level of quality control typically associated with curated abstracting and indexing databases. Drawbacks to using these search engines, beyond the perceived quality control issues, include difficulties in determining the sources of materials crawled and the need for the researcher to spend additional time filtering the relevant from the non-relevant retrievals. The inability to identify specifically which journal sources were included and for what date ranges made the inclusion of academic web search engines unfeasible for this case study. Even with these limitations, academic web search engines can be reasonable choices for initial information retrieval activities, particularly when searching broad topic areas.

2.5 CONCLUSION

The data presented illustrates the importance of database selection and the need to work with multiple databases when doing knowledge assessment in the food sciences. All of the databases evaluated in this study indexed articles unique to them; this proved to be true in the general sense and in the specific "case study" section of the study. A logical extension of this finding is that databases not included in the present study may also include articles that are both unique to those databases and relevant to the stated search query. Thus, it should be recognized that even after searching multiple databases there exists the possibility that pertinent information/articles may not have been recovered. There are several approaches for addressing the comprehensiveness of an information retrieval exercise (Papaioannou, Sutton, Carroll, Booth, & Wong, 2010). "Comprehensiveness" is often assessed by following citation trails, either forward or backward, of key papers in the target field of research; essentially asking the extent to which one's database mining has retrieved articles cited in accessible papers (Wright, Golder, & Rodriguez-Lopez, 2014).

AUTHOR CONTRIBUTIONS

Tuba Karaarslan Urhan contributed to the design of study, collected data, contributed to data analysis, prepared the first draft of manuscript and participate in the manuscript revisions. Hannah Gascho Rempel participated in the design of the study, provided guidance pertaining to practical aspects of information retrieval, and participated in the manuscript revisions. Lisbeth Meunier-Goddik contributed to the design of the study and participated in the manuscript revisions. Michael H. Penner conceived the study, directed parts of the experimental work, contributed to data analysis and participated in the manuscript revisions.

Table 2.1. Commonly recommended bibliographic databases for information retrieval in the "food sciences" subject area[1]

Academic Search Premier (E,I,J)[2]
AGRICOLA (A,B,C,D,E,F,H,I,J)[3]
Biological Abstracts (A,B,C,D,F,J)[4]
CAB Direct (A,B,C,D,E,G,H,I,J)[5]
Food Science and Technology Abstracts (A,B,C,D,E,F,H,J)
PubMed (A,B,D,E,F,G,I,J)[6]
SciFinder (A,B,D,E,F,H,I,J)
Scopus (D,I,J)
Web of Science (A,D,E,F,G,I,J)

[1] Web pages from campus libraries at ten representative U.S. universities with established food science programs were accessed to ascertain databases commonly recommended for information retrieval in the subject field "food sciences." The "food sciences" subject area at different libraries was identified as "food science(s)," "food science and nutrition," "food and nutrition," or "food science and technology."

[2] In all cases, parenthetical letters indicate the universities recommending particular databases; A. Cornell University, B. Michigan State University, C. North Caroline State University, D. Ohio State University, E. Oregon State University, F. Pennsylvania State University, G. University of Georgia, H. University of Massachusetts Amherst, I. University of Minnesota, J. University of Wisconsin-Madison. To be included in the list above, a database must have been suggested by a minimum of three of the ten universities.

[3] Acronym for "AGRICultural OnLine Access"

[4] Recommended as "Biological Abstracts" or "BIOSIS Previews;" the latter combines Biological Abstracts and Biological Abstracts/Reports/Reviews/Meetings.

[5] "CAB Direct" is a database platform providing access to CABI (Centre for Agriculture and Biosciences International) database subscriptions, including CAB Abstracts and CAB Abstracts Archives.

[6] Recommended as PubMed or MEDLINE; the former includes MEDLINE, PubMed Central (PMC) and National Center for Biotechnology Information (NCBI) Bookshelf.

Table 2.2. Characteristics of selected commonly recommended bibliographic databases for information retrieval in the "food science" subject area.[1]

Attributes	Databases					
	Academic Search Premier[2] (ASP)	AGRICOLA[2]	CAB Direct	Food Science and Technology Abstracts[2] (FSTA)	PubMed	Web of Science (WoS)
Web Address	https://www.ebsco.com/products/research-databases/academic-search-premier	https://agricola.nal.usda.gov	https://www.cabdirect.org	https://www.ifis.org/fsta	https://www.ncbi.nlm.nih.gov/pubmed	https://webofknowledge.com/
Managing Entity (country)	EBSCO Publishing (US)	National Agricultural Library (NAL), United States Department of Agriculture (US)	The Centre For Agriculture and Biosciences International (CABI) (UK)	International Food Information Service (IFIS) Publishing (UK)	National Center for Biotechnology Information (NCBI), National Library of Medicine (NLM), (US)	Clarivate Analytics (US)
Open Access or Subscription Based	Subscription	Open Access	Subscription	Subscription	Open Access	Subscription
Databases Covered	ASP Database	NAL Catalog	CABI Databases[3]	FSTA Database	MEDLINE, OLDMEDLINE, PubMed Central, NCBI Bookshelf	Web of Science Core Collection[4]
Update Frequency	Daily	Daily	Monthly, Random	Weekly	Daily	Daily
Subject Areas	Life Sciences, Physical Sciences, Social Sciences, Humanities, Engineering, Technology	Agriculture and Allied Disciplines	Applied Life Sciences	Food Science and Technology, Human Nutrition	Biomedical and Life-Science Related	Sciences, Technology, Social Sciences, Arts and Humanities
Covered Items Include[5]	BK, CP, GD, J, L, M, MB, N, R, SP, V	B, BK, CP, D, EM, J, M, MA, P, R	BK, CP, D, J, MA, MB, P, R, S	BK, CP, D, J, L, P, R, S	B, BK, CP, CT, D, J, N, P, R	B, BK, CP, DR, EM, J, MA, P, R

Table 2.2. Characteristics of selected commonly recommended bibliographic databases for information retrieval in the "food science" subject area.[1] (Continued)

[1] Information gathered from database websites (provided above) and links therein, January 2018.
[2] Database was accessed via the EBSCOhost portal
[3] Vendors provide options with respect to CABI databases included in subscriptions
[4] Subscription flexibility allows additional databases to be added to the Web of Science Core Collection. The Web of Science Core Collection per se consists of the following ten indexes: Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, Emerging Sources Citation Index, Conference Proceeding Citation Index-Science, Conference Proceeding Citation Index-Social Sciences and Humanities, Book Citation Index-Science, Book Citation Index-Social Sciences and Humanities, Current Chemical Reactions, and Index Chemicus. Further details of index coverage can be found at the following link: http://images.webofknowledge.com.ezproxy.proxy.library.oregonstate.edu//WOKRS530JR6/help/WOS/hp_database.html).
[5] 'B,' Bibliographies; 'BK,' Books; 'CP,' Conference Proceedings; 'CT,' Clinical Trials; 'D,' Dissertations and Theses; 'DR,' Database Reviews; 'EM,' Editorial Materials; 'GD,' Government Documents; 'J,' Journals; 'L,' Legislation/Law; 'M,' Monographs; 'MA,' Meeting Abstracts; 'MB,' Magazines/Bulletins; 'N,' Newspaper Articles; 'P,' Patents; 'R,' Scientific, Technical, Industrial and/or Educational Reports; 'S,' Standards; 'SP,' Speeches; 'SR,' Software Reviews; 'V,' Videos; lists of covered items are based on database declarations and may not be exhaustive.

Table 2.3. Journal coverage and extent of journal overlap for selected databases[1]

Databases[2,3] → ↓	WoS	ASP	PubMed	CAB Direct	FSTA	AGRICOLA
WoS	19,312					
ASP	6,880	14,596				
PubMed	5,893	3,094	13,036			
CAB Direct	3,724	2,627	2,252	7,476		
FSTA	673	437	385	762	1,028	
AGRICOLA	633	380	330	576	225	834

[1] Values in the main diagonal cells refer to the total number of journals indexed by the databases corresponding to those cells; these values are based on the number of database-declared journals having unique ISSN (see "Methods"). Numbers in sub-diagonal cells refer to the number of journals that are indexed in both of the databases corresponding to those cells (i.e., the number of journals that are common to both databases and thus represent the absolute extent of journal overlap for the two databases); sub-diagonal values were obtained by overlap analysis as described in "Methods."
[2] Databases in column one are listed in descending order of predominance by number of journals indexed; acronyms are as described in Table 2.2
[3] Numbers of journals were obtained from database sources. The journal list for WoS was obtained via the website of Clarivate Analytics in October 2017 (http://mjl.clarivate.com); that for ASP was downloaded from the website of EBSCO*host* in October 2017 (https://www.ebsco.com/products/research-databases/academic-search-prem%C3%ADer); that for MEDLINE and PMC was obtained by direct communication with U.S National Library of Medicine personnel in October 2017 (numbers reflect current plus former journals; this value can also be retrieved through "journalspmc[All Fields] OR reportedmedline[All Fields]" from NLM Catalog online); that for CAB Direct was obtained via direct communication with CABI personnel in September 2017; that for FSTA was obtained via direct communication with IFIS personnel in October 2016; that for AGRICOLA was obtained from Oregon State University Library records in April 2016. Numbers obtained from database sources were refined by removal of entries for non-journal listings, those without p-ISSN designations, and replicate p-ISSN designations. Thus, values reported in the table are for peer-reviewed journals with p-ISSN designations.

Table 2.4. Coverage by different databases of selected food science journals [1,2]

Journal Title[3]	p-ISSN[4]	Databases					
		ASP	AGRICOLA	CAB Direct	FSTA	PubMed	WoS
AM J ENOL VITICULT	0002-9254	N	Y	Y	Y	N	Y
CEREAL CHEM	0009-0352	N	Y	Y	Y	N	Y
FOOD CHEM	0308-8146	Y	Y	Y	Y	Y	Y
FOOD HYDROCOLLOID	0268-005X	Y	Y	Y	Y	N	Y
FOOD MICROBIOL	0740-0020	Y	Y	Y	Y	Y	Y
FOOD RES INT	0963-9969	Y	Y	Y	Y	Y	Y
FOOD STRUCT	2213-3291	N	N	N	Y	N	N
HORTSCIENCE	0018-5345	Y	Y	Y	Y	N	Y
J AGR FOOD CHEM	0021-8561	N	Y	Y	Y	Y	Y
J DAIRY SCI	0022-0302	Y	Y	Y	Y	Y	Y
J FOOD BIOCHEM	0145-8884	N	Y	Y	Y	N	Y
J FOOD COMPOS ANAL	0889-1575	Y	Y	Y	Y	N	Y
J FOOD ENG	0260-8774	Y	Y	Y	Y	N	Y
J FOOD PROCESS PRES	0145-8892	N	Y	Y	Y	N	Y
J FOOD PROTECT	0362-028X	Y	Y	Y	Y	Y	Y
J FOOD SAFETY	0149-6085	Y	Y	Y	Y	N	Y
J FOOD SCI	0022-1147	Y	Y	Y	Y	Y	Y
J FOOD QUALITY	0146-9428	N	Y	Y	Y	N	Y
J AM SOC BREW CHEM	0361-0470	N	Y	Y	Y	N	Y
J SCI FOOD AGR	0022-5142	Y	Y	Y	Y	Y	Y
LWT-FOOD SCI TECHNOL	0023-6438	Y	Y	Y	Y	N	Y
MEAT SCI	0309-1740	Y	Y	Y	Y	Y	Y
POSTHARVEST BIOL TEC	0925-5214	Y	Y	Y	Y	N	Y
POTATO RES	0014-3065	Y	Y	Y	Y	N	Y

Table 2.4. Coverage by different databases of selected food science journals [1,2] (Continued)

[1] Y = yes, the journal is covered in specified database; N = no, the journal is not covered in specified database; whether or not journals are indexed by given databases is based on journal lists described in Table 2.3.
[2] In all cases the "N" designation indicates that at the time of this study the indicated database did not declare it indexed the specified journal. However, in some cases articles from "non-indexed" journals can be found in databases due to inclusion for a variety of reasons. For example, NIH-funded studies published in a journal not typically indexed by PubMed may still be found in the PubMed database. This anomaly is relevant to the data presented in Table 2.5.
[3] Journal abbreviations as indicated at "Web of Science – Journal Title Abbreviations" (https://images.webofknowledge.com/images/help/WOS/A_abrvjt.html)
[4] p-ISSN = print-ISSN

Table 2.5. Number of articles indexed from selected journals by different databases [1,2]

Journal Titles[3]	Total Citations [4,5]						1976 Citations [4,6]						1996 Citations [4,6]						2016 Citations [4,6]					
	ASP	AGRICOLA	CAB Direct	FSTA	PubMed	WoS	ASP	AGRICOLA	CAB Direct	FSTA	PubMed	WoS	ASP	AGRICOLA	CAB Direct	FSTA	PubMed	WoS	ASP	AGRICOLA	CAB Direct	FSTA	PubMed	WoS
AM J ENOL VITICULT	NA	1,786	1,702	1,934	1	2,551	NA	-	21	30	-	35	NA	62	43	43	-	64	NA	-	53	38	-	50
CEREAL CHEM	NA	4,467	4,390	5,561	NA	5,733	NA	-	76	118	NA	117	NA	142	59	138	NA	139	NA	90	93	89	NA	92
FOOD CHEM	19,014	19,659	20,188	21,307	10,152	21,454	-	-	5	11	-	-	-	87	128	199	-	208	2,032	2,055	1,919	1,905	1,922	1,895
FOOD HYDROCOLLOID	3,915	4,028	3,666	4,358	13	4,408	-	-	-	-	-	-	-	57	11	52	-	57	541	520	504	502	2	494
FOOD MICROBIOL	2,564	2,898	2,691	3,133	1,968	2,847	-	-	-	-	-	-	-	56	32	49	-	56	198	168	167	167	147	161
FOOD RES INT	5,343	3,856	5,030	5,751	784	5,264	-	-	-	-	-	-	-	-	50	109	-	92	432	426	385	385	117	356
FOOD STRUCT	NA	141	NA	210	NA	NA	NA	-	NA	-	NA	NA	NA	-	NA	-	NA	NA	NA	-	NA	13	NA	NA
HORTSCIENCE	4,723	5,061	13,635	2,251	61	10,871	-	-	240	43	-	99	-	232	282	43	4	280	259	-	226	63	-	231
J AGR FOOD CHEM	NA	30,775	34,778	28,297	28,638	37,498	NA	-	245	206	306	288	NA	695	492	556	-	734	NA	1,086	1,080	826	1,105	1,067
J DAIRY SCI	10,429	13,026	34,657	7,256	18,075	21,102	-	-	338	67	186	261	-	282	282	120	223	280	978	4	938	352	940	925
J FOOD BIOCHEM	NA	1,349	1,091	1,602	2	1,714	NA	-	-	-	-	-	NA	37	-	40	-	44	NA	51	79	75	1	77
J FOOD COMPOS ANAL	2,147	901	2,161	2,219	26	1,780	-	-	-	-	-	-	-	-	25	26	-	-	168	-	137	136	2	134
J FOOD ENG	6,728	7,527	6,063	7,723	3	7,371	-	-	-	-	-	-	-	143	1	118	-	117	405	376	378	373	1	363
J FOOD PROCESS PRES	NA	1,601	1,804	2,518	2	2,533	NA	-	-	-	-	-	NA	35	-	34	-	35	NA	72	155	155	-	154
J FOOD PROTECT	4,842	8,528	8,397	11,833	6,527	9,676	-	-	-	-	-	-	-	207	172	235	32	236	278	271	274	266	276	264
J FOOD SAFETY	740	959	824	1,143	1	1,133	-	-	-	-	-	-	-	15	-	15	-	13	71	33	67	66	-	67
J FOOD SCI	17,765	7,974	10,725	18,458	4,281	17,403	367	2	115	362	-	301	288	225	118	286	-	287	399	175	357	357	357	353
J FOOD QUALITY	NA	1,423	809	1,313	1	1,561	NA	-	-	-	-	-	NA	39	-	-	-	39	NA	33	85	85	-	85
J AM SOC BREW CHEM	NA	435	604	1,520	NA	840	NA	-	1	42	NA	-	NA	-	4	56	NA	58	NA	-	32	31	NA	32
J SCI FOOD AGR	2,710	9,365	13,368	9,807	5,196	12,695	-	-	130	117	86	170	-	224	152	159	-	223	621	284	585	498	590	549
LWT-FOOD SCI TECHNOL	5,802	972	5,960	7,771	3	7,376	-	-	-	50	-	14	-	91	48	117	-	107	816	-	794	794	-	790
MEAT SCI	5,183	6,209	5,119	6,693	6,660	6,273	-	-	-	-	-	-	-	127	24	125	131	128	450	303	297	448	298	294
POSTHARVEST BIOL TEC	2,965	3,236	3,346	3,078	1	3,185	-	-	-	-	-	-	-	99	89	86	-	94	273	263	257	246	-	255
POTATO RES	137	646	1,758	390	NA	1,264	-	-	33	7	NA	11	-	-	52	7	NA	51	24	11	24	8	NA	24

Table 2.5. Number of articles indexed from selected journals by different databases [1,2] (Continued)

[1] Searches were done during the first week of October, 2017; PubMed, Web of Science, and CAB Direct were accessed via their database platforms; AGRICOLA, FSTA and Academic Search Premier were accessed via EBSCOhost.
[2] Database acronyms as described in Table 2.2
[3] Journal abbreviations as indicated at "Web of Science – Journal Title Abbreviations" (https://images.webofknowledge.com/images/help/WOS/A_abrvjt.html)
[4] "NA" = not applicable due to journal not being indexed; "-" = journal currently indexed by database but no articles recovered for specified year
[5] Total number of articles in databases from specified journals (without filtering for year of publication)
[6] Number of articles in databases from specified journals for specified years (filtered with respect to specified year of publication)

Table 2.6. Search parameters for retrieval of articles dealing with "in vitro bile acid binding properties of dietary fibers" [1]

