

Natural Deep Eutectic Solvents (NADES) Research Framework: Bibliometric Analysis

1 **ABSTRACT**

2

Aims: The Natural Deep Eutectic Solvents (NADES) method is an extraction method currently being developed using affordable green solvents with low cytotoxicity. This research aims to (a) identify developments in Natural Deep Eutectic Solvents (NADES) research, and (b) develop research gaps for Natural Deep Eutectic Solvents (NADES) for future research.

Study design: This research was conducted using a bibliometric analysis

Place and Duration of Study: Library sources refer to research articles available online that can be accessed via websites or search engines by entering specific keywords related to the topic.

Methodology: A research approach using quantitative methods was carried out using bibliometric analysis. Data analysis using bibliometric analysis of Natural Deep Eutectic Solvents (NADES) produced 1,045 Scopus documents.

Results: The results show a growing research trend in Natural Deep Eutectic Solvents (NADES), but there are still several gaps that need to be addressed as mentioned in the proposed research framework.

Conclusion: Future research should focus on more comprehensive comparisons, more detailed method explanations, deeper understanding of molecular mechanisms, and long-term stability evaluations to improve the applicability of NADES in various fields. This paper contributes to the development of Natural Deep Eutectic Solvents (NADES).

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Keywords: Alginate Extraction, Bibliometric, Natural Deep Eutectic Solvents, Research Gap

7 1. INTRODUCTION

8
9 In recent years, the exploration of more efficient, sustainable, and environmentally friendly
10 extraction methods has become a major focus in the scientific and industrial worlds. The
11 extraction of natural materials has a main role in the production of high-value materials.
12 However, conventional extraction methods often involve the use of chemical solvents that
13 have the potential to negatively impact the environment and human health. Many organic
14 solvents release volatile compounds into the atmosphere, contributing to air pollution and
15 potentially causing respiratory problems among exposed populations [1]. Traditional solvent-
16 based extraction processes require substantial amounts of energy for heating and
17 distillation, leading to higher operational costs and greater carbon footprints. Additionally, the
18 removal of spent solvents contributes significantly to overall process energy consumption
19 [2].

20
21 One of the latest developments that is attracting attention is the use of NADES (Natural
22 Deep Eutectic Solvents) as an alternative in the extraction process of natural ingredients. In
23 view of this, the use of NADES as an alternative solvent offers a promising approach.
24 Natural Deep Eutectic Solvents (NADES) is an extraction method currently being developed
25 using affordable green solvents with low cytotoxicity [3]. According to [4], the NADES method
26 has been proven to be effective in extracting flavonoids, phenolic acids, polyphenols,
27 saponins, etc. from natural ingredients. A review highlighted the potential of NADES in
28 extracting bioactive from agro-food residues, emphasizing their unique properties such as
29 low toxicity and biodegradability. This makes them suitable for applications in the food,
30 nutraceutical, and pharmaceutical industries [5],[6],[7].

31
32 Alginate is a type of *polysaccharide* found in *Phaeophyceae* cell walls with levels reaching
33 40% of the total dry weight [8]. Alginate does play an important role in maintaining the
34 structure of algae cell tissue. This polysaccharide compound is a major component of brown
35 algae cell walls and contributes significantly to structural integrity and physiological function
36 of algae [9],[10]. On the other hand, alginate, a polysaccharide found in brown algae, has
37 unique properties that make it useful in a variety of industrial applications. However, the
38 process of extracting alginate from brown algae often involves complex chemical and
39 physical treatments, which can impact the quality and sustainability of the process.
40 Therefore, the search for more efficient and environmentally friendly extraction methods for
41 alginate is highly relevant.

42
43 Research on the use of NADES in alginate extraction has emerged as an interesting
44 research topic in response to concerns over the environmental and human health impacts of
45 conventional chemical solvents. NADES has been successfully used for the extraction of
46 polyphenols and bioactive compounds from natural products [11],[12],[13]. This shows great
47 potential for applications in alginate extraction. The combination of the environmentally
48 friendly solvent properties of NADES and its ability to dissolve polar and non-polar
49 compounds can open new avenues in the alginate extraction process. This research has the
50 potential to not only produce a purer and better-quality final product but also reduce negative
51 impacts on the environment and speed up the extraction process.

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53 The extraction of alginate from natural sources such as *Sargassum polycystum* has become
54 an interesting research topic. Alginate is a biopolymer commonly found in brown algae and
55 has various applications in the food, pharmaceutical, and heavy industries. Research related
56 to alginate extraction using conventional methods has been carried out, but the use of
57 NADES (Natural Deep Eutectic Solvents) as a more environmentally friendly and effective
58 alternative is starting to gain attention [14]. There is a study that has explored the use of
59 NADES in the extraction of alginate from *Sargassum polycystum* grown in Vietnam. This
60 study found that the optimal extraction conditions were at a temperature of 60°C, a solvent-
61 to-material ratio of 40/1 (v/w) using Na₂CO₃ at pH 9, and a single extraction process. The
62 results showed that the highest alginate content obtained was 176.22 mg uronic acid
63 equivalent per gram dry weight, with suitable antioxidant activity [15].
64

65 Therefore, the objectives of this study are to (a) identify research developments and trends
66 in Natural Deep Eutectic Solvents (NADES), and (b) develop an Natural Deep Eutectic
67 Solvents (NADES) research gap for future research. This research uses a quantitative
68 research approach from bibliometric analysis. Specifically, the scope of this research is
69 based on the article and review where experts based on their experience in the field of
70 Natural Deep Eutectic Solvents (NADES). This research will contribute to the future
71 development of Alginate Extraction and Natural Deep Eutectic Solvents (NADES) from the
72 research gaps revealed in the research framework. The structure of this paper is as follows.
73 Section 2 explains the background of this research and related research. Section 3 explains
74 the research method. Section 4 data analysis. Section 5 is the final section that summarizes
75 the findings.
76

77 **2. METHODOLOGY**

78 **2.1 Related Works**

79 The type of research carried out to analyze the Natural Deep Eutectic Solvents (NADES)
80 literature appears in several terms, such as systematic review, bibliometric analysis, scient
81 metrics, or even traditional literature review. This section allows us to evaluate some
82 previous studies that apply bibliometric analysis to the Natural Deep Eutectic Solvents
83 (NADES) in general and especially for alginate extraction literature.
84
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86 The research conducted on Alginate Extraction was entitled "Seaweeds as Promising
87 Resource of Bioactive Compounds: Overview of Novel Extraction Strategies and Design of
88 Tailored Meat Products" by [16]. In this research, the aspects collected relate to the latest
89 technology used to obtain and isolate bio compounds from seaweed. The use of whole
90 seaweed and its bioactive extracts to develop meat foods that provide health benefits while
91 reducing components considered unhealthy in meat is under review [17],[18]. In addition, the
92 prevention of oxidation events is also explained. However, there are still several challenges
93 regarding the organoleptic and sensory properties of the products produced, which affect
94 consumer acceptance. So, more research is needed to address the gap to enable seaweed-
95 based meat products to be marketed.

96 Furthermore, in research on Natural Deep Eutectic Solvents (NADES) in the paper entitled
97 "Green extraction of value-added compounds form microalgae: A Short Review on Natural
98 Deep Eutectic Solvents (NADES) and Related Pre-treatments" by [19]. This research
99 discusses the potential application of NADES for the extraction of intracellular compounds

100 from microalgae biomass and related pre-treatment to increase extraction efficiency. NADES
101 are formed from a mixture of natural components, usually consisting of a hydrogen bond
102 acceptor (HBA) such as choline chloride and a hydrogen bond donor (HBD) such as an
103 organic acid, sugar, or amino acid. The formation of NADES is driven by hydrogen bonding
104 between the components, resulting in a eutectic mixture with a melting point lower than that
105 of the individual components. Key properties of NADES include high biodegradability, low
106 toxicity, biocompatibility, low volatility, and high solubilization capacity [20],[21].

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108 **2.2 Research Question**

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110 First, the author considers Natural Deep Eutectic Solvents (NADES) to be interesting fields
111 for future development. To our knowledge, no bibliometric analysis has been carried out to
112 analyze the Alginate Extraction and Natural Deep Eutectic Solvents (NADES) literature in
113 the last decade. The following Research Question (RQ) is designed to identify research
114 developments and trends in Alginate Extraction and Natural Deep Eutectic Solvents
115 (NADES):

116 RQ 1 : How many research documents are published by each journal based on the level
117 of relevance to the theme of Natural Deep Eutectic Solvents (NADES)?

118 RQ 2 : What is the impact of each journal that publishes papers on the theme of Natural
119 Deep Eutectic Solvents (NADES)?

120 RQ 3 : How are growth resources relevant to Natural Deep Eutectic Solvents (NADES)
121 research?

122 RQ 4 : How to analyze the thematic map that appears based on the title of the document
123 with the research theme Natural Deep Eutectic Solvents (NADES)?