Search Parameters	Database					
	Academic Search Premier (via EBSCOhost)[2]	AGRICOLA (via EBSCOhost)[2]	CAB Direct	FSTA (via EBSCOhost)[2]	PubMed	Web of Science
Fields Searched[3] (includes every word in identified field)	Title (including source title), Abstract, Author, Author Keywords, Subject	Title, Abstract, Author, Author Keywords, Subject	All Fields[4]	Title, Abstract, Author, Author Keywords, Subject	Title, Abstract, Medical Subject Headings and Subheadings[5], Other Terms[6], Chemical Names, Secondary Source Identifiers[7]	Title, Abstract, Author Keywords, and KeyWords Plus[8]
Search Terms [9,10,11]	Group 1 (dietary fiber related terms): (Fiber OR Fibre OR Grain OR Wheat* OR Buckwheat OR Oat OR Bran OR Glucan OR Psyllium OR Cellulose OR Lignin OR Hemicellulose OR Pectin OR Hull OR Cereal)					
	Group 2 (bile acid related terms): (bile OR cholic OR cholate OR glycocholic OR glycocholate OR taurocholic OR taurocholate OR ursodeoxycholic OR ursodeoxycholate OR glycochenodeoxycholic OR glycochenodeoxycholate OR taurochenodeoxycholic OR taurochenodeoxycholate OR lithocholic OR lithocholate OR deoxycholic OR deoxycholate)					
	Group 3 (in vitro studies): Vitro					
	Group 4 (binding/association related terms): (associa* OR dissocia* OR bind* OR affinit* OR sequest* OR absor* OR adsor* OR sorpti*)					
Searches Performed	Search 1 (S1) = Group 1 AND Group 2					
	Search 2 (S2) = Group 1 AND Group 2 AND Group 3					
	Search 3 (S3) = Group 1 AND Group 2 AND Group 4					
	Search 4 (S4) = Group 1 AND Group 2 AND Group 3 AND Group 4					

Table 2.6. Search parameters for retrieval of articles dealing with "in vitro bile acid binding properties of dietary fibers" [1] (Continued)

[1] Retrievals were limited to English language journal articles.
[2] Search parameters were dictated by Oregon State University's access via EBSCOhost
[3] "Fields Searched" were based on those automatically accessed by Web of Science for "Topic" searches. "Fields Searched" for the other databases were chosen with the intent of keeping search fields as similar as possible across searches. Differences in "Fields Searched" were a result of each database having somewhat different field groupings that are automatically linked.
[4] "All Fields," in CAB Direct, includes article titles, abstracts, author names, author affiliations, and descriptors
[5] "Medical Subject Headings" (MeSH) are based on the National Library of Medicine's controlled vocabulary thesaurus; they are used to categorize articles represented in MEDLINE. "Subheadings" are qualifiers often used with MESH for further clarification/division.
[6] "Other Terms" includes non-MeSH subject terms (assigned keywords) and author-supplied keywords
[7] Secondary Source Identifiers" are those that supply further citation information, e.g., other data sources, databanks, and accession numbers of molecular sequences (e.g., GenBank, ClinicalTrials.gov)
[8] Keywords Plus are index terms generated from the titles of cited articles.
[9] "Search terms" (keywords) were chosen by the investigator based on the "research topic" specified in the text. Search terms were consistent for all database searches.
[10] Truncation: used to search the multiple forms of words. Enter the root of a search term with "*" at the beginning and/or the end of the term as appropriate (left- versus right-hand truncation).

Table 2.7. Number of English language journal articles retrieved from selected bibliographic databases using combined search terms.

Database[1]	Selected Search Terms[2]				Number of Articles Unique to Database[3] (search scenario S4)
	S1	S2	S3	S4	
Web of Science	2,136	941	468	261	114
PubMed	2,092	908	288	163	57
CAB Direct	1,414	570	255	159	31
Food Science and Technology Abstracts	533	287	153	106	21
Academic Search Premier	948	393	156	80	17
AGRICOLA	610	291	146	103	10
Combined Databases[4]	4,160	1,793	739	425	--

[1] Databases are listed in descending order of predominance by number of unique articles retrieved using search scenario S4
[2] Search terms are defined in detail in the lower portion of Table 2.6. "S1" refers to "Search 1" as described in of Table 2.6, which was based on combined search terms from the fiber grouping and the bile acid grouping; "S2" was based on combined search terms from the fiber grouping, the bile acid grouping, and the term vitro; "S3" was based on combined search terms from the fiber grouping, the bile acid grouping, and the association/binding grouping; "S4" was based on combined search terms from all four groupings: fiber, bile acid, vitro, and association/binding.
[3] Number of individual articles retrieved from specified database using search parameters corresponding to S4 (see Table 2.6) which were not available in other databases when using the same search parameters.
[4] Sum of articles retrieved from PubMed, Web of Science, AGRICOLA, Food Science and Technology Abstracts, Academic Search Premier, and CAB Direct; replicates were deleted prior to summation.

Table 2.8. Pairwise comparison of numbers of retrieved articles and article overlap for selected databases (subject area: "in vitro bile acid binding properties of dietary fibers")[1]

Overlap Analysis	Database Pairings[2]														
	WoS - PbM	WoS - Agrc	WoS - FSTA	WoS - ASP	WoS - CAB	PbM - Agrc	PbM - FSTA	PbM - ASP	PbM - CAB	Agrc - FSTA	Agrc - ASP	Agrc – CAB	FSTA - ASP	FSTA - CAB	ASP - CAB
Total Articles[3]	339	283	291	285	314	221	227	218	251	150	145	187	148	185	194
TO (%)[4]	25.1	28.6	26.1	19.6	33.8	20.4	18.5	11.5	28.3	39.3	26.2	40.1	25.7	43.2	23.2
ROA (%)[5]	32.6	31.0	29.1	21.5	40.6	27.6	25.8	15.3	43.6	57.3	36.9	72.8	35.8	75.5	56.3
ROB (%)[6]	52.1	78.6	71.7	70.0	66.7	43.7	39.6	31.3	44.7	55.7	47.5	47.2	47.5	50.3	28.3

[1] Search parameters are defined in Table 2.6, scenario S4
[2] Database pairs are presented in columns, the upper database designated "A," the lower database is designated "B;" PbM = PubMed, Agrc = AGRICOLA, CAB = CAB Direct, other acronyms as used in Table 2.2
[3] The number of retrieved articles for a given combination of databases after removing duplicates (i.e., the number of articles retrieved from A and B after removing duplicates)
[4] TO (%) = "traditional overlap" calculated as the percent of the total articles retrieved (excluding duplicates) that were indexed in both databases (see "Methods" for equation)
[5] ROA (%) = overlap relative to database A, "A" being the upper database of the pair listed at the top of the column; calculated as the percent of records in database A that are also indexed in database B.
[6] ROB (%) = overlap relative to database B, "B" being the lower database of the pair listed at the top of the column; calculated as the percent of records in database B that are also indexed in database A.

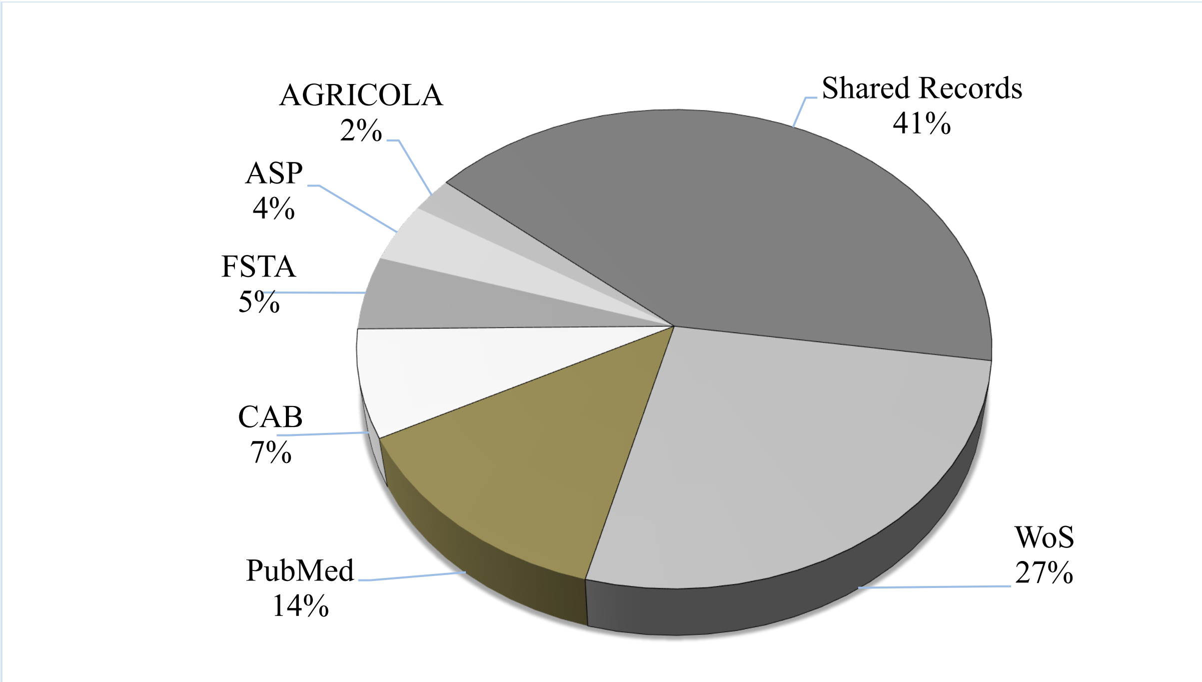

Figure 2.1. Percent of total articles retrieved from a combined search of AGRICOLA, Academic Search Premier (ASP), CAB Direct, Food Science and Technology Abstracts (FSTA), PubMed, and Web of Science (WoS) that are attributable to specific databases. Searches were done using S4 parameters (see Table 2.6 for details). Percent values for individual databases were calculated as 100 x (number of articles unique to database/sum of articles retrieved from all databases); values are rounded to the nearest whole number. "Shared records" are those articles indexed by at least two databases.

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CHAPTER 3

PERFORMANCE ANALYSIS OF BIBLIOGRAPHIC DATABASES FOR IDENTIFYING STUDIES FOR SYSTEMATIC REVIEWS: A CASE STUDY SEARCHING FOR IN VITRO BILE ACID ASSOCIATIONS WITH A DIETARY FIBER, LIGNIN

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3.1 ABSTRACT

The objective of this study was to compare the performance of the bibliographic databases Academic Search Premier (ASP), Agricultural Online Access (AGRICOLA), CAB Direct, Food Science and Technology Abstracts (FSTA), PubMed and Web of Science (WoS) when searching for studies on in vitro bile acid associations with a dietary fiber, lignin. Search strategies were created for six commonly used bibliographic databases in the food sciences to gather citations for a systematic review. The databases' performance was evaluated using sensitivity, precision, and number needed to read (NNR). Results showed that electronic databases retrieved 361 citations, of which 17 were relevant to the review. Additionally, 2 relevant citations were included from other non-electronic sources. The highest number of citations was retrieved from WoS (222), followed by CAB Direct (135), PubMed (124), FSTA (89), AGRICOLA (85), and lastly ASP (69). However, of the 19 citations that met eligibility criteria for the review; WoS retrieved 10, followed by CAB Direct (9), FSTA (7), AGRICOLA (6), PubMed (6), and ASP (3). Considering electronic databases alone (17), almost ~18 % were identified uniquely by WoS (3), ~6% by PubMed (1), CAB Direct (1), and ASP (1), and no unique identification was found by FSTA and AGRICOLA. Approximately 65% of the relevant articles included were identified by two or more databases. WoS had the highest yield retrieving about ~53% of the relevant citations. FSTA was the most precise with ~7.9% of screened citations included. NNR was higher for ASP (23), WoS (~22), and PubMed (~21), while generally similar for CAB Direct (15), AGRICOLA (~14), and FSTA (~13). This study provides evidence not only that multiple database usage is important to retrieve all relevant citations, but it also confirms the need to extend the search to other sources in a systematic review. Of the bibliographic databases used, WoS has higher sensitivity than the other five databases. This study also highlights the importance of well-designed database-specific search strategies.

KEYWORDS: search strategy; databases; performance; food science

3.2 INTRODUCTION

The importance of comprehensive search strategies for identifying all relevant studies when conducting systematic reviews is well known (Dickersin, Scherer & Lefebvre, 1994). These strategies include not only extensive literature searching using multiple databases but also other methods such as citation searching, reference checking, and contacting experts (Papaioannou, Sutton, Carroll, Booth, & Wong, 2010; Wright, Golder & Rodriguez-Lopez, 2014). However, this approach may yield thousands of citations, and eventually a very small number of these citations may be relevant to the review. It is important to maximize the retrieval of relevant citations while reducing the number of irrelevant ones. Maximizing the retrieval of relevant citations can be done through careful selection of databases that cover the disciplinary field, targeted search strategies that take into consideration sensitivity and precision, the databases' ability to identify unique articles not available in other sources, and time and cost (Wright et al. 2014). Studies have reported the performance of bibliographic databases in terms of sensitivity and precision after finalizing a systematic review (Betrán, Say, Gülmezoglu, Allen & Hampson 2005; Katchamart, Faulkner, Feldman, Tomlinson & Bombardier, 2011; Wright et al. 2014). Similarly, our study was done after performing a systematic review. Assessing the performance of bibliographic databases after a systematic review is fairly novel in the food science discipline. However, systematic reviews have been widely conducted in food science and have explored topics such as the effects of food constituents on health and diseases (Ho et al. 2016), food safety (Thaivalappil, Waddell, Greig, Meldrum, & Young 2018), food security (Abiad and Meho, 2018), food microbial contamination (Park et al. 2012), and other related issues, e.g., method development (Woolnough, Monro, Brennan, & Bird 2008).

The objective of this study was to compare the performance of the bibliographic databases ASP, AGRICOLA, CAB Direct, FSTA, PubMed and WoS for identifying in vitro studies of bile acid associations with lignin.

3.3 METHODS

3.3.1 The search strategy for selected databases

A comprehensive search strategy was performed for the selected databases in the context of a systematic review on "binding of bile acid to lignin performed in vitro experiments." The methodology of the systematic review and search strategy have been described elsewhere in full. Briefly, the search was done in six commonly recommended bibliographic databases in the food sciences: ASP, AGRICOLA, CAB Direct, FSTA, PubMed and WoS through March 2018. The information retrieval search parameters are summarized in Table 3.1. The search was limited to English language journal articles. The reference lists of review articles were inspected to identify additional studies that were not retrieved in the searches from the bibliographic databases. The retrieved citations were downloaded into the reference manager software Zotero. All citations retrieved from the selected databases were reviewed to identify articles that met the inclusion and exclusion criteria for this review. Briefly, selection of studies involved two stages; the first stage consisted of screening of the title and/or abstract; and the second stage consisted of full-text evaluation of those studies that were not excluded in the first stage. Overall, studies were included in this review if they evaluated bile acids association with lignin or with a fiber in which lignin content was known.

3.3.2 Performance analysis of the selected databases

The total number of eligible studies in the review was derived from the citations retrieved from bibliographic databases as well as from review article reference list checking. We calculated the number of citations identified per source, the number of relevant citations included per source, and the number of relevant citations that were unique to the source. The number of relevant articles retrieved from the databases was compared using sensitivity, precision, and number needed to read (NNR) (Bachmann, Coray, Estermann, & Ter Riet, 2002; Katchamart et al. 2011; Wright et al. 2014). Sensitivity is defined as the number of eligible studies identified by a source over the total number of eligible studies in the review. Precision is the number of eligible studies identified by a source divided by the number of both relevant and irrelevant articles retrieved by that that source. The number needed to read (NNR) is an index of how many papers from a source need to be read to find one relevant article or the reciprocal of the source's precision.

$$\text{Sensitivity (\%)} = \frac{\text{Number of eligible studies identified by a source}}{\text{Total number of eligible studies in the review}} \times 100 \qquad (1)$$

$$\text{Precision (\%)} = \frac{\text{Number of eligible studies identified by a source}}{\text{Total number of retrieved studies identified by a source}} \times 100 \qquad (2)$$

$$\text{Number-needed-to-read (NNR)} = \frac{\text{Total number of retrieved studies identified by a source}}{\text{Number of eligible studies identified by a source}} \qquad (3)$$

3.4 RESULTS

Table 3.2 shows the results by source including the number of citations retrieved from each source, relevant and unique citations to each source, sensitivity, precision and NNR. 361 citations from bibliographic databases were identified, of which 17 met the eligibility inclusion criteria. Additionally, two relevant citations were included from other sources. The total number of records identified from all citation sources was 363 after removing duplicates. WoS retrieved the greatest number of citations at 222, followed by CAB direct at 135, PubMed at 124, FSTA at

89, AGRICOLA at 85, and ASP at 69. Overall, bibliographic databases identified ~90% of the citations included in the systematic review. Except for FSTA and AGRICOLA, each of the resources contributed at least one unique record to the total number of citation records. Considering citation records from electronic databases alone (17), almost 18% were identified uniquely by WoS, and 6% uniquely by PubMed, CAB Direct, and ASP, respectively. Approximately 65% of the articles included were identified by two or more databases.

Two eligible articles (Oakenfull & Fenwick, 1978 and Eastwood & Hamilton, 1968) were not retrieved from the bibliographic database searches. The study by Oakenfull & Fenwick (1978), published in the British Journal of Nutrition was indexed in WoS, PubMed, FSTA, AGRICOLA, and CAB Direct. Except for the FSTA database, this article was indexed in these bibliographic databases using either the title, or the title and abstract. The FSTA database is known for identifying and selectively including content at the article level that is relevant to food, beverages, and nutrition even if the journal is indexed in this database. As a result, FSTA may not have selected to index this article based on a perceived lack of topic match. The other databases did not index the article with the “in vitro” subject heading; thus, our search did not retrieve the article. In the case of the study by Eastwood & Hamilton (1968), published in the Biochimica et Biophysica Acta (BBA)-Lipids and Lipid Metabolism, only PubMed indexed both the article and journal. However, the article was missed from the PubMed search because there was not an “in vitro” subject heading applied to this study. These two citations would have been identified by these bibliographic databases if the searches had been carried out without the addition of the “in vitro” search term. But this search strategy was not practical, as it yielded thousands of citations from which only a small number were eventually included in the review as the majority were for in vivo studies (results not shown).

In terms of sensitivity, WoS and CAB Direct, which identified 52.6% and 47.4% of the included citations respectively, were the most sensitive. The least sensitive database was ASP with 15.8% sensitivity. In terms of precision, the most precise database was FSTA from which 7.87% of the screened citations were included; AGRICOLA and CAB Direct followed this with 7.1% and 6.7%, respectively (Table 3.2). PubMed, WoS and ASP were similarly precise with 4.4%, 4.5% and 4.8%, respectively. The NNR was particularly high for ASP (23), WoS (22.2) and PubMed (20.67) while the NNRs for CAB Direct (15), AGRICOLA (14.1), and FSTA (12.7) were generally similar.