124 The bibliometric analysis in this study followed several basic protocols in the review process
125 [22]. This process is carried out systematically and uses explicit stages so that it can be
126 reproduced by other researchers. Bibliometric analysis can also be carried out with a mind-
127 mapping approach that shows the limits of knowledge [23]. Bibliometric analysis is generally
128 used in various scientific disciplines and focuses on quantitative studies in journal articles,
129 books, or other forms of written publications [24]. In this research, five main steps of
130 bibliometric analysis will be carried out, consisting of determining search keywords, checking
131 initial search results, refining search results, compiling related data, and data analysis.

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133 **3. RESULTS AND DISCUSSION**

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135 The search was carried out on December 2023 using keywords in the form of search strings
136 relevant to Natural Deep Eutectic Solvents (NADES) where keywords were searched based
137 on the title, keywords and abstract of the article. Based on the keywords that have been
138 determined, an article search process is carried out in the electronic database used as a
139 source of information. The electronic database used in this research is Scopus, considering
140 that Scopus is the largest reputable scientific database currently available and provides
141 various journal articles that have gone through a peer-review process [25]. In this way, the
142 quality obtained can be guaranteed.

143

144 **4.1 Initial Search Result**

145

146 Initial search results with the keyword Natural Deep Eutectic Solvents (NADES) produced
147 1,045 Scopus documents. In searching for articles, the period is not limited because this

148 research aims to map research developments (state of the art) on the theme of Natural
 149 Deep Eutectic Solvents (NADES). Based on the research results, articles related to the
 150 Natural Deep Eutectic Solvents (NADES) theme were first discovered in 2011, as shown in
 151 Tables 1.

152 **Table 1. The term “Natural Deep Eutectic Solvent (NADES)” appears for the first**
 153 **time in the journal**

Writer	Title	Source	Year of Publication
Choi, Y. H., van Spronsen, J., Dai, Y., Verberne, M., Hollmann, F., Arends, I. W., Witkamp, G. J., & Verpoorte, R.	Are Natural Deep Eutectic Solvents the Missing Link in Understanding Cellular Metabolism and Physiology?	Plant Physiology	2011
Mobinikhaledi&Amiri	Natural eutectic salts catalyzed one-pot synthesis of 5-arylidene-2-imino-4-thiazolidinones	Research on Chemical Intermediates	2013
Dai, Y., Van Spronsen, J., Witkamp, G. J., Verpoorte, R., & Choi, Y. H.	Natural deep eutectic solvents as new potential media for green technology	Analytica chimica acta	2013
Dai, Y., Witkamp, G.-J., Verpoorte, R., Choi, Y.H.	Natural Deep Eutectic Solvents as a New Extraction Media for Phenolic Metabolites in <i>Carthamus tinctorius</i> L.	Analytical Chemistry	2013
Egan, P.A., Van Der Kooy, F.	<i>Xanthorrhizol</i> and curcuminoids NADES extraction from <i>C. xanthorrhiza</i>	Chemistry and Biodiversity	2013

154
 155 Research by [26] showed that NADES can act as an alternative solvent in biochemical and
 156 physiological processes of cells, especially in extreme conditions such as drought and high
 157 temperatures. Research by [27] discussed the synthesis of 5-arylidene-2-imino-4-
 158 thiazolidinones compounds through a one-pot reaction using natural eutectic solvents (deep
 159 eutectic solvents, DES) as catalysts and reaction media. This method was developed as a
 160 more environmentally friendly alternative compared to conventional synthesis methods that
 161 use hazardous organic solvents. Natural Deep Eutectic Solvents (NADES) as a potential
 162 new medium for green technology. NADES offers an environmentally friendly and effective
 163 alternative to conventional solvents in various applications [28]. The use of natural eutectic
 164 solvents (Natural Deep Eutectic Solvents/NADES) as a new extraction medium for phenolic
 165 metabolites from safflower (*Carthamus tinctorius* L.) [29]. Research by [30] examines the
 166 use of natural eutectic solvents (NADES) for the extraction of xanthorrhizol (XTZ) and
 167 curcuminoids from *Curcuma xanthorrhiza* rhizomes. Four types of NADES were prepared
 168 and their physicochemical properties, including polarity, viscosity, density, and pH, were
 169 characterized. FTIR analysis confirmed the formation of hydrogen bonds between NADES
 170 components.

171 NADES was first reported and developed by [26]. In the study, Choi et al. developed a series
 172 of natural eutectic solvents consisting of primary metabolites commonly found in living cells
 173 and named them Natural Deep Eutectic Solvents (NADES). NADES was developed as a

174 green solvent to replace organic solvents that are generally toxic, volatile, and harmful to
175 human health and the environment. Initially, the NADES method was applied in the
176 pharmaceutical and health sectors, but currently the application of the NADES method is
177 very broad, including in the food industry for alginate extraction.

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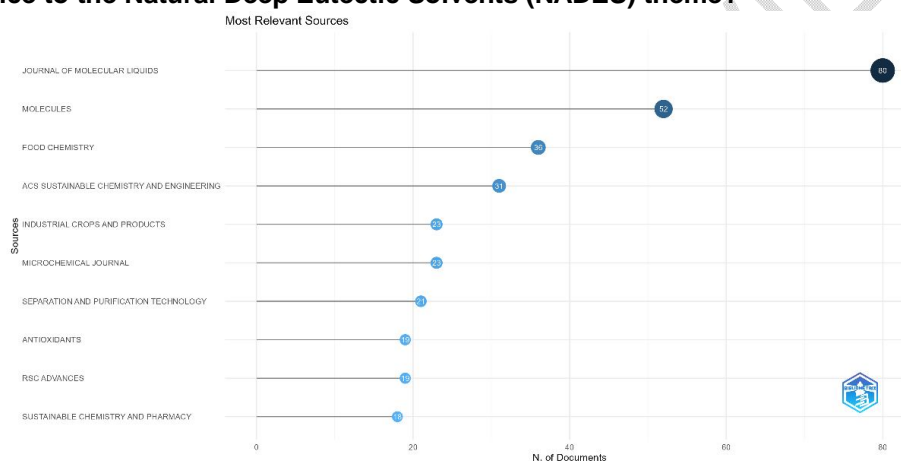
179 4.2 Statistical Compilation of Data

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181 As previously mentioned, the data collected after searching is stored in the form of a BibTex
182 file. Then the file is processed with the help of Bibliometric software to complete the
183 metadata of the articles obtained such as author's name, title, keywords, abstract, and
184 journal description (journal name, year of publication, volume, issue, pages). The dataset is
185 verified, and necessary information is added when there is incomplete data. Then the search
186 result data is analyzed and classified based on the verified data collection.

187

188 **How many research documents are published by each journal based on their level of
189 relevance to the Natural Deep Eutectic Solvents (NADES) theme?**



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Fig. 1. Most Relevant Source Natural Deep Eutectic Solvent (NADES)

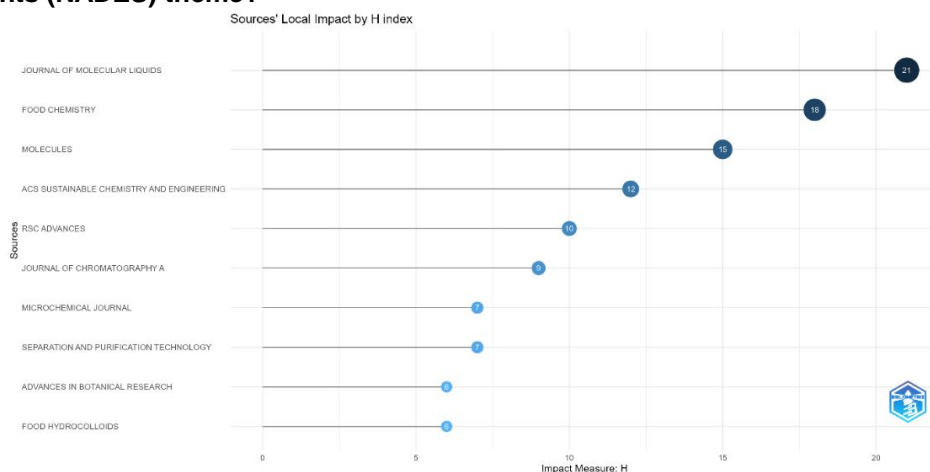
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193 Figure 1 shows the number of research documents published by each journal based on their
194 level of relevance to the Natural Deep Eutectic Solvent (NADES) theme. This data displays a
195 list of the names of journals that are widely published and the intervals for the number of
196 documents published with a blue bar chart. The darker the blue color indicates the greater
197 the quantity and relevance to the research theme, the number of documents published by all
198 journals ranges from 0 to 80 documents. Journal of Molecular Liquids is a journal in the top
199 position with a total of 80 published documents with a dark blue bar chart compared to the
200 bar charts of other journals. This is because the journal is relevant to the theme discussed.