3.5 DISCUSSION

Sensitivity indicates the ability of the search strategy to retrieve relevant records. A high level of sensitivity is required to ensure as few potentially relevant records as possible are missed. Conversely, search strategies with a lower sensitivity will miss a high proportion of relevant articles. In this review, WoS had a higher sensitivity (52.6%) than the other bibliographic databases; followed by CAB Direct (47.4%), FSTA (36.9%), AGRICOLA (31.6%), PubMed (31.6%), and ASP (15.8%).

The more sensitive a search is, the less precise it is because more sensitive searches retrieve a greater number of irrelevant citations (Watson & Richardson, 1999). Our study showed that WoS, which retrieved the highest number of relevant unique articles (3), had one of the lowest precisions (4.5%) as well as the highest sensitivity (52.6%). WoS was one of the critical sources in this study because of the value it provided in terms of returning unique citations even though it had a moderate to low level of sensitivity as compared to the other sources used. However, some larger systematic reviews involve significant financial and human resources

(Betrán et al. 2005); thus, a low precision might make the study uneconomical in practice for the evaluation of thousands of retrieved citations.

The number of articles “unique” to each database provides further insight into the amount of information that would be “missed” by not searching a given database, assuming the other five databases were searched. Searching through other non-electronic sources identified ~10.5% of relevant studies for the review, which had not been identified by searching bibliographic databases. Among the bibliographic databases, the highest number of unique articles was identified by WoS (3), followed by ASP (1), CAB Direct (1) and PubMed (1). It is surprising that the two most specialized databases in food sciences, FSTA and AGRICOLA did not retrieve unique articles in this review when evaluated based on the citations retrieved from the other four databases. This finding was observed after the articles were examined in full-text. Consequently, it is tempting to omit these two databases from the review. However, FSTA and AGRICOLA retrieved 36.8% and 31.5% of the included citations, respectively, and excluding these databases from the review at the very beginning could have result in missing relevant citations. For example, a relevant citation, Chen, Guoo & Chang (1982), was retrieved from both AGRICOLA and FSTA. Thus, this article was not considered as a unique article in Table 3.2, and excluding these two databases would have result in missing this citation.

There is little published evidence on the efficacy of bibliographic databases for systematic reviews done in the food science field. Our comparison for WoS, PubMed, AGRICOLA, FSTA, CAB Direct, and ASP was based on the results of the searches conducted for one systematic review of one specific topic. To our knowledge, there are no studies that have been done on the performance of these 6 commonly used bibliographic databases together on a research topic in food science. This study showed that searching all six bibliographic databases

(AGRICOLA, ASP, CAB Direct, FSTA, PubMed, and WoS) and reference checking was required to retrieve all relevant articles in this review. However, the generalizability of our results needs to be tested in other reviews. Studies done in other disciplines such as health science have reported a wide range of sensitivity, precision, and/or NNR on some of the databases used in our review. For example, Katchamart et al. (2011) found that PubMed has a sensitivity of 90%, a precision of 0.9%, and NNR at 113 for their systematic review. On the other hand, Betrán et al. (2005) reported that sensitivity, precision, and NNR was at ~62%, 4.1%, and 24 for Medline (a subset of PubMed), respectively; and 7.4%, 4.4%, and ~23 for CAB Direct, respectively.

We encountered some limitations in this study. When using CAB Direct, the website frequently crashed when we combined all the search terms and limited results to English journal articles. The search was completed by rerunning all of the search terms several times. Also, after running the searches, the website returned the approximate number of retrieved citations, not an absolute number. None of these problems occurred when using other bibliographic databases.

3.6 CONCLUSION

This case study concurs with several previous studies, which have shown that searching beyond bibliographic databases is necessary to identify relevant studies for systematic reviews. No single bibliographic database retrieved the complete set of relevant articles in this review; thus, a search of all databases should be performed when doing this type of review. Of the bibliographic databases used, WoS had a higher sensitivity than the other five databases, PubMed, CAB Direct, FSTA, AGRICOLA, and ASP with comparable precision and NNR. Even though no unique articles were retrieved, FSTA was the most precise bibliographic database in this review; so, less time is required for the evaluation of retrieved citations from this database.

Additionally, consulting with a librarian is an important strategy for improving the comprehensiveness of a systematic review search.

Table 3.1. Search parameters for retrieval of articles [1]

Search Parameters	Database					
	ASP[3] (via EBSCOhost)[2]	AGRICOLA[4] (via EBSCOhost)[2]	CAB Direct	FSTA[5] (via EBSCOhost)[2]	PubMed	Web of Science
Web Access Address	https://www.ebsco.com/products/research-databases/academic-search-premier	https://www.ebsco.com/products/research-databases/agricola	https://www.cabdirect.org	https://www.ebsco.com/products/research-databases/fsta	https://www.ncbi.nlm.nih.gov/pubmed	https://webofknowledge.com/
Fields Searched (includes every word in identified field)	Title (including source title), Abstract, Author, Author Keywords, Subject	Title, Abstract, Author, Author Keywords, Subject	All Fields[6]	Title, Abstract, Author, Author Keywords, Subject	Title, Abstract, Medical Subject Headings and Subheadings, Other Terms, Chemical Names, Secondary Source Identifiers	Title, Abstract, Author Keywords, and KeyWords Plus
Search Terms	Group 1 (fiber related terms): (Fiber OR Fibre OR Grain OR Cereal OR Bran OR Hull OR Wheat* OR Oat OR Lignin)					
	Group 2 (bile acid related terms): (bile OR cholic OR cholate OR glycocholic OR glycocholate OR taurocholic OR taurocholate OR ursodeoxycholic OR ursodeoxycholate OR glycochenodeoxycholic OR glycochenodeoxycholate OR taurochenodeoxycholic OR taurochenodeoxycholate OR lithocholic OR lithocholate OR deoxycholic OR deoxycholate)					
	Group 3 (in vitro studies): Vitro					
	Group 4 (binding/association related terms): (associa* OR dissocia* OR bind* OR affinit* OR sequest* OR absor* OR adsor* OR sorpti*)					
Search Performed	Group 1 AND Group 2 AND Group 3 AND Group 4					

Table 3.1. Search parameters for retrieval of articles [1] (Continued)

[1]Retrievals were limited to English language journal articles.
[2]Search parameters were dictated by Oregon State University's access via EBSCOhost.
[3]Acronym for "Academic Search Premier"; [4]Acronym for "AGRICultural OnLine Access"; [5]Acronym for "Food Science and Technology Abstract"; [6]"All Fields," in CAB Direct, includes article titles, abstracts, author names, author affiliations, and descriptors.

Table 3.2. Records identified by each of the sources in the review

Source	Number Retrieved	Number Included[2]	Unique Number Included[3]	Sensitivity (%)	Precision (%)	Number needed to read
Databases[1]						
Web of Science	222	10	3	52.6	4.5	22.2
CAB Direct	135	9	1	47.4	6.7	15.0
PubMed	124	6	1	31.6	4.8	20.7
FSTA	89	7	0	36.8	7.9	12.7
AGRICOLA	85	6	0	31.6	7.1	14.2
ASP	69	3	1	15.8	4.4	23.0
All databases [4]	361	17	NA	89.5	4.7	21.2
Others [5]	2	2	2	10.5	NA	NA
Total [6]	363	19	NA	NA	5.2	19.1

[1] Bibliographic databases are listed in descending order of predominance by number of articles identified using search parameters in Table 3.1; and acronyms as described in Table 3.1.
[2]Refers to the number of articles that met the eligibility inclusion criteria.
[3] Refers to the number of articles that were exclusively identified by each database.
[4] Refers to all citations identified through the databases after duplicate articles are removed.
[5] Includes manually checking review article reference lists
[6] Refers to all citations identified through all methods after duplicate articles were removed
NA: not applicable

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CHAPTER 4

TECHNICAL PROPERTIES OF WHEAT STRAW-DERIVED BIOREFINERY-BYPRODUCT FIBER PREPARATIONS

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4.1 ABSTRACT

The aim of this study was to determine the potential of fiber preparations derived from alkali processed and/or enzyme saccharified wheat straw as potential food ingredients based on their technical properties, including hydration properties, emulsion and antioxidant capacities. A process based on an alkali pretreatment was applied to fractionate wheat straw into byproducts likely to be generated via biochemicals platform processing under optimal conditions for each fraction. Also, an enzyme saccaharification procedure was followed to obtain a fiber preparation. The composition and technical properties (water- and oil-holding capacities, swelling activities, solubility, emulsion capacities and antioxidant properties) of each fraction were analyzed. Alkali extracted hemicellulose (AEHC) exhibited higher water-holding capacity (10.3 g water/ g dry weight (DW)), swelling ability (18.7 mL/g DW), and oil holding capacity (10.6 g oil/g DW) than alkali lignin (AL) and alkali treated/enzyme saccharified residue (ATESR). Among all tested fiber preparations, the solubility of AL was increased at higher pHs (>5) and lower ionic strength of buffer. High emulsifying activity was exhibited by AEHC (92.3%), compared to AL (61.6%) and ATESR (57.3%), though the latter had 95.7 % emulsification stability. AL had highest antioxidant capacity as determined by the ABTS method. The differences in the functional properties of the tested fibers can be rationalized based on their compositions. This study demonstrates the potential of using AL as fiber rich antioxidant functional ingredient that can be selectively utilized in various food applications. These results highlight the great potential of these fiber fractions to incorporate in the formulation of low-calorie, high-fiber foods as a valuable source of dietary fiber ingredients.

KEYWORDS: Biorefinery feedstock, dietary fiber, wheat straw byproduct, alkali pretreatment, enzymatic saccharification, lignin, technical properties.

ABBREVIATIONS: AEHC, Alkali extracted hemicellulose; AL, alkali lignin; ATESR, alkali treated/enzyme saccharified residue; DW, dry weight.

HIGHLIGHTS:

- Fiber byproducts likely generated through biorefinery platform were extracted from wheat straw upon alkali pretreatment and enzymatic saccharification.
- The composition characterization and technical properties of fiber preparations were evaluated.
- These fiber preparations can be used for the development of fiber-rich foods and unique applications by food manufacturers and product developers.

4.2 INTRODUCTION

Biofuel production generates significant amounts of low-value residues and wastes that are left unused. The residues/wastes can be used as low-cost substrates for conversion to value-added products such as technologically appropriate direct and/or indirect food additives. Bioethanol can be produced from a variety of cheap substrates. Lignocellulosic biomass, such as grass and agricultural residues, has received an interest as promising resources for ethanol production considering availability, low cost and higher ethanol yields (Irmak, 2017; Saini, Saini, & Tewari, 2015). Wheat straw is a good example of a low value, high volume agricultural residue that can be used as a feedstock in a biorefinery concept (Clark et al., 2006).

Wheat straw is a lignocellulosic biomass. The cell wall of lignocellulosic biomass consists mostly of three structural organic compounds; cellulose, hemicellulose, and lignin that make up more than 80% of total dry-weight. Lignin is the primary organic non-carbohydrate polymer in lignocellulosic materials. It is a phenolic polymer comprised of phenylpropanoid units. The lignin content of lignocellulosic agricultural residues ranges approximately from 5.9% to 22%; lignin content is typically lower than cellulose content and similar to hemicellulose content (Sun, 2010). The digestibility of lignocellulosic materials is often inversely correlated with their lignin content.

The presence of lignin in lignocellulosic biomass complicates bioconversion processes targeting value-added products (Himmel et al., 2007; Kumar, Barrett, Delwiche, & Stroeve, 2009; Yuan & Sun 2010; Meunier-Goddik & Penner, 1999). Various lignin-removing processing operations have been proposed to overcome this limitation. Alkali-based treatments are widely used for such purposes, including those employed in the pulp and paper, ruminant animal feed, and biofuel industries. A result of such processing is an abundance of lignin-rich byproducts.

Economical value-added processing of these byproducts is challenging and complex due to lignin's structure and the lack of structure/function information about lignin per se (Lu & Ralph, 1999). Thus, most of the lignin-rich byproducts are directly burned for energy recovery.

Lignin-rich fiber byproducts derived from alkali processing of wheat straw were the focus of this study based on their relevance to the bioconversion processing of this important agricultural residue. We evaluated the potential of these byproducts for use in the food sector since that is an area that has received relatively little attention. The food industry seeks to increase fiber levels in foods in response to calls for healthier products. One practical means of increasing the fiber level of foods is to substitute non-caloric fiber components for caloric non-fiber components in formulated foods. Incorporation of underutilized fiber sources in formulated foods is expected to have environmental as well as health promoting benefits since this approach makes use of byproducts as functionally relevant food extenders.

On the other hand, huge quantities of agricultural by-products are generated and not utilized. These byproducts contain valuable compounds that could be optimized to make high-value food products. If these by-products could be used as a dietary fiber source, it would reduce pollution and add value to industry. The dietary fibers of agricultural wastes have gained much attention. As a new source of dietary fibers, they could be used in the development of new applications and value-added food products as ingredients. Dietary fiber can be added to a number of products, e.g bread, breakfast cereals, pasta, jam and marmalades, beverages, dairy products, meat products, and others (Cardador-Martínez, Espino-Sevilla, del Campo, & Alonzo-Macías, 2017). The incorporation of dietary fibers as a food ingredient can offer several technological properties to food, including hydration properties (solubility, water holding capacities, swelling ability), oil-binding capacity and antioxidant properties (Elleuch et al., 2011;

Quirós-Sauceda et al., 2014; Xie, Wang, Wu, & Wang, 2016). Fibers can be used as anti-caking and anti-sticking agents due to their hydration and oil holding properties that help to retard staling, control moisture and ice crystal formation, reducing syneresis and increasing stabilization of high fat foods products and emulsion (Elleuch et al., 2011; Lecumberri et al., 2007). Fibres that pose high antioxidant activities allow the stabilization of fatty foodstuffs, thereby improving their oxidative stability and prolonging their shelf life (Elleuch et al., 2011). Moreover, the use of dietary fiber as a food supplements are likely to increase in near future not only because of the technological properties provided to food but also its physiological functionalities such as laxative, reduction of blood cholesterol and glucose, reduction of risk of chronic disorder (Elleuch et al., 2011; Quirós-Sauceda et al., 2014).

To our knowledge, this study is the first systematic characterization of food-pertinent technical properties of fiber byproducts resulting from bioconversion processing of wheat straw. The primary aim of the study was to provide knowledge that is relevant to the establishment of the suitability of using such fiber preparations as “dietary fiber” ingredients in formulated foods. The following food-relevant technical functional properties were assessed: water holding capacity, swelling ability, oil holding capacity, solubility, emulsion capacity, and antioxidant activity. These properties, termed “functional properties by food technologists,” are critical for assessing potential uses for novel ingredients in formulated foods.

4.3. MATERIALS AND METHODS

4.3.1 Feedstock

Wheat straw was purchased at a local farm-supply store, air-dried, and then knife milled to pass a 2 mm screen (Retsch GmbH, Germany). Milled straw was stored in sealed clear glass jars at room temperature prior use.

4.3.2 Reagents and Enzymes

All chemicals used for pretreatments, scarification and analytical procedures were reagent grade. Sugar standards (Sigma) were HPLC grade. Glucose oxidase/peroxidase kit (GOPOD-FORMAT) was purchased from Megazyme (Ireland). Cellic CTec2 (mixture of cellulase, β-glucosidase and hemicellulose) was a gift from Novozyme (Franklington, NC). The celllulase activity of the enzyme preparation was determined using the National Renewable Energy Laboratory (NREL) specified filter paper assay (Adney & Baker, 1996); the preparation had 108 FPU/ml.

4.3.3 Compositional analyses

Assays of the chemical composition of samples followed laboratory analytical procedures (LAP) specified by the NREL. Moisture content and total solids were determined in triplicate following NREL specified protocols (NREL/TP-510-42621) (Sluiter, Hames, et al., 2008). Briefly, moisture content was determined gravimetrically based on the weight difference after drying 0.5 g sample (weighed to the nearest 0.1 mg) to constant weight at 105 °C in a convection oven. Total solids were calculated from moisture content data samples. The structural carbohydrate and lignin content of the original wheat straw was determined following removal of "extractives" by sequential 24-hour extractions with water and 95%-ethanol in a Soxhlet apparatus (NREL LAP/TP-510-42619). Total "extractives" were determined gravimetrically after vacuum oven drying the extractives-containing solvents at 40 °C for 24 h (Sluiter et al., 2008). Extractive-free wheat straw was subjected to compositional analysis by two step hydrolysis (72% w/w H_2SO_4 at 30°C for 1 h followed by 4% w/w H_2SO_4 at 121 °C for 1 h) (Sluiter et al., 2010). Hydrolysate was vacuum filtered using a glass gooch crucible (10-15 µm pore size). The acid insoluble residues (AIR) were dried at 105°C for 5 h. The acid insoluble lignin (AIL) was determined gravimetrically after correction for the ash content (575 °C for 24 h) of the AIR. The filtrate was then divided into two parts; one part was used to quantify acid soluble lignin (ASL) by UV-Visible spectroscopy (λ = 320 nm), the other part was used to determine neutral sugars (i.e., monosaccharides) using HPLC. Prior to HPLC analyses, hydrolysates were first neutralized with $CaCO_3$ and then filtered through 0.2 µm Acrodisc syringe filters (Pall, USA) into autosampler vials. Monosaccharide (arabinose, galactose, glucose, mannose, and xylose) quantification was accomplished using an HPLC system (Shimadzu model Prominence UFLC, Columbia, MD) equipped with Aminex HPX-87P column (300 x 7.8mm, Bio-Rad, USA) and deashing guard column (Bio-Rad, USA), and an evaporative light scattering detector (ELSD model: ELSD-LTII) (350kPa; Gain 6; Temperature 60°C). Chromatographic separation was obtained with conditions of: isocratic elution with mobile phase for Milli-Q grade water; column temperature, 85 °C; injection volume, 20 µl; running time, 30 min. LC solution Software was used to analyze the chromatograms (Shimadzu).