201

202 An example of a journal published by the Journal of Molecular Liquids is the journal entitled
203 "NADES as Potential Solvents for Anthocyanin Pectin Extraction from *Myrciariacauliflora*
204 Product: In Silico and Experimental Approach Solvent Selection" written by [31]. In this
205 research, silico and experimental approaches were combined to select Natural Deep
206 Eutectic Solvents (NADES) compounds aimed at selective and sequential extraction of
207 anthocyanins and pectin from *Myrciariacauliflora* products. The results obtained from this
208 research are based on in silico evaluation, NADES and the target compound show
209 amphoteric character which indicates an affinity between the two. Acid-based NADES
210 showed the highest affinity in the H-bond acceptor region, while betaine and water-content
211 NADES showed the best affinity in the H-bond donor region. However, all NADES showed
212 low affinity towards non-polar compounds.

213 **What is the impact of each journal that publishes papers on the Natural Deep Eutectic**
214 **Solvents (NADES) theme?**



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Fig. 2. Source Impact Natural Deep Eutectic Solvent (NADES)

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Journal calculations are not only based on the quantity produced or its relevance. However, this research was also carried out based on the impact produced by each journal that published papers on the theme of Natural Deep Eutectic Solvent (NADES) by calculating the H-index of the journal which is depicted in the blue bar diagram. Apart from showing the H-Index value obtained, the diagram above also illustrates the impact produced by the journal through the blue color displayed. The darker the blue color on the graph, the greater the impact generated by the journal. The journal H-Index interval in this study ranged from 0.0 to 21.0. Figure 5 shows the Journal of Molecular Liquids is in the top position with an H-index of 21.0 which is marked in dark blue. Furthermore, Food Chemistry is in second place with an H-index of 18.0. Meanwhile, in journals with an H-index of 6.0, there are 2 journals marked in light blue on the diagram, which indicates the low impact of these journals.

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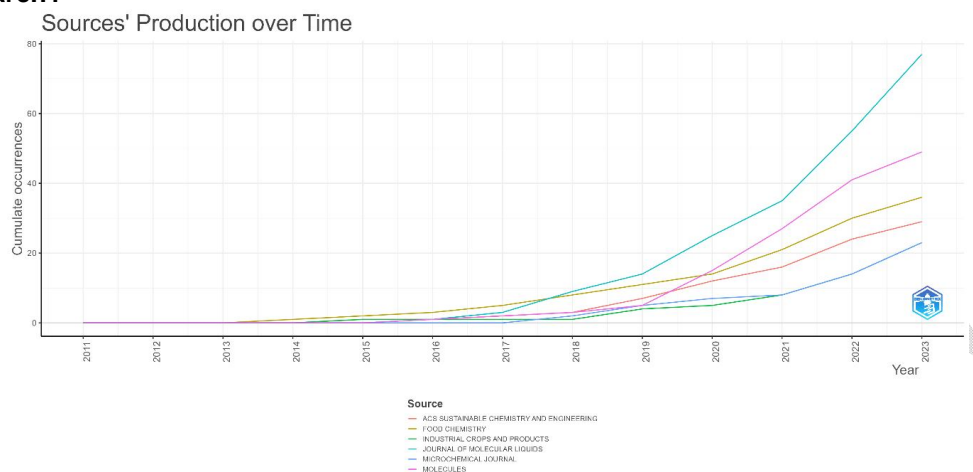
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The journal with the highest impact is the Journal of Molecular Liquids. Journal of Molecular Liquids is an international journal that focuses on fundamental aspects of structure, interactions, and dynamic processes in simple, molecular, and complex fluids. This journal is published by Elsevier. This journal aims to publish scientific research, theory, and application development from various fields of inquiry regarding chemistry, physics, and materials. The most cited article about Natural Deep Eutectic Solvent (NADES) was entitled "Properties and thermal behaviour of natural deep eutectic solvents" by [32]. The study investigated the properties and thermal behaviour of natural deep eutectic solvents (NADES) based on choline chloride, organic acids, amino acids and sugars. Key properties examined included density, thermal behaviour, conductivity and polarity. The paper provides a comprehensive characterization of various NADES systems, offering insights into their thermal behaviour and physicochemical properties that are important for their development as sustainable solvents.

245 **How is the growth of sources relevant to Natural Deep Eutectic Solvents (NADES)**
246 **research?**



247
248 **Fig. 3. Source Growth Natural Deep Eutectic Solvent (NADES)**

249
250 This research also discusses the development of journals which are sources of research
251 with the theme of Natural Deep Eutectic Solvent (NADES). Figure 3 shows the annual
252 growth curve for each journal from 2011 to 2023 so that we can get an idea of whether the
253 journal experienced an increase or decrease in the curve line during the research period,
254 especially in the publication of papers with the theme Natural Deep Eutectic Solvent
255 (NADES). This curve illustrates that research with the theme of Natural Deep Eutectic
256 Solvent (NADES) tends to experience increasing growth in publications each year.

257
258 From the curve above it can also be seen that the Journal of Molecular Liquids is in the first
259 place, experiencing significant growth from 2013 to 2023, and has the potential to continue
260 to grow in the following years. In 2011, NADES emerged as part of the broader group of
261 Deep Eutectic Solvents (DES), focusing on the use of natural components [33]. Starting from
262 this, NADES was recognized as a promising environmentally friendly solvent for the
263 extraction of compounds from plant materials [34]. From 2013, the primary focus was on
264 understanding the basic properties of NADES and their potential in fields like green
265 chemistry and extraction processes, especially for bioactive compounds from plants. By the
266 mid-2010s, research expanded to investigate NADES for food preservation, cosmetics,
267 pharmaceuticals, and biotechnology, due to their ability to enhance solubility, reduce toxicity,
268 and improve extraction efficiency [35],[36],[37]. The year 2014 marked the beginning of a
269 significant increase in research on NADES. The number of publications on NADES has
270 increased rapidly since 2014.

271
272 By 2020, the versatility of NADES had been widely explored, especially in the extraction of
273 antioxidants, phenolic compounds, and proteins from food waste. The solvents were
274 increasingly used in industrial applications such as biorefineries and cryopreservation. The
275 development of NADES in 2020 such as,

- 276 1) Bioactive Compound Extraction
277 NADES proved effective in extracting antioxidants, phenolic compounds, and proteins
278 from food waste and plant materials. Examples include the extraction of phenolic
279 compounds from olive pomace, phlorotannins from seaweed, and bioactives from
280 microalgae [28]. In the other hand, NADES has shown great potential in the extraction
281 of various bioactive compounds, including anthocyanins. A study in 2023 showed that
282 lactic acid (LA)-based NADES is highly polar and can increase the solubility of
283 anthocyanins. In addition, ethylene glycol (EG) and butanediol (BDO)-based NADES

284 are also effective in extracting anthocyanins with high monomeric anthocyanin content
285 [39].

286 2) Lignin Isolation

287 NADES has been used as an environmentally friendly alternative for lignin isolation
288 from agricultural waste. A study in 2023 showed that NADES was effective in extracting
289 lignin from various biomass sources [40].

290

291 Recent research, around 2022-2023, further expanded NADES applications to areas like
292 drug delivery systems and nanotechnology. Advances in the preparation techniques have
293 made them more cost-effective and adaptable for specialized uses [41],[42]. The
294 development of NADES in 2022-2023 such as,

295 1) Drug Delivery Systems

296 NADES have been explored for improving drug bioavailability and absorption in
297 pharmaceutical applications. They are being used to enhance the stability and oral
298 bioavailability of some Chinese herbal medicines, thereby improving their therapeutic
299 effects. NADES have shown potential in transdermal drug delivery systems (TDDS) by
300 enhancing the percutaneous absorption of both small molecules and macromolecular
301 drugs like proteins and small interfering RNAs [43].

302 2) Nanotechnology

303 Recent reviews highlight the application of NADES in nanotechnology. NADES are
304 being combined with nanomaterial-based drug delivery systems to improve the safety
305 and therapeutic efficacy of encapsulated drugs [44].

306

307 In the other hand, for food industry sectors, Natural Deep Eutectic Solvents (NADES) have
308 recently been explored for use in creating edible films. These films are made from
309 biocompatible and biodegradable components, offering an eco-friendly alternative to
310 traditional plastic-based food packaging. The NADES-based films are primarily used to
311 enhance food preservation by forming protective barriers that can inhibit the growth of
312 microorganisms, reduce oxidation, and improve the retention of food moisture [26], [42]. The
313 composition of NADES allows for flexibility in the development of films with desired
314 properties such as water resistance, mechanical strength, and thermal stability. These
315 properties can be adjusted by selecting specific hydrogen bond donors and acceptors during
316 the formulation of the solvent. For example, NADES made from choline chloride and
317 glycerol, or organic acids has shown potential in producing edible films with excellent
318 antioxidant and antimicrobial activity, which can extend the shelf life of perishable food
319 products [41],[45].