4.3.4 Alkali treatment of wheat straw

The flow chart depicted in Figure 4.1 shows the processing parameters used to obtain the different wheat straw-derived fiber fractions. The initial step is an alkali treatment of the straw aimed at increasing the enzyme-availability of the straw for subsequent enzyme saccharificiaton and fermentation for energy production. Native wheat straw was treated at 3% solids loading in

5% NaOH (w/v) at 50 °C for 5 h in a shaking water bath. The slurry was then vacuum filtered using a glass fiber filter (10-15 µm pore size) to obtain the alkali extraction liquor (subsequently used as source of alkali extracted hemicellulose and alkali extracted lignin) and the alkali extracted solid (subsequently used as source of alkali treated/enzyme saccharified residue).

Preparation of "Alkali Treated/Enzyme Saccharified Residue" (ATESR). The alkali treated wheat straw residue (Alkali Extracted Solids") was treated with a commercial cellulase/hemicellulase enzyme for carbohydrate saccharification using a slight modification of the NREL protocol (Selig, Weiss, & Ji, 2008). Briefly, 5 mL of 0.1 M sodium citrate buffer, pH 4.8 and 0.1 mL of 2% (w/v) sodium azide (antimicrobial agents) were added to 150 mg alkali pretreated, then water-washed and neutralized solids. Water was added to the suspension to obtain the total weight per reaction mixture of 10 g (1.5% solids loading). The suspension was equilibrated to 50 ^{o}C before adding enzyme. The saccharification reaction was initiated by adding cellulase/hemicellulase enzyme preparation (Cellic CTec2) to give a final enzyme loading of 30 FPU/g glucan. The mixture was incubated at 50°C for 48 h in a shaking incubator at 100 rpm. To follow the progress of the reaction, 0.5 ml aliquots of the reaction mixture were removed at 6 h, 24 h and 48 h and immediately filtered through a 0.45um PTFE syringe filter. Glucose production was quantified using a glucose oxidase/peroxidase assay (Megazyme, Ireland) as described by the supplier. After 48 h of incubation, reaction mixtures were centrifuged at 10,000 rpm for 15 min. The resulting pellet was collected, washed to remove residual enzyme (Qi, Chen, Su, & Wan, 2011) and then freeze-dried. The resulting fiber preparation is herein referred to as "Alkali treated/enzyme saccharified residue" (ATESR).

Preparation of Alkali Extracted Hemicellulose (AEHC). The pH of the "Alkali Extraction Liquor" resulting from the initial alkali treatment of wheat straw was adjusted to pH 6 using 6N

HCl. At pH 6, 2 volumes of 95% aqueous ethanol were added to the suspension and it was left to sit at room temperature for 1 hour to allow hemicellulose precipitation. The resulting suspension was centrifuged at 10,000 rpm for 15 min to collect the solids. Ethanol was removed from the collected solids by by repeated addition of water and rotary evaporation at 40 °C. The resulting preparation was freeze-dried for use in subsequent experiments. This fiber preparation is herein referred to as “Alkali Extracted Hemicellulose” (AEHC).

Preparation of Alkali Extracted Lignin (AL). The supernatant recovered following centrifugation of the pH adjusted, ethanol supplemented suspension described in the previous paragraph was used to prepare alkali extracted lignin. The supernatant was rotary evaporated at 40°C to remove ethanol; the pH of the resulting aqueous solution was then adjusted to 1.5 with 6M HCl and incubated at 40°C for 1 h to precipitate the alkali extracted lignin. The resulting suspension was centrifuged at 10,000 rpm for 15 min; the resulting pellet was washed three times with pH-adjusted water (pH 1.5) followed by a final wash with pure Milli-Q water and subsequently freeze-dried for use in subsequent experiments. This fiber preparation is herein referred to as “Alkali Extracted Lignin” (AL).

4.3.5 Analysis of the functional properties of fiber preparations

4.3.5.1 Color measurements

The color of samples was analyzed using a colorimeter (LabScan XE, Hunterlab, Reston, USA). Ground freeze-dried samples were placed in plastic petri dishes and color parameters determined on six randomly chosen zones. Color parameters, L* (lightness), a = red (+) - green (-) and b = yellow (+) - blue (-) were determined and used to calculate Hue angle = tan-1 (b/a) and chroma = $\sqrt{a^2 + b^2}$.

4.3.5.2 Water-holding capacity and Solubility in Water

Water-holding capacity (WHC) was determined as retained moisture following immersion, centrifugation, and decantation as described by (Fuentes-Alventosa et al., 2009). In a falcon tube, 0.2 g dry-weight of sample was mixed with 10 mL of distilled water, mixed at 100 rpm for 1 h at room temperature, and centrifuged at 11,950 x g for 15 min, the supernatant carefully decanted, and the resulting pellet weighed immediately to the nearest 0.1 mg. WHC was calculated as the grams of water retained per gram of dry sample. The water solubility of the fiber preparations was determined based on the solids remaining in the pellet following the decantation step in the WHC determination. Solids remaining in the pellet were defined as the weight (to the nearest 0.1 mg) of the pellet following drying in a vacuum oven at 40°C for 24 h; solubility is expressed as mg per mL.

4.3.5.3 Oil-adsorption capacity

Oil-adsorption capacity (OAC) was determined using a procedure analogous to that for WHC (Fuentes-Alventosa et al., 2009) with minor modifications. In a falcon tube, 200 mg dry sample was mixed with 5 mL soybean oil (0.92 g/ml density), left overnight at room temperature, centrifuged at 11,950 x g for 15 min, decanted off the excess oil, and reweighed the pellet to the nearest 0.1 mg. The OAC was expressed as gram of oil retained per gram of dry sample weight.

4.3.5.4 Swelling capacity

Swelling capacity (SC) was evaluated following the method described by (Al-Sheraji et al., 2011) with minor modifications. In a graduated falcon tube, 200 mg (weighed to nearest 0.1 mg) dried sample was vigorously mixed with 10 mL of distilled water containing 0.02% sodium azide and then left idle for 18 h at room temperature. Fiber swelling was then assessed by measuring the bed volume attained over the 18-hour period in excess water; SC is expressed as mL per g dry sample.

4.3.5.5 Emulsification Activity and Emulsion Stability

Emulsification Activity (EA) and Emulsion Stability (ES) were evaluated essentially as described by (Chau, Cheung, & Wong, 1997). In 50 ml falcon tubes, 200 mg of fiber preparation in 10 ml water/buffer (2% w/v) was homogenized using a VWR 200 homogenizer at 12,000 rpm (speed 3) for 30 seconds. Ten ml of soybean oil (0.92 g/ml density) was then added to each sample and they were further homogenized for 2 min. The entire sample volume was then transferred to 15 ml graduated falcon tubes and centrifuged (Eppendorf Instruments, Model 5810 R) at 1,200 x g for 5 min at 30 °C. The volume of the emulsion layer was then measured in mL. EA was calculated as the percentage of the samples' total volume contained in the emulsion layer (see equation 1 below). To determine ES, the emulsion prepared in the determination of EA was was heated at 80 °C for 30 min, cooled at room temperature and centrifuged at 1,200 x g for 5 min at 30^{o} C. ES was calculated as the percentage of the original emulsion volume remaining following the heat/centrifuge treatment (see equation 2 below). The layers developed during the centrifugation step of the emulsion studies were (from top to bottom) oil, emulsion, water and solids. Images of the emulsion per se were acquired using a Nikon Eclipse 50i microscope (Nikon Co., Tokyo, Japan) equipped with an Infinity 1-3C camera (Lumenera Corporation, Ottawa, ON, Canada).

$$\text{EA}\ \% = \frac{\text{volume of emulsified layer}}{\text{volume of whole layer}} \text{ x } 100 \qquad (1)$$

$$\text{ES}\ \% = \frac{\text{volume of remaining emulsified layer in a heat treated emulsion}}{\text{volume of original emulsified layer in a untreated emulsion}} \text{ x } 100 \qquad (2)$$

4.3.5.6. Solubility of fiber preparations

In a typical solubility experiment 10 mg of fiber preparation was suspended in 1 mL of the appropriate aqueous solution and agitated for 1 h at room temperature (22-24°C). The resulting suspension was centrifuged at 10,000 rpm for 15 min. The supernatant was carefully decanted and kept for subsequent measurements. The pellets resulting from centrifugation were dried at 40°C for 24 h and weighed to the nearest 0.1 mg. Solubility was calculated based on the loss in weight resulting from this aqueous treatment, considering the presence of buffer components. The pH dependence of fiber preparation solubility was determined using Britton-Robinson buffers of constant ionic strength (0.1M) ranging from pH 2.0 to pH 9.0 (Mongay & Cerda, 1974). The ionic strength dependence of fiber preparation solubility was determined at pH 6 over an ionic strength range of 0.05-0.5M adjusted with KCL as described by reference (Mongay & Cerda, 1974). The water-solubility of fiber preparations was determined in conjunction with the water holding capacity (WHC, see above) as the solids remaining in the pellet following the decantation step in the WHC determination. The solids content of the pellet was defined as the weight (to the nearest 0.1 mg) of the pellet following drying in a vacuum oven at 40°C for 24 h. All solubility values are expressed as mg per mL.

4.3.5.7 Determination of antioxidant activity

ABTS Radical-Scavenging Activity Assay. The ABTS (2,2′-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) radical cation decolorization assay was performed following the method described by (Re et al., 1999) with some modification (Khatua, Ghosh, & Acharya, 2017). $ABTS^{\bullet+}$ was prepared by mixing ABTS and potassium persulfate solutions so as to result in a mixture that was 2.45 mM potassium persulfate and 7 mM ABTS in deionized water; the reaction was then allowed to proceed for 12-16 h at room temperature in the dark. The resulting $ABTS^{\bullet+}$ solution was diluted with deionized water to obtain an initial absorbance of 1.5 at 734 nm. This "$ABTS^{\bullet+}$ working solution" was prepared fresh daily for antioxidant assays. The antioxidant assay per se was initiated by mixing 20 μL of appropriately diluted sample with 180 μL $ABTS^{\bullet+}$ working solution. The kinetics of $ABTS^{\bullet+}$ reduction was initially followed over a 1-hour period by taking absorbance readings every 10 min. Early experiments showed that absorbance readings were essentially stable after the first 10 min and thus 10 min was used as the standard reaction time for the quantification of ABTS-based antioxidant activity. The dietary fiber preparation "samples" used for the antioxidant assays consisted of the soluble components of the fiber preparations; i.e., the components soluble in the pH 6.0, 0.1 M ionic strength, buffer described in the "Solubility" section above. Reaction mixture "blanks" contained 20 μL buffer in lieu of sample. Known concentrations of ascorbic acid were used to develop calibration curves and thus results are expressed as mg ascorbic acid equivalents (AAE)/g dry weight fiber preparation. Analyses were conducted in duplicate using 96-well plates and a microplate reader (SpectraMax M2, Molecular Devices, CA, USA).

4.3.6 Statistical Analysis

All experiments were done in triplicate unless otherwise noted. Results are expressed as the mean ± standard deviation (SD). The statistical significance of differences between treatments were determined using a one-way ANOVA with Tukey HSD test. Differences were considered significant when $p < 0.05$.

4.4 RESULTS AND DISCUSSION

Preparations of fibers from alkali pretreated and/or enzyme saccharified wheat straw

Dietary fiber is recognized as an important food component for both technical and nutritional reasons (Elleuch et al., 2011). An impending, abundant source of dietary fiber with potential applications in the food industry is the dietary fiber-/lignin-rich byproducts that result from the processing of biomass for biofuel/bioproduct production. Wheat straw is a globally important source of herbaceous biomass for such processing (Clark et al., 2006; Sarkar, Ghosh, Bannerjee, & Aikat, 2012). Thus, the functional properties of fiber-rich wheat straw processing byproducts are of general relevance to the use of these byproducts in foods (Brulé and Croguennec, 2016).

The flow chart depicted in Figure 4.1 shows the straw-to-product processing scheme used in this study. The scheme is representative of those under consideration for biochemical-platform processing of biomass for biofuel/bioproduct production (i.e., processing via biomass-derived sugar fermentation; (Talebnia, Karakashev, & Angelidaki, 2010). The fiber-rich byproducts of interest in this study are noted in the flow chart by their being enclosed in hairline boxes (Figure 4.1).

An important question to consider when judging the relevance of a biomass-to-biofuel/bioproduct processing scheme as depicted in Figure 4.1 is the glucose yield resulting from the enzyme saccharification step, since this is an indication of the carbohydrate ("sugar") available for subsequent fermentation to products.

Figure 4.2 illustrates the time-course of glucose production during enzyme saccharificaiton of the alkali treated wheat straw produced in this study. Both the rate of glucose production and glucose yields were good; approximately 70% of available glucose was solubilized within 8 h and final yields were approximately 90% of theoretical (the "theoretical amount" being that amount of glucose that corresponds to the cellulose/glucan content of the original straw). These results indicate the processing scheme used to generate the fiber-rich byproducts in this study is of general relevance to those expected to be employed in the biofuels/bioproducts industry. The glucose production time course for untreated wheat straw is included in Figure 4.2 to illustrate that untreated wheat straw is not suitable for glucose production via enzymatic saccharification.

Compositional date for wheat straw (WS), alkali extracted solid (AES), alkali treated/enzyme saccharified residue, (ATESR), alkali extracted hemicellulose (AEHC), and alkali lignin (AL) are summarized in Table 4.1. The values were determined based on Laboratory Analytical Procedures (LAP) from National Energy Laboratory (NREL). These protocols require removal of extractives from native lignocellulosic when conducting acid soluble and insoluble lignin. The extractives can polymerize with lignin to form lignin-like structures, called "pseudo-lignin" which cause high lignin values (Meng & Ragauskas, 2017; Sannigrahi, Kim, Jung, & Ragauskas, 2011). The overestimation of lignin due to the presence of extractives in native lignocellulosic is well documented (Junyusen, 2013; Sluiter et al., 2010; Thammasouk, Tandjo, & Penner, 1997).

Wheat straw used as substrate for compositional analysis has undergone exhaustive extraction by sequential water and 95% ethanol for 24 h each step prior to analyses. The majority of extractives were in water extract (19.3%) compared to ethanol extract (1.9%). This suggests that most of extractives in wheat straw are hydrophilic compounds. The major components of WS, AES, AEHC were carbohydrates comprising approximately ~54%, ~87%, and ~89% of total solids recovered, respectively. Among lignin-rich fractions, alkali lignin had the highest lignin content with 81%, followed alkali treated/enzyme saccharified residue with approximately

~70%. The lignin content of wheat straw was moderate at approximately ~16.5%. AEHC and AES had the lowest lignin content at approximately ~ 11% and 7%, respectively. Inorganics, represented as ash, were highest in alkali lignin (~ 9%) and wheat straw (8.4%).

Color parameters (L*,a* b*, hue and chroma) have been used to evaluate the appearance of commercial fibers, including AL (Ajao et al., 2018) and AEHC from sugarcane bagasse (Sabiha-Hanim & Siti-Norsafurah, 2012). Analogous data for alkali pretreated WS was not found in literature. Figure 4.3 summarizes the color parameters for the different preparations used in this study L* is an approximate measurement of brightness or luminosity, ranging from black (0) to white (100) (Gazula, Kleinhenz, Scheerens, & Ling, 2007; Granato & Masson, 2010). WS and AL were significantly lighter ($p<0.05$) than the other preparations as indicated the two highest L value, 62.9 and 63.1, respectively. Hue angle is used to define the difference of a certain color with reference to grey color with the same lightness (Pathare, Opara, & Al-Said, 2013), where colors corresponds to: 0° and 360° for red, 90° for yellow, 180° for green, and 270° for blue (McGuire, 1992; Pathare et al., 2013). Hue angles of the all samples showed predominantly yellowness color; WS and AL were not significantly different from each other ($p>0.05$), while the residue resulting from AETSR and AEHC were significantly different ($p<0.05$), meaning a more intense yellow color. Chroma indicates color saturation and higher values indicate greater color intensity of samples perceived by humans. The color of the AL preparation was significantly less than that of the other preparations($p<0.05$).

Lignin is almost colorless in wood but industrial lignins, such as AL, tend to have dark colors (Ajao et al., 2018; J. Wang et al., 2016). Therefore, it was expected that color differences between samples would correlate with lignin concentration (Núñez-Flores et al., 2013; Sabiha-Hanim & Siti-Norsafurah, 2012). However, we did not see this trend in our samples. For example, AEHC was significantly darker ($p<0.05$) while its lignin content was lowest, 6.9% of total lignin. It is known that technical lignin's contain a variety of chromophores (Wang et al., 2016) and that different lignin fractions have different color characteristics (Ajao et al., 2018). Hence, the differences in the color of our preparations may be related to the relative proportions of lignin-derived chromaphores in the different fiber fractions (Ajao et al., 2018).

Hydration properties (water-holding capacity, swelling ability, solubility) and oil-holding capacity

The state of water in foods is intimately associated with their safety, stability, quality and physical properties (Lewicki, 2004). Thus, the relevance of hydration properties when assessing the suitability food ingredients. The hydration properties of the different fiber preparations evaluated in this study are included in Table 4.2. The WHC of the different preparations ranged from a low of 3.1 (AL) up to 10.3 (AEHC) g water per gram solids and was inversely related to the lignin content of the preparations (Table 4.1). The absolute values obtained by typical water holding capacity/water binding capacity measurements, and as done in this study, are dependent on the external force applied for water removal (presently, centrifugation at 12,000 g). Hence, WHC values are best compared relative to an analogous well-recognized food ingredient. Wheat bran (WB) was included in this study for such comparisons; the WHC of wheat bran determined herein is very similar to that found in comparable studies(Holloway & Greig, 1984; Jacobs, Hemdane, Dornez, Delcour, & Courtin, 2015; Sui, Xie, Liu, Wu, & Zhang, 2018a; T. Wang, Sun, Zhou, & Chen, 2012a). The WHC of the lignin-rich samples ATESR and AL were comparable to and somewhat less than that of WB, respectively. The lowest lignin content/highest carbohydrate content preparation (AEHC) had a WHC over double that of WB. Values for WHC, as typically done and as measured here, reflect two processes – water absorption and solute dissolution (Lewicki, 1998). Thus, the soluble portion of tested preparations is excluded from these WHC measurements since it is discarded with the supernatant following centrifugation (Robertson et al., 2000). In this light, the WHC for AEHC is particularly noteworthy since it has the highest percent soluble solids. When reporting WHC based on insoluble solids (ie., the amount of solids retained in the pellet following centrifugation), the value for AEHC increases to 17.7 ml/g. The trend in WHC values was similar to their swelling capacity (SC; Table 4.2). SC was greater than WHC for all preparations, the ratio ranging from approximately 1.3 to 2.0. This is consistent with the assumption that application of an external stress (centrifugation in the WHC measurement) will expel some of the water from the swollen sample, and that both values are calculated with respect to the total amount of solids in the test solutions. The SC of the samples ranged form 5.2 ml/g (AL) to 18.7 ml/g (AEHC). The SC for wheat bran (~ 7.0 ml/g) is similar to that reported by others (5.5 ml/g, Sui et al., 2018; 4.3-12 ml/g,(Jacobs et al., 2015); 5.96, Wang et al., 2012). The SC values for the other fiber preparations are in the same range as that reported for various traditional fiber sources: coconut fiber (17-20 ml/g) (Raghavendra et al., 2006), cacao fiber (6.5 ml/g) (Lecumberri et al., 2007b), dried fruit pomace (2.9-6.5ml/g) apple fiber (4.1-14.3 ml/g) and citrus fiber (4.6-10.3 ml/g) (Gouw, Jung, & Zhao, 2017). The hydration properties of the different preparations are in accord with the chemical and physical character of the different preparations. The high WBC and SC values for AEHC can be rationalized based on its high xylan content; xylan, being a carbohydrate, is more hydrophilic than lignin (Zhang et al., 2018) and it is more amorphous than cellulose (Prusov, Prusova, Radugin, & Zakharov, 2014; Sheikhi & Petroudy, 2018). The low WBC and SC values for AL are attributable to it being high in lignin and lignin itself being relatively hydrophobic (Boulos, Greenfield, & Wills, 2000). The physical, three-dimensional, microstructure of foods plays a key role in their hydration properties (Robertson & Eastwood, 1981; Van der Sman, Paudel, Voda, & Khalloufi, 2013). The wheat bran and wheat straw used in this study are expected to retain some semblance of their original cellular structure; the physical structure of the byproduct preparations is the result of the series of operations leading to their formation. The higher WHC values for AEHC and WS suggest these preparations have higher pore volumes, thus permitting greater solvent absorption.