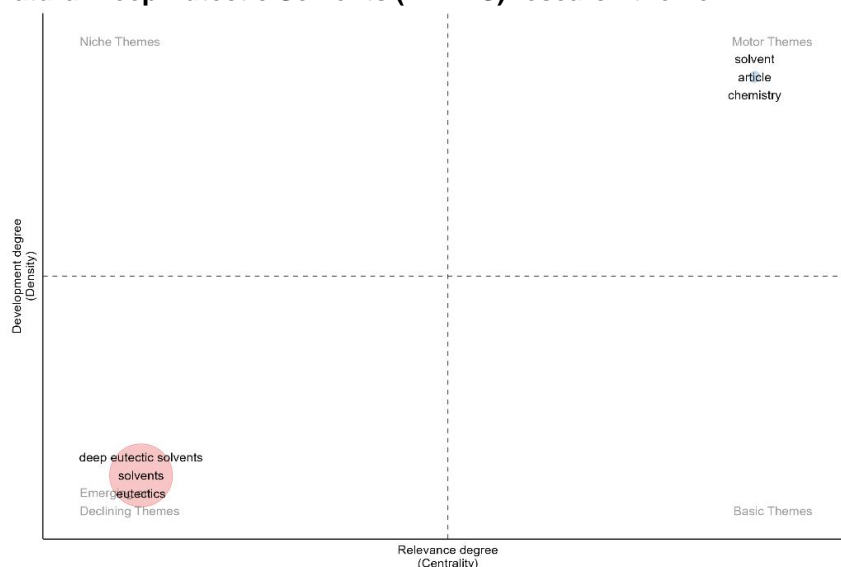
320

321 In the other hand, development in creating eco-friendly active food packaging by utilizing
322 anthocyanins extracted with Natural Deep Eutectic Solvents (NADES) written by [46]. The
323 study aimed to efficiently extract these compounds using ultrasound-assisted methods
324 combined with specially designed NADES. The study tested several NADES formulations
325 (such as those based on glycerol, choline chloride, and organic acids) for extracting
326 anthocyanins from *Lumachequen* berries. These solvents proved effective, with anthocyanin
327 yields ranging from 81.1 to 327.6 mg cyanidin 3-glucoside equivalents per 100 g of dry berry
328 weight. Extracts from the NADES were incorporated into edible films made from
329 carrageenan, which exhibited significant antioxidant and antibacterial activities. The films
330 showed promise in enhancing food preservation, with inhibition of bacterial strains like *E. coli*
331 and *S. aureus*.

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333

334 How do I analyze the thematic map that appears based on the title of the document
335 with the Natural Deep Eutectic Solvents (NADES) research theme?



336
337 **Fig.4. Thematic Map Natural Deep Eutectic Solvent (NADES)**

338
339 This research will also analyze the thematic maps that appear based on density and
340 centrality which are analyzed based on the title of the document with the research theme
341 Natural Deep Eutectic Solvent (NADES) which is divided into 4 quadrants as illustrated in
342 Figure 4. These results were obtained from a semi-automatic algorithm by reviewing titles of
343 all references that are the object of research. The upper left quadrant is a highly developed
344 and isolated theme. This quadrant shows themes that are specific and rarely researched, but
345 have high development, as indicated by high density but low centrality. While the bottom left
346 quadrant is a theme that is developing or declining, this quadrant shows themes that have
347 been used for a long time but are experiencing an increasing or decreasing trend with low
348 density and centrality. The themes in this quadrant are deep eutectic solvents, solvents, and
349 eutectics. Looking at developments with the Natural Deep Eutectic Solvent (NADES) sub-
350 theme in recent years, the trend of words in this quadrant has increased.

351
352 Meanwhile, the upper right quadrant is a motor theme or driving theme which is
353 characterized by high density and centrality, so it needs to be developed and is important to
354 study in further research. Themes that appear in this quadrant are Solvent, Article, and
355 Chemistry. Finally, the lower right quadrant is the basic theme and transverse themes which
356 are characterized by high centrality but low density. These themes are important to include
357 in research because they are general topics that are commonly used. Therefore, there are still
358 many opportunities to develop the Natural Deep Eutectic Solvent (NADES) method.