Oil holding capacity (OHC) is an important parameter with respect to the stabilization and sensory properties of fat containing foods (Elleuch et al., 2011b; Rodríguez-Gutiérrez, Rubio-Senent, Lama-Muñoz, García, & Fernández-Bolaños, 2014). OHC values ranged from a low of approximately 3 up to nearly 11 g oil per gram fiber preparation. The values are, in general, higher than those reported for other byproducts (Masli, Rasco, & Ganjyal, 2018), although direct comparisons are difficult since evaluation methods differ somewhat. The value measured for WB in this study is consistent with those reported previously (Sui et al., 2018a; T. Wang et al., 2012a). The relative ranking of the different fiber preparations with respect to OHC was essentially the same as that for WHC; this is also consistent with that observed by others (Ballesteros, Teixeira, & Mussatto, 2014a; Betancur-Ancona, Peraza-Mercado, Moguel-Ordonez, & Fuertes-Blanco, 2004). The OHC of foods, as typically measured, has been attributed to voids in the microstructure of the foods, rather than their oleophilicity. The similarity in the rankings with respect to WHC and OHC is thus not surprising if both values largely reflect the porosity of the samples. The absolute values for the WHC and OHC of each preparation differed as indicated in Table 4.2. An interesting comparison is the OHC and corresponding WHC/IS for the different preparations (recall WHC/IS is the WHC corrected for the preparations insoluble fiber content; see Table 4.2). This comparison is informative because the fiber components that were soluble in the WHC assay are unlikely to be soluble in the OHC assay. The higher WHC/IS values compared to OHC potentially reflect the greater swelling capacity of the fiber preparations in water than in oil (for discussion of roles of porosity and swelling in food hydration see Van der Sman et al., (2013) The extent of water-induced swelling is expected to correlate with the hydrophilicity of the samples – which is what was observed based on the hydrophilicity of the samples being tied to their carbohydrate content. The WHC/IS of AEHC is approximately 1.7-fold greater than its corresponding OHC (AEHC having the highest carbohydrate content). The sample having the highest lignin content and lowest carbohydrate content (i.e., AL), and thus predicted to be the most hydrophobic, had nearly equivalent WHC/IS and OHC values. We hypothesize that this result is an indication of there being only trivial swelling of the AL preparation; in such a case nearly all of the retained solvent is a result of it filling void spaces within the fiber matrix

The solubility of a fiber preparation is particularly important when considering its technological applications. Therefore, pH and ionic strength effects on the solubility of the different fiber preparations were determined. Figure 4.4 shows the solubility of the different fiber preparations as a function of pH (2-9). The ionic strength of the solutions was kept constant by use of 0.1M Britton-Robinson buffer (see “Methods”). The covered pH range is representative of that for most foods (McGlynn, 2003). The corresponding solubility values of Figure 4.4 and Table 4.2 are in general agreement; the values in Table 4.2 being water solubility. The solubility of WS and ATESR was not pH dependent, the solubility of AEHC was moderately pH dependent, and the solubility of AL was highly dependent on pH. AEHC had the highest solubility, up to approximately 43%, at pHs below neutrality (ranged from ~25% at pH 2 up to ~43% at pH 7). AL had the highest solubility at pHs above neutrality (up to ~77% at pH 8.7).

The solubility of AL dropped off relatively sharply as the pH was lowered to approximately pH 4 (at pH ≤4 the solubility of AL was < 10%, dropping to a low of ~3% at pH 2). The low solubility of AL at low pHs was expected since its recovery from alkaline processing liquor requires precipitation by pH reduction to 1.5 (see Figure 4.1). The pH dependency of AL strongly suggests the presence of ionizable groups. These groups presumably include carboxyl moieties since such functional groups are present in wheat straw-derived alkali lignins (Domínguez-Robles et al., 2018). The carboxyl groups of AL are expected to become protonated as the pH of the solution is lowered, resulting in decreased electrostatic repulsion, and thus lower solubility. The presence of ionizable phenolic groups having unusually low pKa values may also contribute to the pH dependency of AL in a manner similar to that of carboxyl groups (Ajao et al., 2018; Scalbert & Monties, 1986). The higher solubility of AEHC relative to the other preparations at the lower pHs and the minimal effect of pH on AEHC solubility can be rationalized based on the nature of wheat straw hemicelluloses. They are primarily branched xylans; the branches include arabinofuranosyl, xylopyranosyl, and/or glucopyranosyluronic acids (Peng & Wu, 2010; R. Sun, Lawther, & Banks, 1996). Both branching and the presence of ionic charges are typically associated with increased polysaccharide solubility (Nelson, 2001; Whistler, 1973). The AEHC preparation also contains relatively low amounts of alkali-soluble lignin, which will respond to pH as discussed previously. The low solubility of ATESR is undoubtedly a result of the treatments (extractions, hydrolyses, washes etc.) from which it is a byproduct (Figure 4.1). That preparation did have considerable lignin content and thus the observed slight increase in solubility with increasing pH is potentially due to the same ionic effects as described for AL. The solubility of WS was low across the entire pH range. This was expected considering it is an intact lignocellulosic material that is dominated by secondary cell wall components.

Ionic strength had a relatively minor effect on the solubility of the different fiber preparations (Figure 4.5). These tests were done at pH 6 and ionic strengths ranged form 0.05M-0.5M. The only consistent trend across the pH range was the diminishing solubility of AL with increasing ionic strength. A similar decrease in the solubility of softwood kraft lignin with increasing ionic strength has been considered for applications in lignin recovery processes in the pulping industry (Zhu & Theliander, 2015). The decrease in solubility with increasing ionic strength is likely attributable to charge shielding and thus diminished electrostatic repulsion, leading to increased intermolecular associations.

Emulsion activity and emulsion stability

The emulsifying activity (EA) of a preparation is an indicator of that preparation's ability to foster formation and initial stabilization of an emulsion (Hill, 1996). A preparation's ability to maintain the integrity of an emulsion is commonly referred to as its emulsifying stability (ES; (Sanchez-Zapata et al., 2009). In this study both EA and ES were determined for the different fiber preparations (Figure 4.6A). These measurements are qualitative indices of the potential for application of the different preparations as emulsion stabilizers, while keeping in mind that the absolute values are strictly applicable to the conditions defined herein (Mcclements, 2007). Pectin and lecithin were included in this phase of the study for comparative purposes. The EAs of the ATESR, AL, and AEHC were ~57%, 62%, 92%, respectively. These values are significantly higher than the blank, which contained no added emulsifier, and lower than that for pectin. They are higher than those reported for the fiber fractions of lima bean (Betancur-Ancona et al., 2004), chia (Alfredo, Gabriel, Luis, & David, 2009) and olive (Rodríguez-Gutiérrez et al., 2014). all of which were tested using conditions analogous to those of this study.

The EA of AEHC was not significantly different from that of lecithin, a commercial emulsifier ($p<0.05$) and only slightly below that of pectin.

The ESs for ATESR, AL and AEHC were ~96%, 19% and 79%, respectively. The values for ATESR and AEHC are in the general range of those reported in the literature; the ES for AL is well below that reported for most fiber preparations(Alfredo et al., 2009; Betancur-Ancona et al., 2004; Kuan, Yuen, Bhat, & Liong, 2011; Sanchez-Zapata et al., 2009) (Alfredo et al., 2009; Alobo, 2003; Ballesteros, Teixeira, & Mussatto, 2014b; Du, Jiang, Yu, & Jane, 2014; Jalal et al., 2018; Kuan et al., 2011; Rodríguez-Gutiérrez et al., 2014; Sanchez-Zapata et al., 2009). The low ES for the AL preparation is likely to be at least partially attributable to its poor solubility in water.

Figure 4.7 shows microscopic images of the different emulsions before and after 80°C heat treatment/centrifugation (i.e., prior to an after the ES stress was applied). In general, emulsions prepared with all of the fiber preparations initially showed small droplets, which is typically preferable. The AEHC preparation had the smallest droplets than AL and ATESR. This is consistent with it having the highest EA value. The droplet size remained small in the AEHC-containing emulsion following thermal/centrifugal stress. In contrast, the relatively small particles associated with the AL-containing emulsion prior to application of the stress had clearly coalesced as a result of the stress; this behavior is indicative of a less stable emulsion. This behavior reflects the very low ES value measured for the AL preparation (~19%). After the heat/centrifugal treatment, the ATESR-containing emulsion showed larger and more aggregated droplets than the corresponding AEHC-containing emulsion. This was not anticipated based on the ES value for ATESR (~96%) being higher than that for AEHC (~79%).

It has been noted that EA values that were <50 % makes component not to be considered as good emulsifies (Abdul-Hamid & Luan, 2000). Given that their EA and ES greater than >50%, these fiber preparations, except AL, may be a good emulsifying agent for foods requiring emulsifiers and those with long shelf lives that require long stability such as juice concentrates and confectionaries. In fact, incorporation of AL into food will depend on product type. For products in which long shelf life is required, and thus higher ES, AL can be used because its higher EA (~57%); however, less stability (~19%) might not be so appropriate. In spite of low ES values, the use of fiber which posse ES <13% may stabilize foods with a high percentage of fat and emulsion (Borchani et al., 2012).

Emulsion properties are susceptible to environmental effects, including pH and ionic strength (Harnsilawat, Pongsawatmanit, & McClements, 2006; Laplante, Turgeon, & Paquin, 2005). Hence, the emulsifying properties of the different fiber preparations were evaluated in both a straight oil-in-water system (as discussed above) and in a oil-in-buffer system (Britton-Robinson buffer, pH 6.0, ionic strength of 100 mM); the buffer conditions were chosen based on their general relevance to food systems. The emulsion properties determined in the defined buffer system, in general, mirrored those determined in the straight oil/water system (Figure 4.6A versus 4.6B). The similarities of each preparation's EA and ES values in the two systems, the exception being the AL preparation, likely reflect relatively small impacts due to the differences in ionic strength since the pHs of the oil/water and oil/buffer systems were similar for most preparations (compare pHs of oil/water systems listed in Table 4.2 with that of the oil/buffer system, which was pH 6.0). The relatively large difference observed for the ES value for the AL preparation indicates the importance of the combined change in pH and ionic strength for this preparation. Direct comparison of the emulsion properties of AL under the two conditions (see Figures 4.8A and 4.8B) shows the EA values for the AL preparation were not significantly different in the two systems, but the ES value for the AL preparation in the oil/water system was less than half that of the corresponding value in the oil/buffer system. This result combined with the solubility data discussed previously, where increased pH corresponded with increased solubility, is consistent with the ES efficacy of the fiber increasing with increased solubility. The pH and ionic strength data also suggest the ES efficacy of the AL preparation is at least somewhat dependent on electrostatic repulsion; steric repulsion likely plays a larger role in the ES efficacy of the other preparations, which were not impacted by changes in ionic strength (Xu, Wang, Fu, Huang, & Zhang, 2018).

A further test was carried out to test the effect of solubles and insolubles fiber preparations both in water and in pH6 0.1M Britton-Robinson buffer (Table 4.3). With regard to ATESR, which had ~3% solubility in both water and buffer, the insolubles were important for the emulsification properties of ATESR. The data for AEHC, which had 41% and 43% solubility in water and buffer, respectively, showed both solubles and insolubles of AEHC were responsible for emulsification with solubles being more pronounced. On the other hand, the water-insolubles of AL were mainly responsible of emulsifying activity, and the ES value (~66%) was higher, with ~47 times more than ES (~19%) of AL for 1% fiber suspension. Hung & Zayas (1991) suggested that various factors including pH, droplet size, net charge, interfacial tension, viscosity, and protein conformation could affect the values of ES. In this case, washing AL with water to obtain insoluble might remove residual HCl and change the net charge on AL. This increased ES of AL might be attributed to strong interactions between hydrophobic groups and the lipid phase. As a matter of fact, the observation for buffer-insolubles of AL, which was washed with pH6 buffer was similar EA and ES values with water-solubles of AL. More, buffer-solubles showed higher EA and ES than water solubles, and this could attribute to the electrostatic forces between oil droplets that was covered with negatively charged molecules as a result of dissociated hydroxy and carboxyl groups at higher pHs (Parker & Krog, 1987). Overall, emulsion mechanism of AL could be attributed to stabilization of the layer around the oil droplets by steric and electrostatic repulsion due to its amphiphilic structure; (1) adsorbed hydrophobic groups at the surface of oil droplets results stearic repulsion; and, (2) ions around the charge droplets as a result of the ionization of functional groups, mainly carboxylic and phenolic hydroxyl groups results electrostatic repulsion.

Among our fiber preparations, AEHC showed the highest emulsion capacity. This could be mainly attributed to AEHC that comprise of soluble dietary fibers such as arabinose, galactose, and xylose (Junyusen, 2013). These soluble dietary fibers may assist in the formation as well as stabilization of emulsions by forming a thick hydrated layer surrounding the oil molecules and creating steric hindrance to the droplets from coming together and coalescing. Also, changes in the structural composition of fiber could affect the EA and ES of fiber based on pretreatment applied. Rodriguez-Gutierrez et al (2014) fractionated lignin and hemicellulose from olive byproducts and reported the EA values of these fraction as 5.5 to 44.96 % for lignin and 32% for hemicellulose. In fact, that the EA (~62%) of our AL was relatively greater, and this could be attributed to alkali treatment might exposed hydrophobic groups in the structure in greater extent. These groups might interact with oil molecules in an emulsion and subsequently prevent the coalescence and flocculation of oil droplets by stearic repulsion.

Since only a limited amount of isolated fiber preparations was available for this research, they were not examined further in any of the studies to evaluate the possible effect of pH and ionic strength on the emulsifying capacity of these fiber preparations. The next phase of this research focused on how binary combinations of these fiber preparations behaved in this emulsion studies at an order of magnitude less than their respective EA values.

The combination of fiber preparations may be among best practical strategies for achieving ease of the emulsion capacity (Tadros, 2013), especially if they are using different mechanism for the stability of an emulsion. The outcomes of combinational strategy can be characterized as: synergism, additivity and antagonism. The combinations of these fibers at different ratios to make total 1% fiber suspension was used to test the outcomes. The expected (additive) value was calculated based on the values of EA and ES by each fiber were those that used lower than 1% in suspension after subtracting the effect of control (water/oil mixture).

Figure 4.9 shows the combinational effect of AEHC:ATESR, AEHC:AL and AL:ATESR at ratio of 1:3, 1:1, and 3:1 to make a final 1% suspension in water/oil mix. The treatment of fibers individually with AEHC or AL have EA for ~82% and %47, respectively (Figure 4.9 A). When compared to blank, they increase EA by ~58% and 24%. The expected additive effect for this combination was estimated as 104% for EA, which means 81% increase over the blank. The combination of these two fibers increased EA by ~89%, meaning ~ 65% relative to blank, and more importantly, ~0.8-times lower than the calculated additive effect of these two fibers. Antagonistic effect was observed for this combination's EA. On the other hand, the combination of these two fibers increased ES by ~87% (~57% relative to blank), and more importantly, ~1.7-times higher than the calculated additive effect of these two fibers. Thus, synergistic effect was observed for this combination's ES. On the other hand, the same combination at other two ratios; 1:1 (Figure 4.9 B) and 1:3 (Figure 4.9 C) showed antagonistic effect on emulsion EA and EA for this combination. Furthermore, the combined effect of AL with ATESR and AEHC with ATESR were evaluated. The results indicated the combine treatment of AEHC:ATESR showed antagonistic effect in enhancing EA and ES in each ratios applied (Figure 4.9 D,E,F). In case of the combinations AL:ATESR for each ratio, these two fibers had antagonistic effect in enhancing EA but synergistic effect in enhancing ES (Figure 4.9 G, H, I).

Collectively, the combinations described above displayed antagonistic on EA, but outcome of ES could be grouped into patterns with different behaviors; synergistic and antogonistic. First of all, the combinations of AEHC:ATESR for all ratios and AEHC:AL except 3:1 ratio involved treatments where combinations of fibers were antagonistic on EA still behaved antagonistic on ES. Another type of behavior was observed for the combination of AL and ATESR for all ratio and AEHC:AL for 3:1 ratio involved treatments where combinations of fibers were antagonistic on EA behaved synergistic on ES.