359 4.3 Research Gap

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361
362 The development of this research framework is based on several recent and important
363 studies in the field, which were discovered from the results of bibliometric analysis. Table 3
364 presents the initial research framework in the form of a table of potential future research
365 needs and gaps.
366

367 **Table 2. Preliminary Research Gap**

Reference	Current Latest Research	Future Needs and Gaps
Boiteux <i>et al.</i> , [47]	[This research may focus on certain types of bioactive coatings or post-harvest control applications. The results may not be generalizable to other types of coatings or applications.	Further research is needed to compare the effectiveness of different types of coatings.
Saffarionpour [48]	This study does not provide information regarding analysis of experimental methods, results, or statistical analysis used in the research. This makes it difficult to assess the robustness and reliability of the findings.	In further research, it is necessary to explain the methods used in the research.
Kartini <i>et al.</i> , [49]	The study does not delve deeply into the molecular mechanisms behind the superior extraction performance of NADES. Additionally, comparative analysis with existing solvents beyond environmental benefits could strengthen the study.	Further research needs to investigate the molecular mechanism of NADES extraction performance.
Kowaloneket <i>et al.</i> , [50]	The article does not provide data on the long-term stability of the films, which is crucial for commercial applications. The research is limited to chokeberry and lemon balm and may not apply to other plant extracts or broader food packaging uses.	Future research should conduct experiments so that edible film provides long-term stability and is applied to other products.
Obluchinskaya <i>et al.</i> , [51]	The study does not mention replication or sample sizes, limiting statistical power. Long-term stability of extracts in NADES was not evaluated.	Future research should conduct experiments so that edible film provides long-term stability and redesign the experimental.

368
369 Based on the results in Table 2, Current research in the field of bioactive coatings and post-
370 harvest control applications shows several limitations and opportunities for further
371 development. Although some studies have shown promising results, there are still gaps that
372 need to be addressed in future research.

373
374 One of the main limitations is the lack of comparison of effectiveness between different types
375 of coatings. Current research tends to focus on a specific type of coating or application,
376 making it difficult to generalize the results. In addition, some studies do not provide sufficient
377 information on the experimental methods, results, and statistical analyses used, which limits
378 the assessment of the reliability of the findings.

379
380 In the context of the use of Natural Deep Eutectic Solvents (NADES), further research is
381 needed to investigate the molecular mechanisms behind the superior extraction

382 performance. Comparative studies with existing solvents, beyond environmental benefits,
383 can also strengthen research in this area.

384
385 The long-term stability of edible films is a crucial aspect that needs further investigation,
386 especially for commercial applications. Current research is limited to specific plant extracts
387 and may not be applicable to broader use in food packaging. In addition, some studies do
388 not mention replication or sample size, which limits the statistical power of the results.

389
390 To address this gap, future research needs to focus on comparing the effectiveness of
391 different coating types, elucidating more detailed research methods, investigating the
392 molecular mechanism of NADES, and evaluating the long-term stability of edible films. In
393 addition, more robust experimental designs with adequate sample sizes and proper
394 replication are needed to improve the reliability and applicability of research results in this
395 area.

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397

398 **4. CONCLUSION**

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400 This research uses quantitative methods using bibliometric data analysis. Data analysis
401 using bibliometric analysis of Natural Deep Eutectic Solvents (NADES) produced 1,045
402 Scopus documents. Quantitative data obtained based on bibliometric analysis has revealed
403 trends and developments in Natural Deep Eutectic Solvents (NADES) research. In research
404 with the theme Natural Deep Eutectic Solvents (NADES), the Journal of Molecular Liquids is
405 the journal in the top position with a total of 80 published documents and continues to
406 develop every year. Journal of Molecular Liquids, a high-impact journal, focuses on
407 fundamental aspects of structure, interactions, and dynamic processes in simple and
408 complex molecular fluids. The growth trend of NADES publications tends to increase every
409 year, with Journal of Molecular Liquids leading significant growth from 2013 to 2023. NADES
410 research has been growing rapidly since 2011, with increasingly broad and diverse
411 applications, especially in the fields of bioactive compound extraction, pharmaceuticals, and
412 food technology. There are still many opportunities for the development of NADES methods,
413 given their position in the thematic map.

414 Although recent studies have shown promising results, significant gaps still need to be
415 addressed. Future research should focus on more comprehensive comparisons, more
416 detailed method explanations, deeper understanding of molecular mechanisms, and long-
417 term stability evaluations to improve the applicability of NADES in various fields. Future
418 research needs to focus on several key aspects. First, a comprehensive comparative study
419 is needed to assess the effectiveness of different types of coatings. Second, a more detailed
420 explanation of the research methodology should be a priority. Third, an in-depth exploration
421 of the molecular mechanism of NADES is essential for better understanding. Fourth, a
422 comprehensive evaluation of the long-term durability of edible films should be conducted. In
423 addition, to improve the reliability and relevance of research results in this area, a more
424 robust experimental design with adequate sample size and proper replication is essential.
425 with adequate sample size and proper replication.

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