Antioxidant activity

The general antioxidant properties of many lignin-derived phenolics have been characterized (García, Alriols, Spigno, & Labidi, 2012). It is generally accepted that such compounds are good radical scavengers; making them candidates for use in food systems. Studies demonstrating their radical scavenging activity are typically based on aqueous assay systems. The soluble components of the fiber preparations as described in the "solubility" section was used for the antioxidant assays. ABTS assay was selected to evaluate the antioxidant properties of lignin-derived phenolic-rich fractions as antioxidants in food applications. ABTS assay has been used widely for antioxidant activities of lignin (Aadil, Barapatre, Sahu, Jha, & Tiwary, 2014; Jiang et al., 2018; Qazi, Li, Briens, Berruti, & Abou-Zaid, 2017). It has reported that the mechanisms of the lignin radical scavenging activity of lignin on $ABTS^{\bullet+}$ radical is due to the electron transfer-proton transfer mechanism (Arshanitsa et al., 2013). ABTS assay was suitable to use for samples of over a wide pH range and not being affected by ionic strength (Prior, Wu, & Schaich, 2005).

The antioxidant activity of the fiber preparations by the ABTS assay are shown in Figure 4.10 and 4.11. The trend of antioxidant activity of AL agrees with the solubility of AL in buffered system (see Figure 4.4 and 4.5). AL had higher antioxidant activities than other samples. The antioxidant activity of lignin is directly related to the structure, meaning the structural changes of lignin subunits units and functional groups such as methoxy, phenolic hydroxyl and carboxy hydroxyl (Jiang et al., 2018). The strong antioxidant capacity of AL was likely due to presence of phenolic OH, which could act as a hydrogen donor antioxidant (Q. Lu et al., 2012; Pan, Kadla, Ehara, Gilkes, & Saddler, 2006; S.-N. Sun, Cao, Xu, Sun, & Jones, 2014). In addition to phenolic OH, the carboxyl groups of lignin were reported to promote ABTS capacity (Aadil et al., 2014). The antioxidant capacity of other fiber preparations was lower except for soluble components of ATESR at pH 8 and pH 9, which is likely due to the lignin content (Figure 4.10). On the other hand, the effect of the structural composition on lignin's antioxidant activity is not clear. For example, aliphatic OH content was reported to have a negative effect on antioxidant activity of organosolv-ethanol lignin (Pan et al., 2006), while a positive influence of aliphatic OH on the antioxidant activity of lignin model compounds was reported (Dizhbite, Telysheva, Jurkjane, & Viesturs, 2004).

4.5 CONCLUSION

The processing of wheat straw by-products obtained from wheat straw as a biorefinery feedstock by alkali pretreatment and/or enzymatic saccharification allowed for the fractionation of the three main fiber preparations present in the lignocellulosic matrix. The fractionation method of obtaining fiber preparations caused some variability in the chemical composition of the fiber preparations, i.e the content of total carbohydrate and total lignin. The fiber preparations could provide as a water- and oil-holding, emulsion-enhancing and radical scavenging agents. Especially, AEHC had good water- and oil-holding capacities higher than those found for ATESR and AL. The solubility of AEHC was increased with buffer pH, but the solubility of AESR was not affected by buffer pH. On the other hand, the solubility of AL was affected by pHs and ionic strength of buffer, possibly attributed to its high lignin content (81%). The extend of emulsifying activity demonstrated that especially considering their oil-holding capacities and emulsifying ability, ATESR, as well as AHEC, may be used as emulsifier in the food that consists of emulsions. On the other hand, the combine effect of binary mixtures of these extracted fiber preparations on emulsion showed antagonistic outcome on emulsifying activity. More, AL had high ABTS radical scavenging activity, suggesting the potential to improve oxidative stability and extending shelf life of foods due to its antioxidant property. This study suggest these fiber preparations can be used for the development of fiber-rich foods and unique applications by food manufacturers and product developers for incorporation as low-calorie bulk ingredients in foods.

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CONTRIBUTORS

Michael H. Penner conceived the research, designed the study, provided insight into the data interpretations and edited manuscript. Lisbeth Meunier-Goddik contributed to the design of the study. Tuba Karaarslan Urhan designed and completed the experiments, analyzed the data and performed statistical analysis, drafted the manuscript.

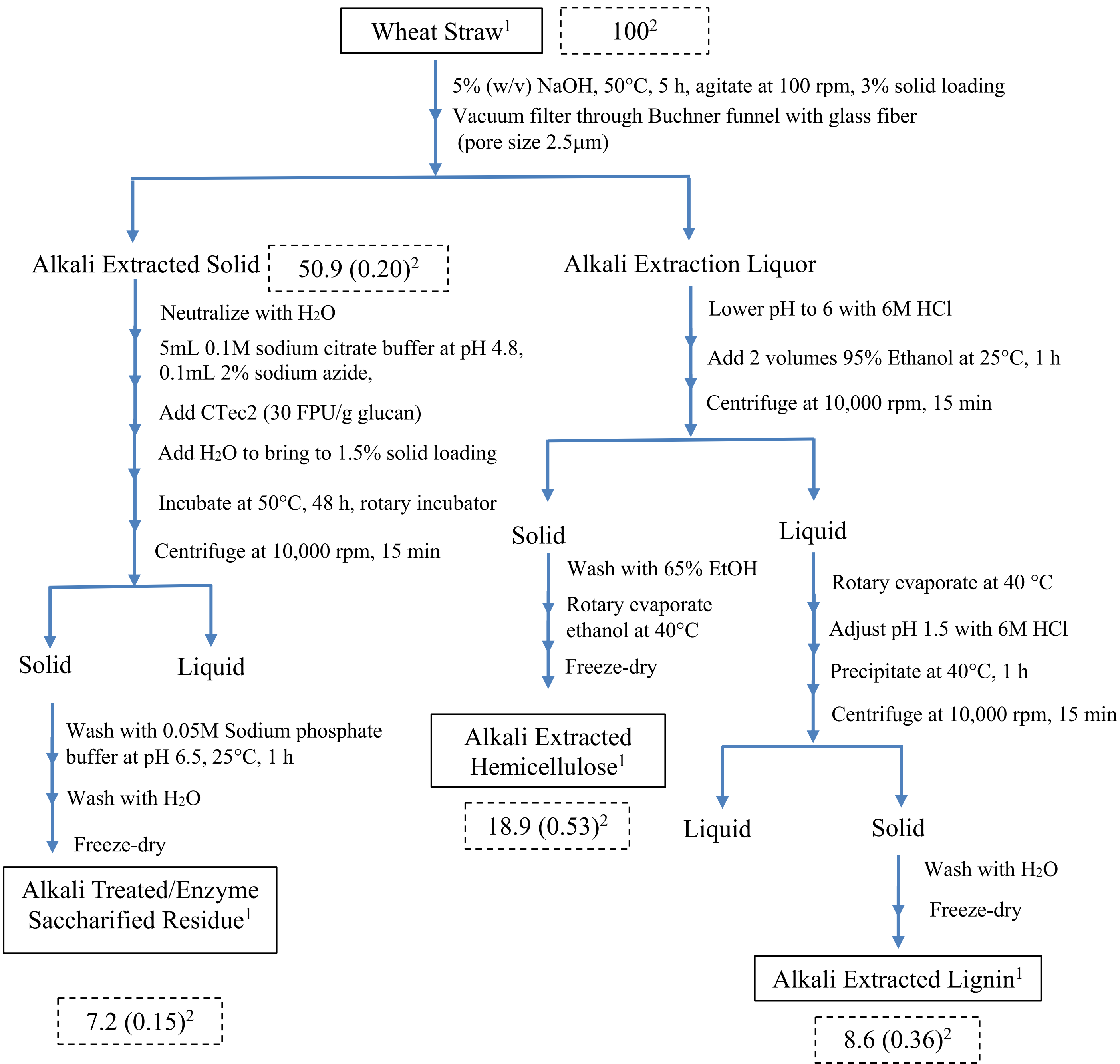

Figure 4.1. Flow chart of preparations of lignin-rich byproducts from alkali pretreated wheat straw.

[1]The substrates was used for further experiments.
[2]The values represents as gram recovered per 100 gram original dry-weight wheat straw; mean (SD).

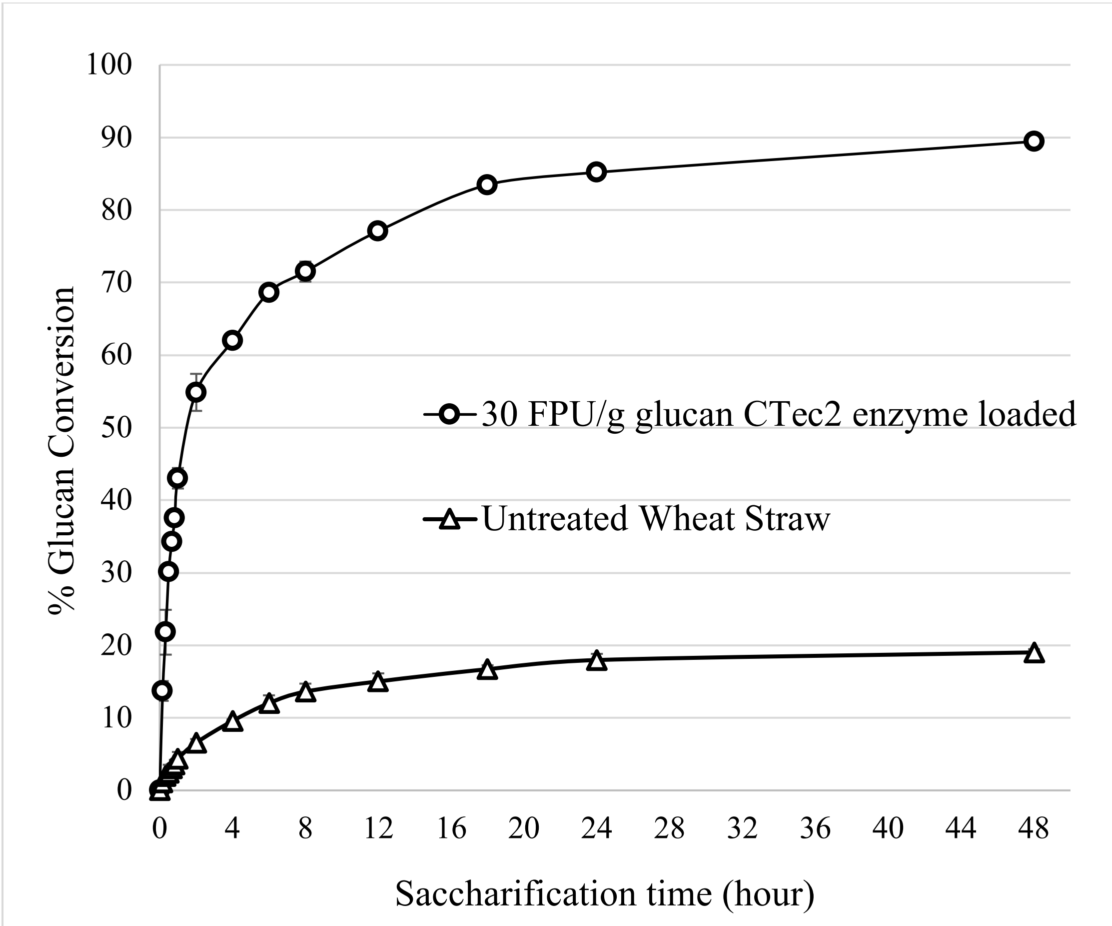

Figure 4.2. Effect of Cellic CTec2 supplementation on glucan conversion of enzymatic hydrolysis of alkali pretreated wheat straw, called alkali extracted solid versus untreated wheat straw. Pretreatment condition: 5% (w/v) NaOH, 50°C, 5h, 3% solid loading. Saccharification condition: Cellic CTec2 loading=30 FPU/g glucan, pH 4.8, 50°C, 48 h. Results are expressed as means ±SD for three trials.

Table 4.1 Composition of structural components of wheat straw and fibers from alkali treated wheat straw. Values represents per 100 gram dry-weight matter of total solids recovered; mean (SD).

Components [1]	Samples [1]				
	WS	AES	ATESR	AEHC	AL
Total extractives [2]	21.3 (0.84)	*ND	*ND	*ND	*ND
Water extractives	19.3 (0.74)	*ND	*ND	*ND	*ND
Ethanol extractives	1.9 (0.2)	*ND	*ND	*ND	*ND
Total carbohydrate [3]	58.8 (0.84)	86.4 (2.93)	14.4 (0.25)	83.9 (3.53)	1.8 (0.09)
Glucan	35.3 (1.47)	68.4 (2.80)	9.7 (0.31)	2.7 (0.40)	1.8 (0.09)
Xylan	18.7 (0.99)	12.9 (0.51)	2.2 (0.22)	70.7 (3.51)	#nd
Galactan	1.2 (0.08)	1.4 (0.06)	1.1 (0.02)	3.4 (0.25)	#nd
Arabinan	2.8 (0.04)	2.5 (0.16)	0.7 (0.14)	6.4 (0.55)	#nd
Mannan	0.9 (0.02)	1.0 (0.01)	0.8 (0.09)	0.8 (0.01)	#nd
Total lignin[4]	16.5 (0.01)	10.9 (0.71)	69.5 (0.31)	6.9 (0.14)	81.0 (0.2)
Acid soluble lignin	1.1 (0.07)	0.8 (0.08)	1.5 (0.09)	1.9 (0.16)	2.5 (0.19)
Acid insoluble lignin[4]	15.4 (0.09)	10.1 (0.62)	68.0 (0.29)	5.0 (0.12)	78.5 (0.18)
Ash	8.4 (0.01)	2.2 (0.39)	7.5 (0.38)	4.6 (0.04)	8.9 (0.19)

[1] Acronym for wheat bran, WB; wheat straw, WS; alkali treated/enzyme saccharified residue, ATESR; alkali extractive hemicellulose, AEHC; and alkali lignin, AL.
[2] Soxhlet extraction was applied to obtain water extractives with water for 24 h followed by ethanol extractives with 95% ethanol for 24 h.
[3] Extractives-free wheat straw was used for the composition analysis of wheat straw.
[4] The values were not corrected for protein content.
*ND is not determined.
#nd is not detected

Color Paramaters[2]	Samples [1]			
	WS	ATESR	AEHC	AL
				
L*	62.9 (0.78)^{a}	56.5 (0.88)^{b}	47.7 (0.4)^{c}	63.1 (0.93)^{a}
Hue	76.6^{0} (0.36)^{a}	78.7^{0} (0.56)^{b}	73.1^{0} (0.34)^{c}	76.9^{0} (0.22)^{a}
Chroma	25.1 (0.19)^{a}	27.1 (1.8)^{b}	28.7 (0.31)^{c}	23.7 (0.18)^{d}

Figure 4.3. Color profile of wheat straw, alkali treated/enzyme saccharified residue, alkali extractive hemicellulose, and alkali lignin.
[1] Acronym for wheat bran, WB; wheat straw, WS; alkali treated/enzyme saccharified residue, ATESR; alkali extractive hemicellulose, AEHC; and alkali lignin, AL
[2]L* measures lightness from black to white (0-100); a* indicates red (+) to green (–) color; b* measures yellow (+) to blue (–) color. Hue and Chroma represents color class and chromatic intensity, respectively and were calculated as; Hue angle= $\tan^{-1}(b^*/a^*)$; Chroma= $\sqrt{a^{*2} + b^{*2}}$. Results are expressed as means (SD) for six trials.
Means with different superscript letters across the row were significantly different as determined by one-way Anova and Tukey-HSD test ($p<0.05$).

Table 4.2. Functional properties as hydration properties (water holding capacities, swelling ability, and solubility) and oil holding capacities of wheat straw and fiber preparations derived from wheat straw.

Samples [1]	Properties [2]					
	WHC	WHC/IS	SA	Sol		Oil Holding Capacity
				% Sol	pH of suspension	
WB	5.4 (0.20)[a]	5.7 (0.21)[a]	7.0 (0.31)[a]	4.5 (0.33)[a]	6.2 (0.05)[a]	3.8 (0.31)[a]
WS	8.6 (0.66)[b]	9.6 (0.73)[b]	12.3 (0.30)[b]	10.6 (1.06)[b]	6.5 (0.03)[b]	5.6 (0.55)[b]
ATESR	5.8 (0.26)[a]	5.9 (0.27)[a]	9.8 (1.02)[c]	3.2 (0.66)[c]	7.1 (0.05)[c]	3.8 (0.69)[a]
AEHC	10.3 (0.27)[c]	17.7 (0.47)[c]	18.7 (1.08)[d]	41.7 (0.86)[d]	7.2 (0.05)[c]	10.6 (0.37)[c]
AL	3.1 (0.13)[d]	3.2 (0.14)[d]	5.2 (0.45)[e]	2.1 (0.89)[c]	3.1 (0.08)[d]	3.1 (0.30)[a]

[1] Acronym for wheat bran, WB; wheat straw, WS; alkali treated/enzyme saccharified residue, ATESR; alkali extractive hemicellulose, AEHC; and alkali lignin, AL.
[2] Acronym for water holding capacity, WHC; water holding capacity based on insoluble solids, WHC/IS; swelling ability, SA; Solubility, Sol; oil holding capacity, OHC.
Results are expressed as means (SD) for four trials. Means with different superscript letters across the column were significantly different as determined by one-way Anova and Tukey-HSD test ($p<0.05$).

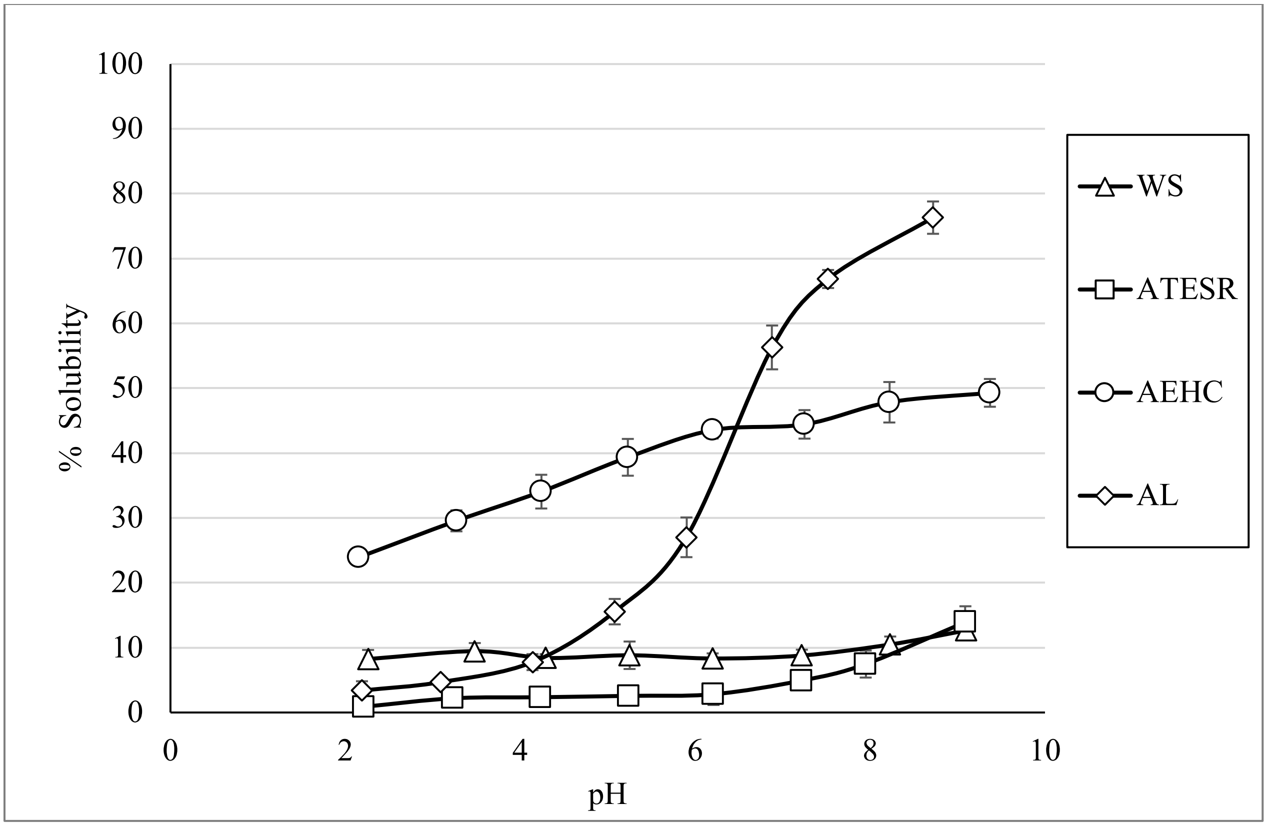

Figure 4.4. The effect of pH on the solubility of wheat straw (WS), alkali pretreated/enzyme saccharified residue (ATESR), alkali extracted hemicellulose (AEHC), and alkali extracted lignin (AL). Condition: 1% solid loading, 0.1M Britton-Robinson buffer at pH ranges from 2 to 6, shaking at 25 °C for 1 h, centrifuge 10,000 rpm for 15 min. Results are expressed as means ± SD for two trials.

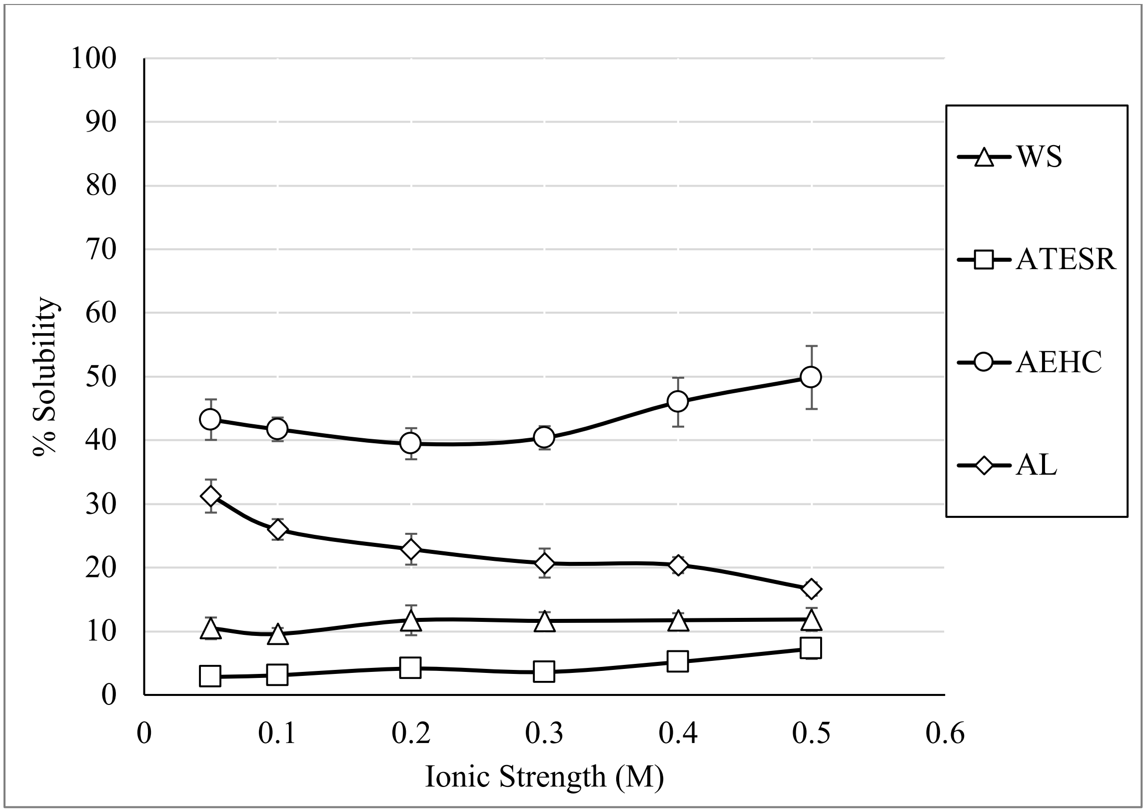

Figure 4.5. The effect of ionic strength on the solubility of of wheat straw (WS), alkali pretreated/enzyme saccharified residue (ATESR), alkali extracted hemicellulose (AEHC), and alkali extracted lignin (AL). Condition: 1% solid loading, pH 6 Britton-Robinson buffer at ionic strength ranges from 0.05 M to 0.5 M, shaking at 25 °C for 1 h, centrifuge 10,000 rpm for 15 min. Results are expressed as means ± SD for two trials.

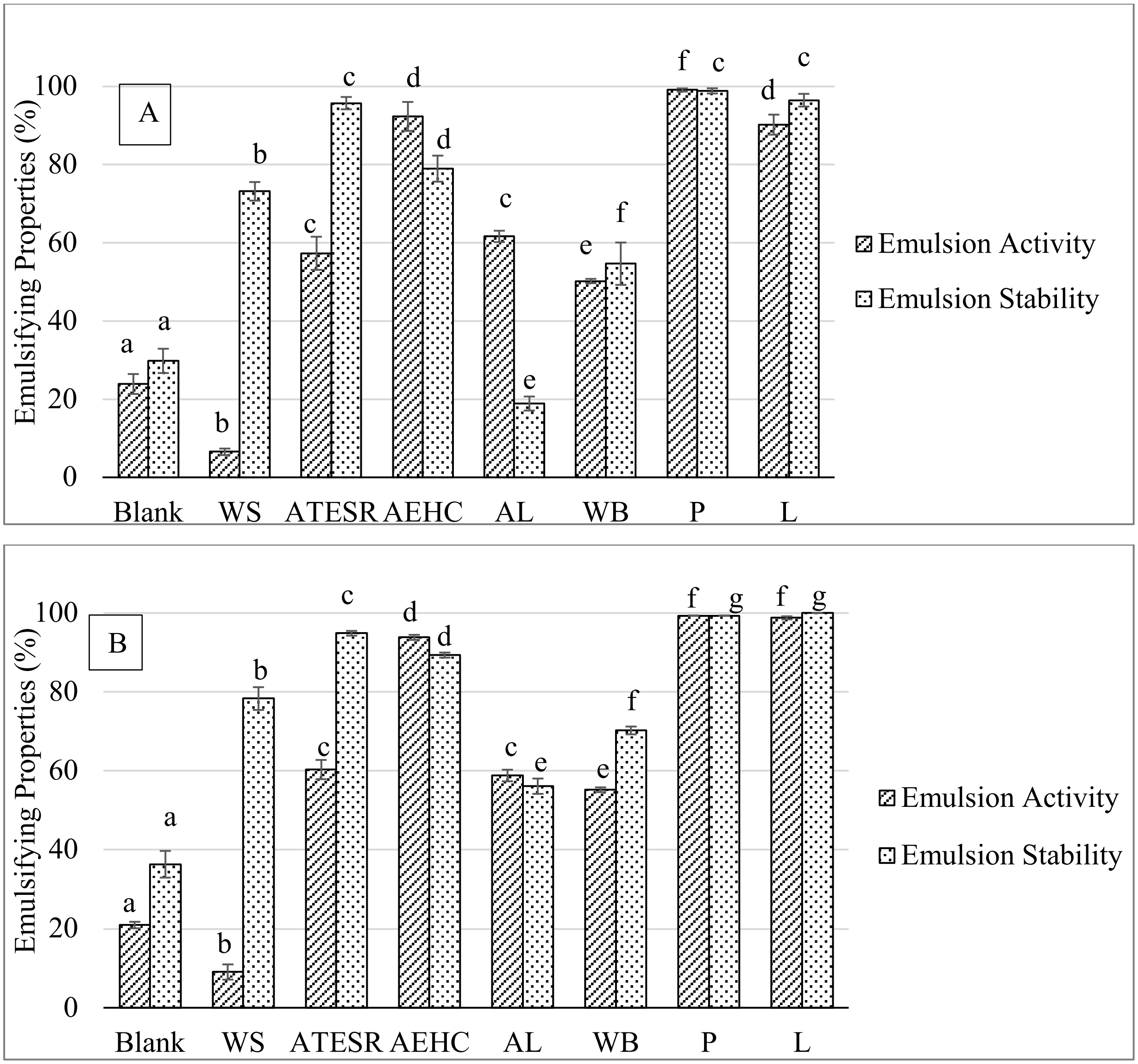

Figure 4.6 (A) Emulsion Activity (EA) and Emulsion Stability (ES) of wheat straw (WS), alkali pretreated/enzyme saccharified residue (ATESR), alkali extracted hemicellulose (AEHC), and alkali extracted lignin (AL) and other fiber sources; Wheat bran (WB), Pectin(P) and Lecithin (L) for 1% suspension in water/oil mix.

(B) Emulsion Activity (EA) and Emulsion Stability (ES) of wheat straw (WS), alkali pretreated/enzyme saccharified residue (ATESR), alkali extracted hemicellulose (AEHC), and alkali extracted lignin (AL) and other fiber sources; Wheat bran (WB), Pectin(P) and Lecithin (L) for 1% suspension in pH6 0.1M Britton-Robinson buffer/oil mix.

Results are expressed as means ±SD for four trials. Means with different superscript letters for EA and ES were significantly different as determined by one-way Anova and Tukey-HSD test ($p<0.05$).

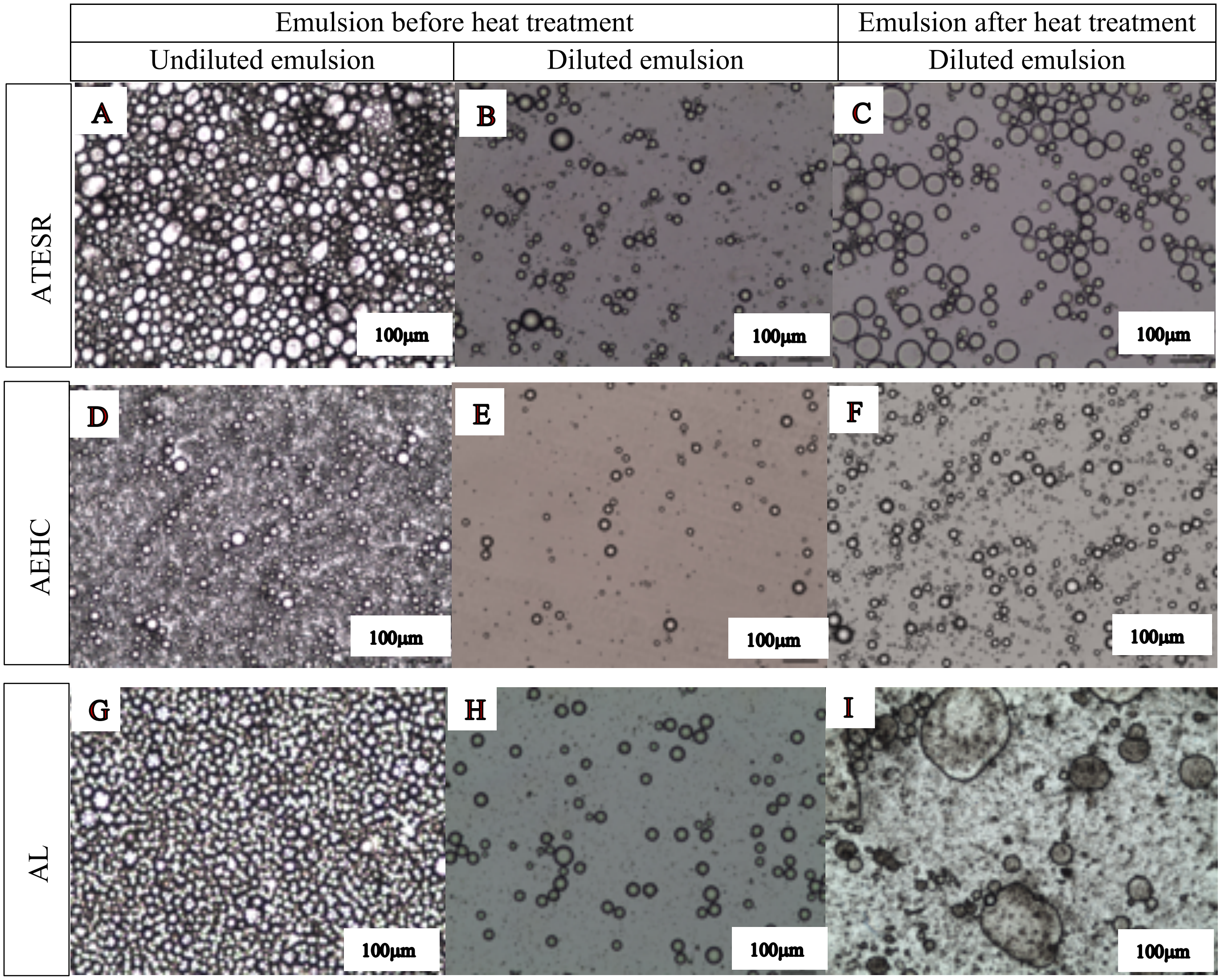

Figure 4.7. Microscopic images of water/oil emulsions containing with alkali pretreated/enzyme saccharified residue (ATESR), alkali extracted hemicellulose (AEHC), and alkali extracted lignin (AL). First two columns represent images of emulsion without heat treatment, representing EA (▨) in Figure 4.6 (A); and, third column represents images of same emulsion after heat treatment, representing ES (▒) in Figure 4.6 (A). A, B, C are images for ATESR emulsion; C, D, E are images for AEHC emulsion; G, H, I are images for AL emulsions.

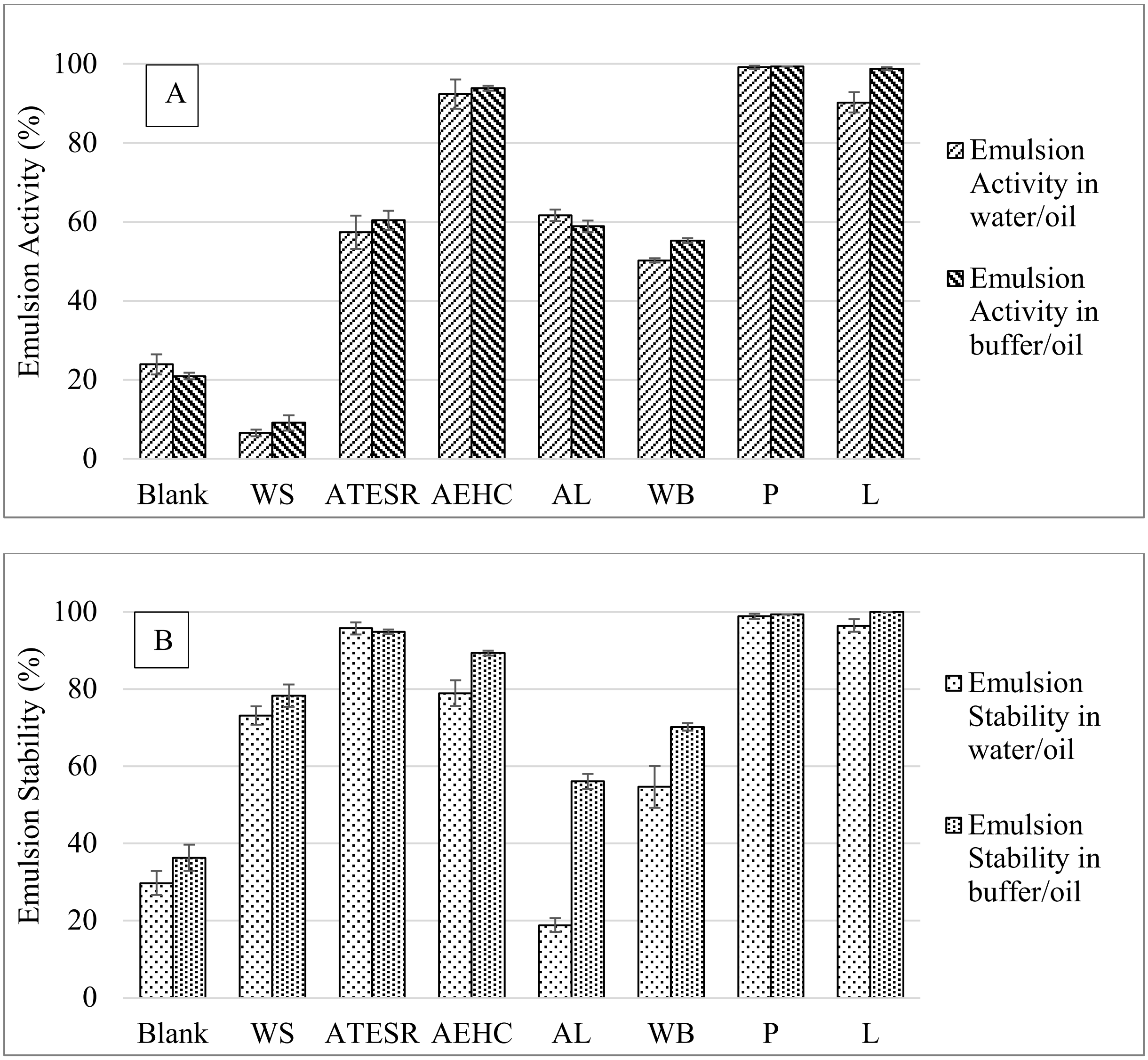

Figure 4.8 (A) Emulsion Activity (EA) of wheat straw (WS), alkali pretreated/enzyme saccharified residue (ATESR), alkali extracted hemicellulose (AEHC), and alkali extracted lignin (AL) and other fiber sources; Wheat bran (WB), Pectin(P) and Lecithin (L) for 1% suspension in water/oil mix ( ) and in pH6 0.1M Britton-Robinson buffer/oil mix ( ).
(B) Emulsion Stability (ES) of wheat straw (WS), alkali pretreated/enzyme saccharified residue (ATESR), alkali extracted hemicellulose (AEHC), and alkali extracted lignin (AL) and other fiber sources; Wheat bran (WB), Pectin(P) and Lecithin (L) for 1% suspension in water/oil mix ( )and in pH6 0.1M Britton-Robinson buffer/oil mix ( ).

Table 4.3. Emulsion Activity (EA) and Emulsion Stability (ES) of solubles and insolubles in water and 0.1M pH 6 buffer for emulsions prepared with ATESR, AEHC, and AL in water or Britton-Robinson buffer (pH 6, 0.1M). Results are expressed as means (SD) for two trials.

Samples[1]	Solvent							
	Water				Britton-Robinson buffer (pH 6, 0.1M)			
	Soluble		Insoluble		Soluble		Insoluble	
	EA%	ES%	EA%	ES%	EA%	ES%	EA%	ES%
ATESR	3.7 (0.47)	22.5 (3.53)	46 (0.94)	98.6 (0.02)	1.1 (0.35)	0	52.9 (4.14)	99.4 (0.87)
AEHC	85.4 (2.21)	84.1 (0.73)	51.1 (0.67)	87.9 (4.17)	76.7 (9.42)	85.2 (7.40)	68.3 (2.35)	90.8 (4.51)
AL	0.3 (0.07)	0	53.3 (2.26)	65.4 (1.81)	23.4 (4.71)	35.4 (2.94)	54.3 (6.12)	69.8 (13.82)

[1] 2% fiber was suspended in water or in buffer, shaked for 1h at room temperature and centrifuged at 10,000 rpm for 15 min to separate solubles and insoluble of AL, AEHC, ATESR in water or buffer. Each part then was mixed with 1:1 soybean oil; thus, the additive amount of fibers in each condition is less than 1%.

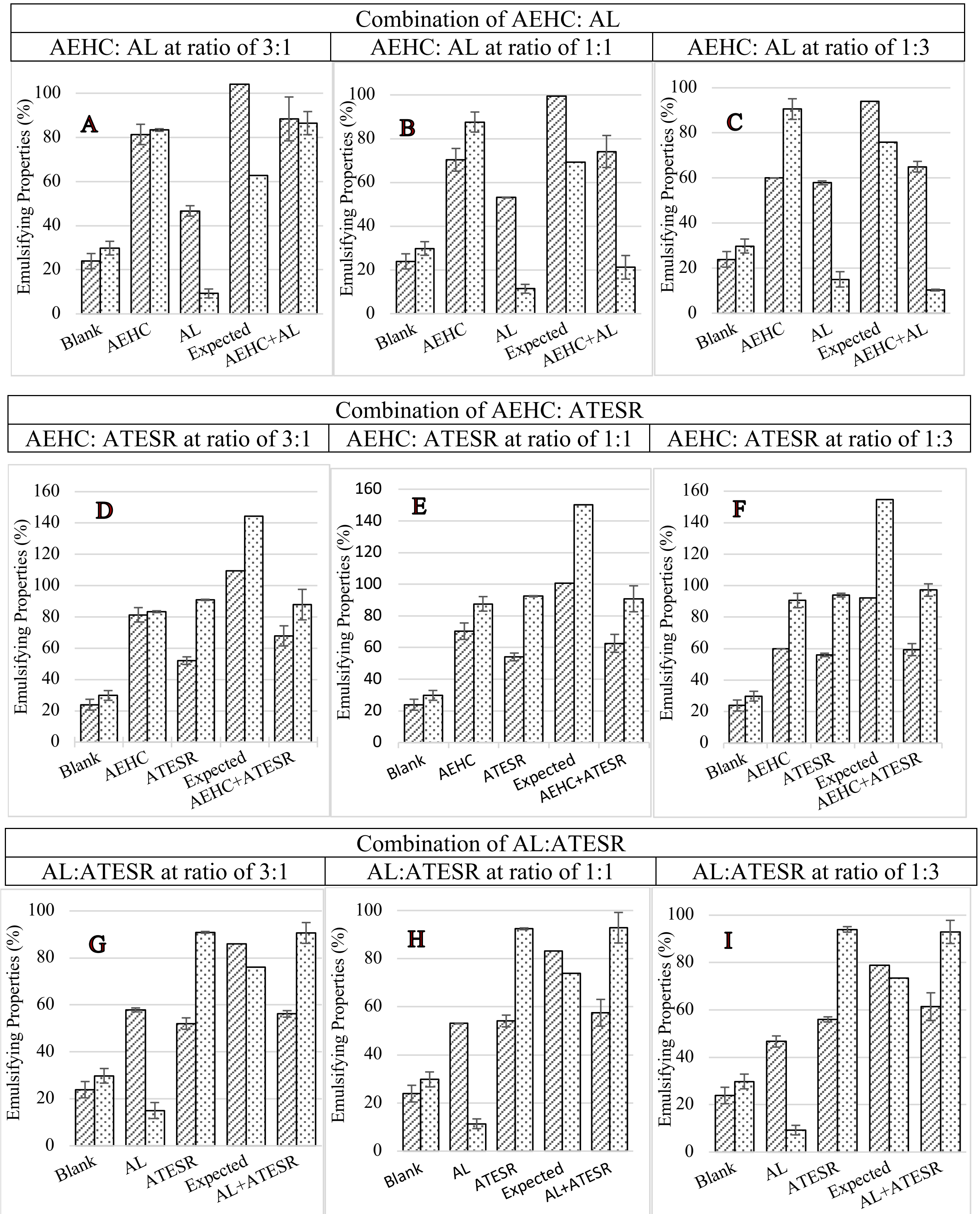

Figure 4.9. (see next page)

Figure 4.9. (continued) The effect of the combination of AEHC and AL (A, B, C); AEHC and ATESR (D, E, F); and AL and ATESR (G, H, I) on emulsion activity (▨) and emulsion stability (░). The combinations were prepared including 1% total fibers at ratio of 3:1, 1:1 and 1:3 for each combination. Blank represents water/oil mix. Results are expressed as means ± SD for two experiments.

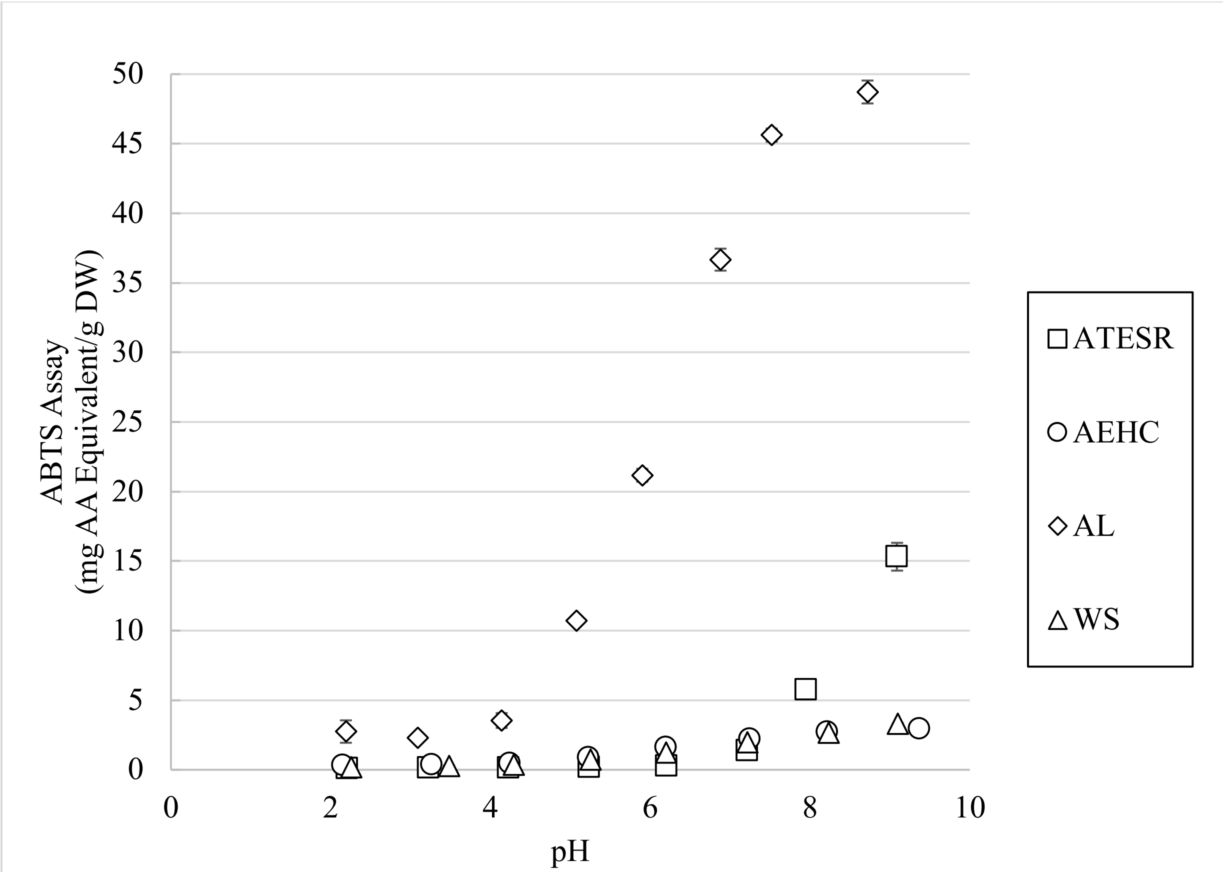

Figure 4.10. The ABTS radical scavenging activity of the soluble component of fiber preparations; wheat straw (WS), alkali pretreated/enzyme saccharified residue (ATESR), alkali extracted hemicellulose (AEHC), and alkali extracted lignin (AL) by different pH value. Condition: 1% solid loading, 0.1M Britton-Robinson buffer at pH ranges from 2 to 6, shaking at 25 °C for 1 h, centrifuge 10,000 rpm for 15 min to obtain soluble components. Results are expressed as means ± SD for two trials.

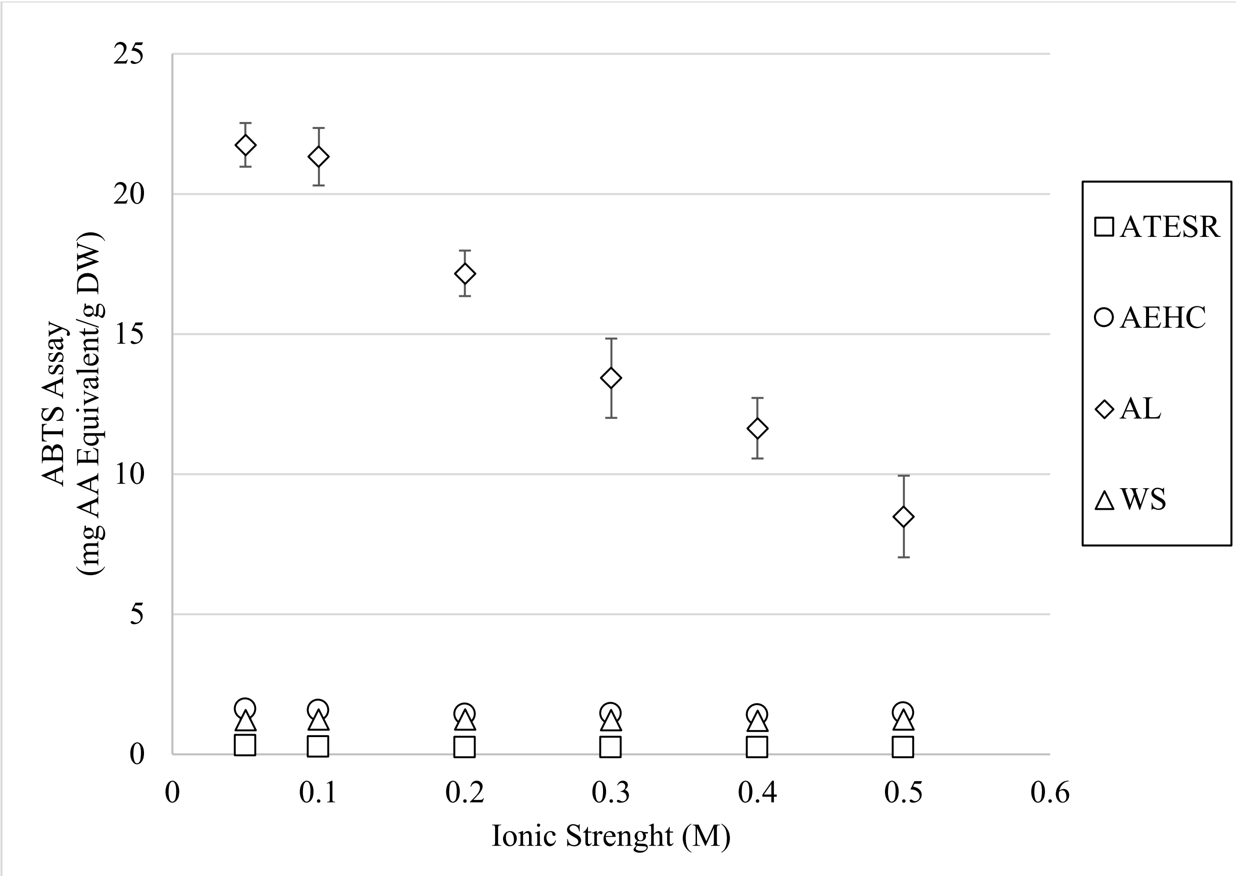

Figure 4.11. The ABTS radical scavenging activity of the soluble component of fiber preparations; wheat straw (WS), alkali pretreated/enzyme saccharified residue (ATESR), alkali extracted hemicellulose (AEHC), and alkali extracted lignin (AL) by different ionic strength. Condition: 1% solid loading, pH 6 Britton-Robinson buffer at ionic strength ranges from 0.05 M to 0.5 M, shaking at 25 °C for 1 h, centrifuge 10,000 rpm for 15 min to obtain soluble components. Results are expressed as means ± SD for two trials.

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CHAPTER 5

GENERAL CONCLUSION

The initial phase of this dissertation research focused on understanding the relevance of database selection and multiple database usage by considering the retrieval of food science-related publications in general. Search concepts were then demonstrated through a "case study" of information retrieval for a specific, currently pertinent, research topic: "*in vitro* bile acid binding properties of dietary fibers." Commonly recommended databases for information retrieval in the "food sciences" subject field were Academic Search Premier (ASP), AGRICOLA, Biological Abstract, CAB Direct, Food Science and Technology Abstract (FSTA), PubMed, SciFinder, Scopus, and Web of Science (WoS). Six of these databases which are accessible via Oregon State University Valle Library were evaluated further. Based on the number of journals covered, WoS was the largest and AGRICOLA was the smallest database. in terms of comparing the extend of coverage from selected food science-discipline journals, PubMed indexed the fewest, followed by ASP, whereas the other databases covered all but one journal. Case study illustrated the importance of database selection and the need to work with multiple databases when doing knowledge assessment in the food sciences. All of the databases evaluated in this study indexed articles unique to them; this proved to be true in the general sense and in the specific case study section of the study. A logical extension of this finding is that databases not included in the present study may also include articles that are both unique to those databases and relevant to the stated search query. Thus, it should be recognized that even after searching multiple databases there exists the possibility that pertinent information/articles may not have been recovered.

In the second phase of this dissertation work the focus was on effectiveness of different databases in identifying studies for a systematic review: *in vitro* studies of bile acid associations with a dietary fiber, lignin. The study indicates that searching beyond bibliographic databases is necessary to identify relevant studies. No single bibliographic database retrieved the complete set of relevant articles in this review; thus, a search of all databases should be performed when doing this type of review. Of the bibliographic databases used, WoS had a higher sensitivity than the other five databases, PubMed, CAB Direct, FSTA, AGRICOLA, and ASP with comparable precision and number needed to read. Even though no unique articles were retrieved, FSTA was the most precise bibliographic database in this review; so, less time is required for the evaluation of retrieved citations from this database. Additionally, consulting with a librarian is an important strategy for improving the comprehensiveness of a systematic review search.

The third phase of this dissertation focused on fractionation of fibers from wheat straw by alkali pretreatment and enzymatic saccharification for possible applications in the use of foods as "dietary fiber" ingredients. The processing of wheat straw by-products obtained from wheat straw as a biorefinery feedstock by alkali pretreatment and/or enzymatic saccharification allowed for the fractionation of the three main fiber preparations present in the lignocellulosic matrix. The fractionation method of obtaining fiber preparations caused some variability in the chemical composition of the fiber preparations, i.e the content of total carbohydrate and total lignin. The emphasis of this study was on evaluation of food-pertinent technical properties of these fiber preparations for hydration properties, emulsion and antioxidant capacities. The fiber preparations could provide as a water- and oil-holding, emulsion-enhancing and radical scavenging agents. Especially, AEHC had good water- and oil-holding capacities higher than those found for ATESR and AL. The solubility of AEHC was increased with buffer pH, but the solubility of

AESR was not affected by buffer pH. On the other hand, the solubility of AL was affected by pHs and ionic strength of buffer, possibly attributed to its high lignin content (81%). The extend of emulsifying activity demonstrated that especially considering their oil-holding capacities and emulsifying ability, ATESR, as well as AHEC, may be used as emulsifier in the food that consists of emulsions. On the other hand, the combine effect of binary mixtures of these extracted fiber preparations on emulsion showed antagonistic outcome on emulsifying activity. More, AL had high ABTS radical scavenging activity, suggesting the potential to improve oxidative stability and extending shelf life of foods due to its antioxidant property. This study suggest these fiber preparations can be used for the development of fiber-rich foods and unique applications by food manufacturers and product developers for incorporation as low-calorie bulk ingredients in foods.

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